Research article

The Effect of Moderate and High-Intensity Fatigue on Groundstroke Accuracy in Expert and Non-Expert Tennis Players

Mark Lyons [1]✉**, Yahya Al-Nakeeb** [2,3]**, Joanne Hankey** [4] **and Alan Nevill** [5]

[1] Department of Physical Education and Sport Sciences, University of Limerick, Ireland; [2] Graduate School, Newman University College, Birmingham, UK; [3] College of Education, Qatar University, Doha, Qatar; [4] Department of Biomolecular and Sport Sciences, Coventry University, UK; [5] School of Sport, Performing Arts and Leisure, University of Wolverhampton, Walsall, UK.

Abstract
Exploring the effects of fatigue on skilled performance in tennis presents a significant challenge to the researcher with respect to ecological validity. This study examined the effects of moderate and high-intensity fatigue on groundstroke accuracy in expert and non-expert tennis players. The research also explored whether the effects of fatigue are the same regardless of gender and player's achievement motivation characteristics. 13 expert (7 male, 6 female) and 17 non-expert (13 male, 4 female) tennis players participated in the study. Groundstroke accuracy was assessed using the modified Loughborough Tennis Skills Test. Fatigue was induced using the Loughborough Intermittent Tennis Test with moderate (70%) and high-intensities (90%) set as a percentage of peak heart rate (attained during a tennis-specific maximal hitting sprint test). Ratings of perceived exertion were used as an adjunct to the monitoring of heart rate. Achievement goal indicators for each player were assessed using the 2 x 2 Achievement Goals Questionnaire for Sport in an effort to examine if this personality characteristic provides insight into how players perform under moderate and high-intensity fatigue conditions. A series of mixed ANOVA's revealed significant fatigue effects on groundstroke accuracy regardless of expertise. The expert players however, maintained better groundstroke accuracy across all conditions compared to the novice players. Nevertheless, in both groups, performance following high-intensity fatigue deteriorated compared to performance at rest and performance while moderately fatigued. Groundstroke accuracy under moderate levels of fatigue was equivalent to that at rest. Fatigue effects were also similar regardless of gender. No fatigue by expertise, or fatigue by gender interactions were found. Fatigue effects were also equivalent regardless of player's achievement goal indicators. Future research is required to explore the effects of fatigue on performance in tennis using ecologically valid designs that mimic more closely the demands of match play.

Key words: Fatigue, tennis, expertise, achievement motivation.

Introduction

Numerous papers have been published in recent years related to fatigue in tennis (Booras, 2001; Davey et al., 2002; Hornery et al., 2007a; Kovacs, 2006; Marks et al., 2006; Mendez-Villanueva et al., 2007). A number of key themes have emerged from these papers including that success in competitive tennis may be, in part, determined by a player's ability to resist fatigue (Mendez-Villanueva et al., 2007). Hornery et al. (2007b) presented a number of challenges for investigators attempting to evaluate

fatigue effects on tennis performance in field settings. They also noted four key limitations of past research studies including (1) a restricted movement approach to the multi-faceted skills that form the basis for match performance, (2) a lack of sensitivity and large variability in skill or performance measures, (3) usage of non-tennis-specific methods to induce fatigue, and (4) fatigue levels failing to reflect those recorded in match play. Nevertheless, there is a need to examine the influence of fatigue on tennis performance (Girard and Millet, 2008; Mendez-Villanueva et al., 2007).

Past research by Davey et al. (2002) explored the effects of fatigue on skilled tennis performance. In an effort to replicate the demands of tennis match play, participants performed the Loughborough Intermittent Tennis Test (LITT) to volitional exhaustion. Groundstroke accuracy (range of shots) was assessed against a tennis ball service machine and service accuracy was determined using a scoring system developed by the researchers. There was a 69% decline in groundstroke hitting accuracy following the LITT test and a 30% decline in service accuracy to the right-hand court. Vergauwen et al. (1998) found an increase in groundstroke errors during defensive rallies and an increase in errors on first serves after a two hour strenuous training session.

More recently, Wu et al. (2010) found that in the absence of supplementation, service and forehand groundstroke consistency scores declined significantly after a simulated match. The findings have been inconsistent however, across studies to date. For example, Davey et al. (2002) found that the decline in groundstroke accuracy was not consistent across all shots. Service accuracy to the left court was unaffected by the ensuing fatigue. Finally, Aune et al. (2008) examined the effects of serial fatigue using a custom-built apparatus on table tennis hitting accuracy. The protocol was based on a series of four minute stages where the players were required to work at one-third of their maximal isometric forces with the aim of developing localized fatigue. One of few studies to explore fatigue effects in skilled and recreational players, they found that highly skilled players were capable of maintaining high accuracy performance while fatigued. Recreational players' performance however, decreased significantly (p = 0.005) in their study. They concluded that expertise enhances the potential to adjust motor co-ordination

strategies as a reaction to induced physical fatigue (Aune et al., 2008). It is clear therefore that there are discrepant findings here which emphasise further the need for additional research.

The study of personality as it relates to athletic performance has a long and rich history within the sport sciences (Gee et al., 2007). Under fatigue conditions, there are likely to be a host of personality factors that influence performance. One such factor which has been emphasized by numerous authors (Arnett et al., 2000; Ash, 1914; Caldwell and Lyddam, 1971; Delignieres et al., 1994; Hogervorst et al., 1996; Mousseau, 2004; Noakes, 2000; Schwab, 1953) is that of motivation. More recently, Girard and Millet (2008) emphasized the importance of motivation specifically in terms of the mechanisms underlying neuromuscular fatigue in racket sports.

The importance of motivation in maintaining task performance under challenging conditions dates back to earlier research conducted by Ash (1914) and Schwab (1953). Over the past 60 years, achievement motivation theorists have sought to identify and explain the factors involved in energizing and directing competence-relevant behavior (Conroy et al., 2003). A central construct in the literature on contemporary achievement motivation is that of achievement goals. These reflect how individuals construe (i.e. interpret and react) competence in a given achievement situation or context (Elliot, 1999).

In the domain of sport, achievement goals have been almost exclusively discussed in terms of a dichotomous mastery vs. performance goal distinction (Duda and Nicholls, 1992). The 2 × 2 model (Elliot and McGregor, 2001) is the major theoretical framework that has guided research on sport participants' achievement motivation in recent years. It assumes four goals to be operational in achievement contexts: a) mastery approach (striving to attain self-/task-referenced competence), b) mastery avoidance (attempting to avoid the demonstration of self-/task-referenced incompetence), c) performance approach (focusing on the attainment of normatively referenced competence) and, d) performance avoidance (striving to avoid the demonstration of normatively referenced incompetence). Research in the physical domain has revealed mastery approach goals to be associated with positive achievement patterns, such as intrinsic motivation (Cury et al., 2002) and performance (Elliot et al., 2006). The adoption of a performance approach goal is also expected to lead to some positive consequences, but less than a mastery approach (Elliot and Conroy, 2005). Elliot and Conroy (2005) tentatively proposed that mastery avoidance goals should correspond to less positive responses. The limited studies to date in the sport domain have revealed mastery avoidance goals to be associated with maladaptive patterns (Conroy et al., 2006). Few studies to date have explored whether aspects of an athlete or player's personality provide clues or insight into the factors that influence or affect a player's performance under fatigue conditions.

McGlynn et al. (1979) identified that previous studies concerning the effect of prior or concomitant exercise on performance almost always used male participants and it is possible that women may respond to various kinds and intensities of exercise quite differently from men. They concluded that there is a need to examine the effects of fatigue on performance in women. Consequently, the primary aim of this research was to examine the effect of moderate and high-intensity fatigue on groundstroke accuracy in expert and non-expert tennis players. A secondary aim was to explore whether the effects of moderate and high-intensity fatigue on groundstroke accuracy are the same regardless of gender and players achievement goal characteristics.

Methods

Participants
Thirteen expert tennis players (7 male and 6 female) and seventeen non-expert tennis players (13 male and 4 female) participated in this study. The players were recruited using volunteer and opportunistic sampling methods. The expert players were all current county standard players, training three times per week, playing regular competitive matches, with an LTA rating of 6.2. The non-expert players had an average LTA rating of 10.2 and comprised club-standard players. The mean age, stature and body mass of the expert tennis players was 19.5 ± 3.0 years, 1.76 ± 0.08 m, and 71.2 ± 13.7 kg respectively. The mean age, stature and body mass of the non-expert tennis players was 24.9 ± 9.6 years, 1.80 ± 0.10 m, and 73.2 ± 13.0 kg respectively.

Testing site
All testing was carried out on a single indoor hard-court that comprised a granular rubber base with 2 mm elastic polyurethane top layer (Pulastic 2000, Sports Surfaces International Ltd, England). The temperature was monitored using a digital barometer (Model BA116, Oregon Scientific, China) and regulated/maintained at 17-19° C with comfortable, stable humidity.

Experimental design
This study used a mixed factorial design. Informed consent and a medical history questionnaire were completed by all participants after being fully informed of the nature and demands of the study. All procedures were reviewed and approved by the Institutional Ethics Committee. Each participant attended three testing sessions (rest, moderate fatigue and high-intensity fatigue) in a counterbalanced order.

Baseline measurements
During the initial testing session, all procedures were explained in full to the participants. Stature and body mass were assessed using a Seca stadiometer and weighing scales (Seca Instruments Ltd, Germany). Participants were fitted with a heart rate monitor (Polar RS800, Polar Electro Oy, Kempele, Finland) to assess heart rate throughout the testing. Participants were given five minutes familiarisation with the tennis ball serving machine (Tennis Tutor Plus, Sports Tutor, USA) and court surface. During this time, tennis balls were served to the forehand and backhand sides at speeds of 66-68 km/hr and a frequency of 15 balls per minute. Participants were

instructed to return the groundstrokes at their normal warm-up pace in any direction. Following this, participants were given five minutes to perform their typical range of stretches prior to playing tennis competitively. After a 3-5 minute rest period, participants then began familiarisation blocks on the modified Loughborough tennis skills test.

The modified Loughborough Tennis Skills Test: Groundstrokes

The modified Loughborough Tennis Skills Test (mLTST) was used to assess groundstroke accuracy (Figure 1). In the original test (Davey et al., 2002) the accuracy target areas were 1.5 m^2 but for the purposes of this study, were increased to 2 m^2. The modification was made following pilot studies (examining the range of scores) with both expert and non-expert players. The target areas of 2 m^2 were marked out in the rear singles court area using standard court markers placed flat on the floor. The tennis ball serving machine was positioned in the middle of the court with the front edge 0.35 m from the baseline (Figure 1).
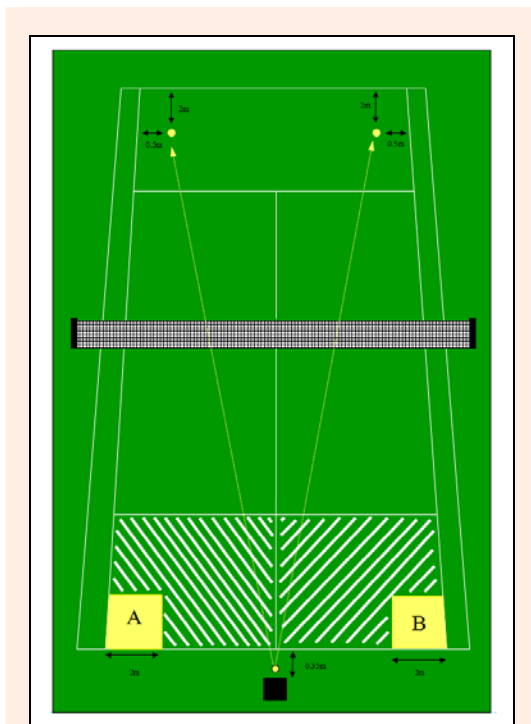

Figure 1. Diagrammatic representation of the mLTST

For each of the familiarisation blocks, the ball was served left and right alternating to the forehand and backhand at a frequency of 20 balls per minute in a continuous manner. For each serve, the ball was delivered with topspin, travelling over the net at a height of 1.5 m and landing 2 m from the baseline and 0.5 m from the tramline on both sides of the court. The participants were required to return all shots in the order of down-the-line forehand followed by cross-court backhand, aiming returns at target A at match pace (Figure 1). The testing continued in this manner until twenty

shots in total were completed (10 down the line forehand and 10 cross court backhand shots). Twenty shots comprised one familiarisation block and in total three blocks were completed. Participants were given 3-5 minutes rest between blocks so as to allow their heart rate to return to resting levels or within 10 bpm of resting levels. Following the three practice blocks participants then completed three further familiarisation blocks this time aiming each shot at target B. The ball serves remained consistent for all familiarisation blocks. The only difference was that on this occasion players were returning serves in the order of down-the-line backhand followed by cross-court forehand aiming returns at target area B (Figure 1). Players were again given 3-5 minutes rest between blocks and completed three blocks. In total therefore, six blocks were completed and players were sufficiently warmed up in preparation for the maximal tennis hitting sprint test which followed.

With respect to scoring the mLTST, each tennis ball that landed within the 2 m^2 areas (targets A & B) or hit the perimeter lines marking out these areas, was considered 'in'. Tennis balls landing within the area or on the perimeter marked out with the diagonal white lines (Figure 1) were considered 'consistent'. Any returned tennis balls that hit the net were replayed. These shots were not counted in the overall scoring of the test. Any ball landing in an area other than those specified above was considered 'out' and did not contribute to either the accuracy or consistency scores. The scoring and replay shot guidelines here are consistent with those outlined in the original test. The raw scores for each skill test were then converted into percentages, whereby:

'Consistency' + 'Accuracy' + 'Out' Scores = 100%

Mean percentage scores were calculated for each of the above parameters and used in subsequent statistical analyses.

Tennis Hitting Sprint Test

It has been established by a number of authors (Delamarche et al., 1987; Therminarias et al., 1991) that laboratory tests significantly underestimate the heart rate achieved in the field when hitting tennis balls using the arms and legs in combined exercise. For this reason, a tennis-specific sprint test developed by Davey et al. (2003) was used to obtain peak heart rate (HR_{peak}) for the purposes of setting the fatigue intensities in this study (Figure 2). This test is specific to the movements experienced in competitive tennis matches and the peak heart rate is much more realistic to that achieved in the field (Davey et al., 2003).

Following the familiarization blocks, participants completed the maximal hitting sprint test starting in the centre of the baseline (base A – Figure 2). On the tester's command, the participant sprinted to point number 1 where a tennis ball was dropped by the investigator for the participant to hit over the net. The participant turned and sprinted back to base A. When they reached base A, the participant turned and sprinted to point number two where a ball was dropped again by the investigator and

hit over the net by the participant. The participant again sprinted back to base A and the test continued in this manner with the participants sprinting to points three, four and five, hitting a tennis ball at each and sprinting back to base A between shots. For each sequence, participants were required to hit forehand groundstrokes at points one and two, a forehand approach shot at point three and backhand groundstrokes at points four and five (Figure 2). This comprised one complete sequence and was followed by a ten-second recovery period. During the recovery period, heart rate and ratings of perceived exertion (RPE) (Borg, 1970) were recorded by the investigator. The RPE values served as an adjunct to the monitoring of heart rate. At the end of the ten-second recovery period the test sequence was repeated again. The test continued in this manner until a plateau in heart rate (two consecutive heart rates within 1-2 bpm were achieved). The higher of the two heart rates achieved during the test was recorded as HR_{peak}. From this HR_{peak} value, both the moderate (70% HR_{peak}) and high-intensity (90% HR_{peak}) fatigue criteria were established based on each player's individual capacity. Once players had completed the baseline measures outlined here, they performed a 3-5 minute cool-down against the ball serving machine followed by a five-minute stretching phase. This comprised the initial baseline testing session.
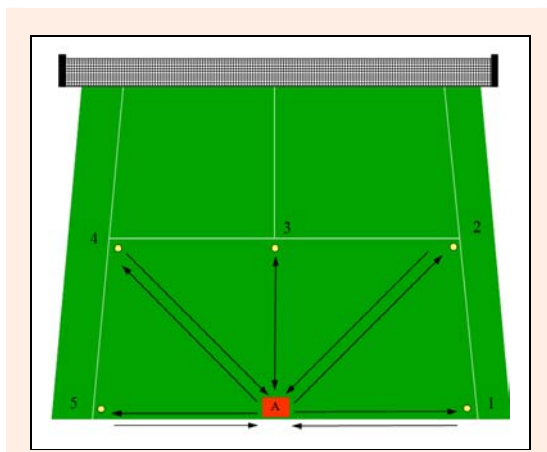

Figure 2. Diagrammatic representation of the maximal Tennis Hitting Sprint Test.

The rest, moderate and high-intensity fatigue conditions were conducted on separate testing days so as to avoid potential cumulative fatigue effects. Each of these testing sessions began with a five-minute standardised warm-up against the tennis ball serving machine, alternating feeds to the forehand and backhand sides at a frequency of 15 balls per minute. Players were informed that they could stand anywhere on court but were instructed to hit the ball as they would during normal match play. They were also instructed to practice all the different strokes required in the mLTST. Following this, participants were given five-minutes to perform their normal range of stretches. Following the standardized warm-up players commenced the Loughborough Intermittent Tennis Test (Davey et al., 2003).

Loughborough Intermittent Tennis Test (LITT)

This LITT consisted of bouts of maximal hitting of four minutes' duration with 40 seconds seated recovery between bouts. The ball machine served the tennis balls in a random fashion (Figure 3) at a frequency of 20 balls per minute which was increased after each 4 minute period. The speed of release was 68-72 km/hr with the tennis machine releasing the ball (with topspin) so it travelled over the net at a height of 1.5 m and landed within 2 m of the baseline. Participants were required to hit returns at maximum effort as they would during competitive match play, within the singles court. The test continued in this manner (four minutes maximal hitting followed by 40 seconds seated recovery) until participants reached the required fatigue level. For the moderate fatigue level, the LITT continued until the player reached 70% HR_{peak} and an RPE level of 15. For the high-intensity fatigue level, the LITT continued until the player reached 90% HR_{peak} and an RPE level of 18. Both criteria had to be met in each case to ensure that players were truly at the desired fatigue level. At this point, the ball-serving setting was switched to wide feed and served the ball left and right to the points on the court shown in Figure 1. Players immediately completed 20 shots (in the order of down the line forehand followed by cross court backhand) aiming each shot at target A. This was followed immediately (without rest) by 20 shots (in the order of down the line backhand followed by cross-court forehand) aiming each shot at target B.
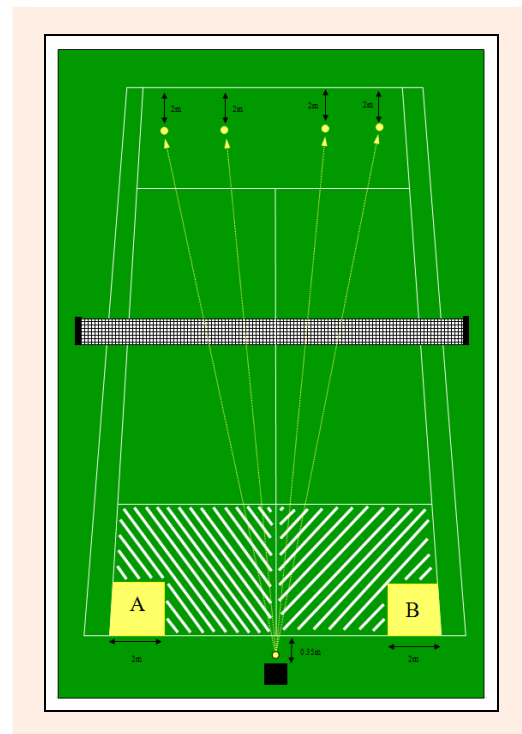

Figure 3. Loughborough Intermittent Tennis Test

Heart rate and RPE values have been used in similar past work as they provide relatively reliable and valid information about a players physical effort and intensity during tennis matches (Fernandez-Fernandez et al., 2006; Gomes et al., 2011; Mendez-Villanueva et al.,

2007; Novas et al., 2003). It took players on average 6.23 minutes to reach the moderate-intensity fatigue state on the LITT and 12.73 minutes to reach the high-intensity fatigue state. The mean heart rates at moderate and high-intensity fatigue were 170.60 ± 7.24 bpm and 186.57 ± 7.49 bpm respectively.

As well as completing the testing under moderate and high-intensity fatigue states, the mLTST was also completed on a separate occasion in a rested state following only a warm-up. The order of all tests and fatigue conditions were counterbalanced.

The 2 x 2 Achievement Goals Questionnaire for Sport (Conroy et al., 2003)

As part of the baseline measurements, each participant also completed the Conroy et al. (2003) 2 x 2 Achievement Goals Questionnaire for Sport (AGQ-S). The questions in the AGQ-S provide the researcher with an indication of key goals that motivate an individual. The AGQ-S consists of four subscales: mastery-approach (striving to master all aspect of personal performance), mastery-avoidance (striving to avoid incompetence), performance-approach (striving to do better than others) and performance-avoidance (striving to avoid doing worse than others). Each of the four subscales of the AGQ-S has been shown to have acceptable internal consistency estimates (0.70, 0.82, 0.88 and 0.87 respectively) (Conroy et al., 2003).

The entire sample AGQ-S data were averaged irrespective of gender/expertise. The data from the two approach subscales were combined and a mean for the entire group was calculated. High and low approach achievement motivation groups were then calculated based on whether an individual was above or below the mean (split mean) for the group. Those above the mean were categorized as a 'high approach' group and those below the mean were categorized as a 'low approach' group. The same procedure was used with the avoidance subscale data. Again, high and low avoidance achievement motivation groups were determined based on a split mean. These groups were used as a between-subject factor in the subsequent analyses which follow.

Statistical analysis

Four shots were analysed during the testing sessions at rest, under moderate and high-intensity fatigue conditions. These were down-the-line forehand (DTLF), down-the-line backhand (DTLB), cross-court forehand (CCF) and cross-court backhand (CCB). For each shot the participant's raw scores were converted into 'accuracy', 'consistency' and 'out' percentages as a means of generating the dependent variables. For the purposes of brevity however, all four groundstrokes were combined to give an overall percentage for 'accuracy', 'consistency' and 'out' groundstrokes. A number of 3 x 2 mixed ANOVAs were then conducted on the overall percentage data. For each analysis, the within-subject factors were the three conditions (rest, moderate and high-intensity fatigue). However, a number of between-subject factors were examined including:

- Expertise level (expert and non-expert players)
- Gender (males and females)
- Approach achievement motivation (high and low approach groups)
- Avoidance achievement motivation (high and low avoidance groups)

As all treatment conditions were planned, a pairwise least significant difference post hoc procedure was used in the case of significant F scores. With each analysis, the residuals of the repeated measures ANOVA were checked for normality using the Shapiro-Wilk test statistic. Homogeneity of variance was evaluated using Mauchly's test of sphericity and when violated, the Greenhouse-Geisser adjustment was used. SPSS Version 17.0 (SPSS Inc., Chicago, IL) was used for all statistical calculations. The level of significance was set at 0.05.

Results

The 'accuracy', 'consistency' and 'out' percentages of expert and non-expert players across individual groundstrokes are presented in Table 1. The 'accuracy', 'consistency' and 'out' percentages for both forehand shots

Table 1. Mean (± SD) percentages of the expert and non-expert tennis players for each shot across all fatigue intensities.

	Accuracy (%) Expert Players			Accuracy (%) Non-Expert Players		
	Rest	70%	90%	Rest	70%	90%
DTLB	21.54 (15.73)	16.15 (13.87)	18.46 (17.25)	16.47 (13.67)	15.29 (12.31)	10.59 (12.98)
DTLF	33.08 (13.17)	31.54 (16.76)	10.00 (10.00)	22.94 (22.30)	12.94 (9.85)	8.24 (8.83)
CCB	16.92 (23.23)	30.00 (12.25)	15.38 (12.66)	12.94 (9.20)	19.41 (17.49)	7.06 (12.13)
CCF	27.69 (13.01)	22.31 (14.23)	15.38 (15.61)	14.12 (15.84)	17.06 (13.12)	7.65 (7.52)
	Consistency (%) Expert Players			**Consistency (%) Non-Expert Players**		
	Rest	70%	90%	Rest	70%	90%
DTLB	54.62 (20.26)	50.00 (11.55)	43.85 (11.21)	34.12 (16.61)	42.35 (14.37)	33.53 (16.93)
DTLF	49.23 (18.91)	50.00 (19.58)	53.85 (10.44)	42.35 (20.78)	45.29 (19.08)	34.12 (13.72)
CCB	56.92 (23.59)	50.77 (13.21)	47.69 (20.88)	42.94 (15.72)	49.41 (17.84)	32.35 (19.85)
CCF	50.00 (10.80)	53.85 (19.38)	54.62 (18.98)	48.82 (21.76)	49.41 (15.60)	41.76 (17.04)
	Out (%) Expert Players			**Out (%) Non-Expert Players**		
	Rest	70%	90%	Rest	70%	90%
DTLB	23.85 (12.61)	33.85 (15.57)	37.69 (14.23)	49.41 (20.15)	42.35 (19.54)	55.88 (21.52)
DTLF	17.69 (12.35)	18.46 (16.76)	36.15 (12.61)	34.71 (20.04)	41.76 (21.57)	57.65 (13.93)
CCB	26.15 (15.57)	19.23 (10.38)	36.92 (17.02)	44.12 (15.84)	31.18 (20.88)	60.59 (22.21)
CCF	22.31 (13.01)	23.85 (13.87)	30.00 (21.21)	37.06 (23.12)	33.53 (18.69)	50.59 (19.83)

Table 2. Mean (± SD) percentages of the expert and non-expert tennis players for both forehand shots combined, backhand shots combined and all shots combined.

	Accuracy (%) Expert Players			Accuracy (%) Non-Expert Players		
	Rest	70%	90%	Rest	70%	90%
Forehand Shots	30.38 (11.98)	26.92 (12.34)	12.69 (9.49)	18.53 (17.92)	15.00 (9.52)	7.94 (6.14)
Backhand Shots	19.23 (12.89)	23.08 (9.69)	16.92 (11.64)	14.71 (9.10)	17.35 (12.64)	8.82 (10.08)
All shots combined	24.81 (10.08)	25.00 (8.96)	14.81 (8.51)	16.62 (10.00)	16.18 (8.98)	8.38 (7.23)
	Consistency (%) Expert Players			Consistency (%) Non-Expert Players		
	Rest	70%	90%	Rest	70%	90%
Forehand Shots	49.62 (11.27)	51.92 (15.48)	54.23 (12.22)	45.59 (16.00)	47.35 (12.39)	37.94 (9.85)
Backhand Shots	55.77 (16.94)	50.38 (9.89)	45.77 (13.97)	38.53 (14.77)	45.88 (12.53)	32.94 (13.00)
All shots combined	52.69 (12.50)	51.15 (5.55)	50.00 (10.00)	42.06 (11.57)	46.62 (7.65)	35.44 (6.97)
	Out (%) Expert Players			Out (%) Non-Expert Players		
	Rest	70%	90%	Rest	70%	90%
Forehand Shots	20.00 (9.13)	21.15 (13.10)	33.08 (12.84)	36.18 (18.84)	37.65 (16.87)	54.12 (12.15)
Backhand Shots	25.00 (13.54)	26.54 (10.68)	37.31 (12.18)	46.76 (16.10)	36.76 (17.67)	58.24 (17.76)
All shots combined	22.50 (9.57)	23.85 (8.70)	35.19 (9.76)	41.47 (13.75)	37.21 (12.08)	56.18 (9.89)

combined, backhand shots combined and all shots combined are presented in Table 2.

A 3 (fatigue intensities) x 2 (expertise levels) mixed ANOVA on the accuracy or 'in' percentage scores for all four shots combined revealed highly significant fatigue effects ($F_{2, 56} = 14.517$, $p < 0.001$, $\eta^2 = 0.341$) and highly significant between-group differences ($F_{1, 28} = 10.302$, $p = 0.003$, $\eta^2 = 0.269$). No fatigue by level of expertise interaction was found however ($p > 0.05$). LSD post hoc procedure revealed a highly significant ($p < 0.001$) difference between performance at rest and performance following high-intensity fatigue. Furthermore, there was a highly significant ($p < 0.001$) difference between moderate and high-intensity fatigue conditions (Figure 4).
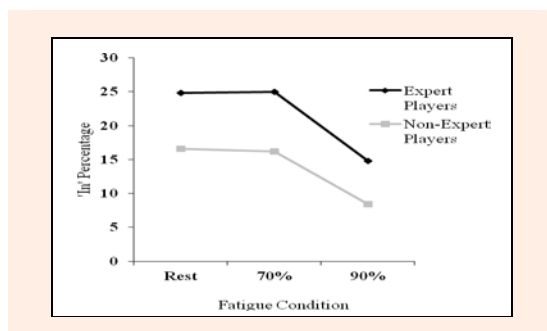
Figure 4. Percentage of 'in' shots across fatigue intensities in expert and non-expert tennis players

A 3 x 2 mixed ANOVA was conducted on the 'out' percentage scores for all four shots combined and again revealed a highly significant fatigue effect ($F_{2, 56} = 27.301$, $p < 0.001$, $\eta^2 = 0.494$) and highly significant between-group differences ($F_{1, 28} = 33.407$, $p < 0.001$, $\eta^2 = 0.544$). The results illustrate that there are marked differences in the number of 'out' shots performed by expert and non-expert players across fatigue intensities. LSD post hoc procedure revealed similar trends to those found for the accuracy percentages. A highly significant difference was found between performance at rest and that following high-intensity fatigue. Furthermore, there was a highly significant difference between performance following moderate and high-intensity fatigue (both, p

< 0.001) but no fatigue by level of expertise interaction ($p > 0.05$) (Figure 5).

The final analyses examined the consistency data. A 3 x 2 mixed ANOVA again revealed a highly significant main effect ($F_{2, 56} = 5.093$, $p = 0.009$, $\eta^2 = 0.154$), highly significant between-group differences ($F_{1, 28} = 15.391$, $p = 0.001$, $\eta^2 = 0.355$) but no fatigue by level of expertise interaction ($F_{2, 56} = 3.145$, $p = 0.051$, $\eta^2 = 0.101$). The LSD post hoc revealed differences between performance at rest and high-intensity fatigue ($p = 0.026$) as well as a highly significant difference between performance following moderate and high intensity fatigue ($p = 0.002$). With respect to the consistency of expert and non-expert players, the trend (Figure 6) is dissimilar to those presented thus far.
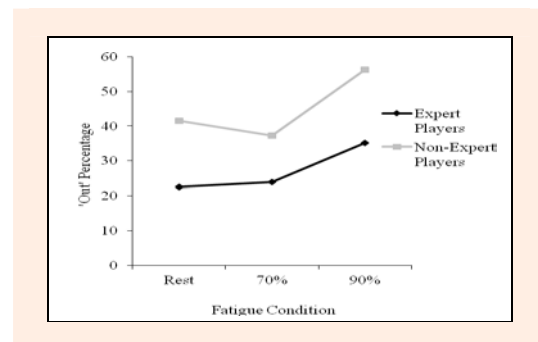
Figure 5. Percentage of 'out' shots across fatigue intensities in expert and non-expert tennis players.
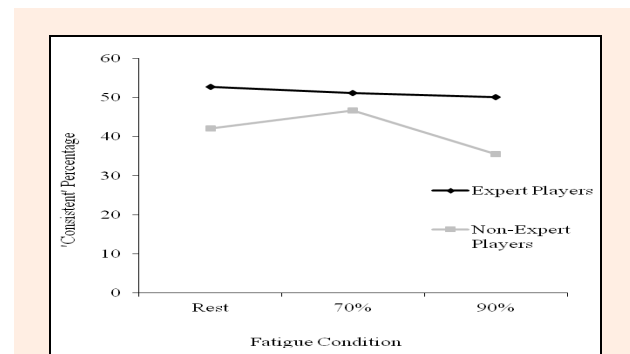
Figure 6. Percentage of 'consistent' shots across fatigue intensities in expert and non-expert tennis players.

Gender

A 3 (fatigue intensities) x 2 (males and females) mixed ANOVA was conducted on the accuracy percentage scores for all four shots combined and indicated that there was a highly significant fatigue effect ($F_{2, 56}$ = 12.404, $p < 0.001$, $\eta^2 = 0.307$). LSD post hoc procedures revealed that there was a highly significant difference between performance at rest and high-intensity fatigue. There was again a highly significant difference between groundstroke accuracy following moderate and high-intensity fatigue (both, $p < 0.001$). No fatigue by gender interaction was found however, and no between-group differences (both, $p > 0.05$). The performance of both groups at rest was analyzed further by means of an independent t-test in an effort to explore whether the differences evident at rest (Figure 7) were significantly different. The t-test revealed that this was not the case ($p > 0.05$). The same ranges of statistical analyses were conducted on the consistency and out percentages with very similar findings. In each case, highly significant main effects were found with no between-group differences (all, $p > 0.05$).
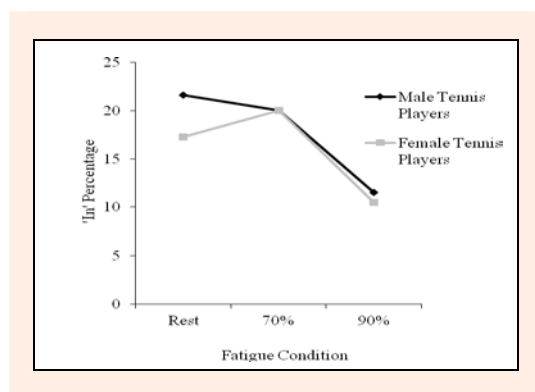

Figure 7. Percentage of 'in' shots across fatigue intensities in male and female tennis players.

Achievement motivation

Concerning the AGQ-S scores, the entire groups of players were grouped into 'high approach' and 'low approach' groups based only on their AGQ-S responses. These high and low 'approach' groups were then used as a between-subject factor in the analyses which follow here. A 3 (fatigue intensities) x 2 (high and low approach) mixed ANOVA was conducted on the accuracy scores for all four shots combined and a highly significant fatigue effect was found ($F_{2, 56}$ = 14.513, $p < 0.001$, $\eta^2 = 0.341$). No fatigues by group interaction or between-group effects were apparent (both $p > 0.05$). LSD post hoc analyses revealed a highly significant difference between performance at rest and high-intensity fatigue ($p < 0.001$) and a highly significant difference between the accuracy scores following moderate and high-intensity fatigue ($p < 0.001$). The same ranges of analyses were conducted on the consistency and out percentage data for all groundstroke shots combined. In each case, highly significant main (fatigue) effects were found. There were no between-group differences or fatigue by group interactions found.

Finally, players were grouped into 'high avoidance' and 'low avoidance' groups based on the AGQ-S responses. The same ranges of analyses as described above were conducted. Again highly significant main (fatigue) effects were found with all analyses (all, $p < 0.01$). No between-group differences or fatigue by avoidance interactions were found across all the analyses (all $p > 0.05$).

Discussion

Fatigue is a topic that continues to fascinate exercise physiologists, psychologists, sport scientists, athletes and coaches alike. This is because fatigue is multifaceted, complex and encompasses a variety of behaviours that are unique to each situation (Gawron et al., 2001). In tennis specifically, physiological, biomechanical, psychological and perceptual elements all integrate (Hornery et al., 2007b) and so the demands imposed on players are not easily simulated (Smekal et al., 2001). This investigation sought to develop fatigue states using a tennis-specific protocol which mimics more closely the type of movements and level of response exhibited during match play. Following the LITT, the mean heart rate at moderate-intensity fatigue was 170.60 ± 7.24 bpm. This is very similar to values reported in the literature pertaining to competitive or simulated match-play (Hornery et al., 2007b; Girard and Millet, 2004; Wu et al., 2010). The heart rate at high-intensity fatigue was 186.57 ± 7.49 bpm. This is slightly higher than the average heart rates reported in some research pertaining to singles tennis match play. However, the importance of brief periods of maximal work should not be understated as it is during these crucial periods that matches can be won or lost (Fernandez-Fernandez et al., 2006). Furthermore, at certain moments in tennis matches heart rate values have been found to reach values of 190-200bpm (Bergeron et al., 1991; Girard and Millet, 2004; Smekal et al., 2001; Torres et al., 2004). Periods of high-intensity fatigue are clearly important therefore in terms of match outcome.

To reinforce, the primary aim of this research was to examine the effect of moderate and high-intensity fatigue on groundstroke accuracy in expert and non-expert tennis players. The 3 x 2 mixed ANOVA's for accuracy, consistency and out percentages all revealed highly significant fatigue effects. In both groups, groundstroke accuracy following high-intensity fatigue was significantly poorer than that at rest and moderate-intensity fatigue (Figures 4 and 5). The finding here provide little support for dynamic systems theory, which posits that movement reorganisation permits increased variation of skill execution in order to achieve a constant task outcome. So performance or task demands can be met with different patterns of movement coordination. Royal et al. (2006) showed this clearly in their study in that as fatigue intensity increased, technical skill decreased but speed and accuracy of the shot remained unchanged. Aune et al. (2008) also found that expert players in their study were capable of maintaining task performance under localized fatigue conditions through an adjusted motor co-ordination strategy. The findings of

this study however, provide no such evidence as groundstroke accuracy deteriorated significantly under high-intensity fatigue conditions in both expert and non-expert tennis players.

In the present study, performances at rest and moderate-intensity fatigue were equivalent within expert and non-expert players. The between-group analyses (for accuracy, consistency and out shots) also revealed highly significant differences. In each case, expert players maintain a higher percentage of 'in' shots across the three conditions. Expert players hit fewer 'out' shots across the three conditions and were also more consistent when compared to the non-expert players. This is consistent with the findings of Aune et al. (2008). However, while between-group differences were found, no fatigue by level of expertise interactions was found. The performance of the expert tennis players in this study provide limited support for Janelle and Hillman's (2003) assertion that expert performers may be capable of dealing with affective states more appropriately, thus maintaining a higher level of performance. While it is true they maintained a consistently higher level of performance compared to the non expert players, groundstroke accuracy (as with the non-expert players) still deteriorated significantly following high-intensity fatigue.

Many of the procedures used in this study were derived from the work of Davey et al. (2002; 2003). Davey et al. (2002) also examined the effect of the LITT on tennis performance in a group of elite tennis players. In their study, players continued to perform the LITT to the point of volitional exhaustion at which there was a 69% decline in groundstroke accuracy. Underlying this decline in groundstroke accuracy in their study could be that players were pushed to 98-100% maximal heart rate, maximal RPE (20) and the LITT was completed for 35 minutes in total. Players in the current study were pushed to 90% of HR_{peak}, an RPE of 18 and the LITT was completed for 12.73 minutes on average. The overall decline in accuracy from rest to high-intensity fatigue observed in this study was 40.3% in the expert players and 49.6% in the non-expert players. The results here show trends consistent with those of Vergauwen et al (1998) who also found an increase in groundstroke errors after a strenuous tennis session and Wu et al (2010) who found forehand groundstroke consistency declined after a simulated tennis match.

Consistent with the findings of Davey et al (2002), this study also showed that there are distinct differences in terms of the effects of fatigue across individual groundstrokes. These are evident in Table 1 where accuracy of the down-the-line forehand declines with increasing levels of fatigue in both expert and non-expert players. Accuracy of the cross-court backhand shot however, improves in both groups at moderate levels of fatigue compared to rest. Fatigue effects on groundstoke accuracy are not consistent across all groundstrokes therefore. This is further evidenced in Table 2 when the two forehand shots are combined separately and the two backhand shots are combined. Accuracy of the forehand groundstrokes (combined) declines in a linear manner

with increasing levels of fatigue in both groups. Accuracy of the backhand groundstrokes (combined) shows improvement at moderate-intensity fatigue compared to resting performance and then decline following high-intensity fatigue.

A secondary aim of this research was to explore whether the effects of moderate and high-intensity fatigue on groundstroke accuracy are the same regardless of (1) gender and (2) players achievement goal characteristics. With respect to the range of analyses examining within and between-group differences in male and female tennis players, a number of interesting preliminary findings were revealed here. Firstly, with all the analyses conducted ('in', 'out' and 'consistency' percentages) significant fatigue effects were found across each analysis, with no between-group effects. Consequently, it seems that both male and female tennis players perform at comparable levels under moderate and high-intensity fatigue conditions and this is clearly evident in Figure 7. The only difference of note here is that at rest. Further analysis however, found no statistically significant differences at rest between the male and female players. The accuracy percentages of males and females across all intensities therefore, were equivalent. Benjaminse et al (2008) in a very different investigation to the present study also found no gender differences in terms of how fatigue alters lower extremity kinematics during a single leg stop jump task. The comparison here is tenuous in light of the obvious differences in the nature of both the fatigue and performance tasks. However, the findings of their study and the present research suggest that there is similarity in the responses of males and females under moderate and high-intensity fatigue conditions. Much more research exploring gender differences under fatiguing conditions is warranted (McGlynn et al. 1979) so as to add to the preliminary findings here.

Human performance under fatigue conditions is likely to be influenced by many variables, not least those involving the psyche (Noakes, 2000). It has long been established in the literature that future researchers need to examine experimentally how different levels of motivation in conjunction with varying exercise intensities and durations may affect cognitive performance (Szabo and Gauvin, 1992). This also holds true of fatigue effects on sports performance. A host of personality and psychological factors may influence performance under intense exercise or fatigue conditions. Arnett, DeLuccia and Gilmartin (2000) put forward that issues regarding the psyche, motivation, and other personality factors/traits need consideration in research of this nature. The final aim of this research was to explore whether a specific aspect of motivation, namely achievement goals, interacts with performance under moderate or high-intensity fatigue. The AGQ-S data were analyzed based on the avoidance and approach subscales, with high and low groups developed based on a split mean. It was proposed that those players who scored high on the approach scale may perform better than their low approach counterparts due to their positive achievement patterns and intrinsic motivation. Conversely, those who scored high on the avoidance may suffer greater decrements in performance

with increasing intensities as avoidance goals have been associated with maladaptive patterns (Conroy et al. 2006). The same ranges of statistical analyses were conducted. In summary, there was no fatigue by approach interaction or fatigue by avoidance interaction (both, p > 0.05). Similarly, no between-group differences were found in each case (both, p > 0.05). The findings here suggest that a player's achievement goal indicators [assessed using the AGQ-S] do not impact or influence groundstroke accuracy at rest, moderate and high-intensity fatigue. The effects on groundstroke accuracy were the same regardless of whether players were high on mastery-approach (striving to master one's personal performance), mastery-avoidance (striving to avoid incompetence), performance-approach (striving to do better than others) or performance-avoidance (striving to avoid doing worse than others).

As with past research pertaining to this topic, the protocols used in this research are not without limitation. In controlled field investigations such as this, it is not possible to fully replicate the demands of competitive match play which vary considerably across matches, playing surfaces and environments. It is also not possible to create the same sensory states of competition. Therefore, in spite of the effort to maximise ecological validity, there will always be some compromise. There are also some assumptions inherent in this research. Verbal encouragement was provided by the researcher during all testing conditions in order to motivate participants. It is assumed therefore, that all the players produced their best effort to achieve the maximal performance they were capable of at that time. There is added difficulty here also in light of the fact that the player is playing against a ball serving machine and not an actual opponent. These points need consideration when interpreting the findings.

With a research topic as broad as fatigue effects on performance in tennis, it is likely that there are many contributing variables, the significance of which need more exploration. Future ecologically sound research is imperative in this respect, examining all aspects of skilled performance in tennis under resting and fatigue conditions. A key challenge for the researcher however, is to develop sport-specific protocols that simulate as closely as possible match conditions. Research relating to fatigue effects on sports performance in expert and non-expert groups, males and females is still very much in its infancy. Much more research is needed here as well as exploration of psychological and / or personality variables in an effort to clarify or better understand how these interact with performance when fatigued. A more holistic approach is needed therefore incorporating physiological, psychological and biomechanical analyses simultaneously so as to allow for a more comprehensive analysis of performance and a deeper understanding of fatigue effects on performance in tennis. An interdisciplinary approach such as this will greatly advance our understanding of this complex multidimensional construct as well as the personality and / or psychological factors that may influence performance under fatigue conditions. Research of this nature would be of immense value to players, coaches and trainers at every performance level.

Conclusion

Coaches and commentators often blame the deterioration in an athlete's skill level at the end of a game on increasing fatigue levels (Royal, 2004). However, physiologists, researchers and sport scientists alike are concerned with the validity of such statements. This research has demonstrated clearly that groundstroke accuracy deteriorates little under moderate-intensity fatigue conditions when compared to resting performance. However, performance declines significantly in both expert (40.3% decline) and non-expert (49.6%) players following high-intensity fatigue. Across all conditions expert players were more consistent, hit more accurate shots and fewer out shots. The research has also demonstrated that the effects of fatigue are equivalent in males and females alike, with similar trends in performance. The effects of fatigue are also the same regardless of player's achievement goal indicators.

Coaches integrating short bouts of high-intensity exercise into skill sessions need to consider the findings here carefully. It is fundamental that the intensity simulates, as much as possible, the bouts typical of a competitive game. Practicing skills under high-intensity fatigue conditions can result in a lessening of the inhibitory effects of fatigue (Goper, 1992; McMorris et al., 1994) but if technique deteriorates, then such training can prove counter-productive (Anshel and Novak, 1989) or worse still, lead to injury. An important consideration for the coach here is to carefully monitor technique during these practice sessions.

References

Anshel, M.H. and Novak, J. (1989) Effects of different intensities of fatigue on performing a sport skill requiring explosive muscular effort: A test of the specificity of practice principle. *Perceptual and Motor Skills* **69(2)**, 1379-1389.

Arnett, M.G., DeLuccia, D. and Gilmartin, K. (2000) Male and female differences and the specificity of fatigue on skill acquisition and transfer performance. *Research Quarterly for Exercise and Sport* **71 (2)**, 201-205.

Ash, I.E. (1914) Fatigue and its effects upon control. *Archives of Psychology* **4**, 1-61.

Aune, T.K. Ingvaldsen, R.P. and Ettema, G.J.C. (2008) Effect of physical fatigue on motor control at different skill levels. *Perceptual and Motor Skills* **106 (2)**: 371-386.

Benjaminse, A., Habu, A., Sell, T.C., Abt, J.P., Fu, F.H., Myers, J.B. and Lephart, S.M. (2008) Fatigue alters lower extremity kinematics during a single-leg stop-jump task. *Knee Surgery, Sports Traumatology, Arthroscopy* **16,** 400-407.

Bergeron, M.F., Maresh, C.M., Kraemer, W.J., Abraham, A., Conroy, B and Gabaree, C. (1991) Tennis: a physiological profile during match play. *International Journal of Sports Medicine* **12**, 474-479.

Booras, M.C. (2001) The relationship of mental skills to performance on a tennis accuracy task under fatigued and no-fatigued conditions. *Unpublished Masters Thesis*. West Virginia University.

Borg, G. (1970) Perceived exertion as an indicator of somatic stress. *Scandinavian Journal of Rehabilitation Medicine* **2(2),** 92-98.

Caldwell, L.S. and Lyddan, J.M. (1971) Serial isometric fatigue functions with variable intertribal intervals. *Journal of Motor Behaviour* **3**, 17-30.

Conroy, D.E., Elliot, A.J. and Hofer, S.M. (2003) A 2 x 2 achievement goals questionnaire for sport: evidence for factorial invariance, temporal stability and external validity. *Journal of Sport and Exercise Psychology* **25 (4)**, 456-476.

Conroy, D.E., Kaye, M.P. and Coatsworth, J.D. (2006) Coaching climates and the destructive effects of mastery avoidance achievement goals on situational motivation. *Journal of Sport and Exercise Psychology* **28 (1)**, 69-92.

Cury, F., Elliot, A.J., Sarrazin, P., Da Fonseca, D. and Rufo, M. (2002) The trichotomous achievement goal model and intrinsic motivation: A sequential mediational analysis. *Journal of Experimental Social Psychology* **38 (5)**: 473-481.

Davey, P.R., Thorpe, R.D. and Williams, C. (2002) Fatigue decreases skilled tennis performance. *Journal of Sports Sciences* **20 (4)**, 311-318.

Davey, P.R., Thorpe, R.D. and Williams, C. (2003) Simulated tennis matchplay in a controlled environment. *Journal of Sports Sciences* **21 (6)**, 459-467.

Delamarche, P., Gratas, A., Beillot, J., Dassonville, J., Rochcongar, P. and Lessard, Y. (1987) Extent of lactic anaerobic metabolism in handballers. *International Journal of Sports Medicine* **8 (1)**, 55-59.

Delignieres, D., Brisswalter, J. and Legros, P. (1994) Influence of physical exercise on choice reaction time in sports experts: The mediating role of resource allocation. *Journal of Human Movement Studies* **27**, 173-189.

Duda, J.L. and Nicholls, J.G. (1992) Dimensions of achievement motivation in schoolwork and sport. *Journal of Educational Psychology* **84 (3),** 290-299.

Elliot, A.J. and Conroy, D.E. (2005) Beyond the dichotomous model of achievement goals in sport and exercise psychology. *Sport and Exercise Psychology Review* **1**, 17-25.

Elliot, A.J., Cury, F., Fryer, J.W. and Huguet, P. (2006) Achievement goals, self-handicapping, and performance attainment: a mediational analysis. *Journal of Sport and Exercise Psychology* **28 (3),** 344-361.

Elliot, A.J. and McGregor, H.A. (2001) A 2 X 2 achievement goal framework. *Journal of Personality and Social Psychology* **80 (3)**, 501-519.

Elliot, A.J. (1999) Approach and avoidance motivation and achievement goals. E*ducational Psychologist* **34 (3)**, 169-189.

Fernandez-Fernandez, J., Mendez–Villanueva, A. and Pluim, B. (2006) Intensity of tennis match play. *British Journal of Sports Medicine* **40**, 387-391.

Gawron, V.J., French, J. and Funke, D. (2001) An overview of fatigue. In: *Stress, Workload, and Fatigue: Human Factors in Transportation*. Eds: Hancock, P.A. and Desmond, P.A. Hahwah, NJ: Lawrence Erlbaum Associates. 581-595.

Gee, C.J., Dougan, R.A., Marshall, J.C. and Dunn, L.A. (2007) Using a normative personality profile to predict success in the National Hockey League (NHL): a 15-year longitudinal study. *Journal of Sport & Exercise Psychology* **29**, S164.

Girard, O. and Millet, G.P. (2008) Neuromuscular fatigue in racquet sports. *Neurologic Clinics* **26**, 181-194.

Girard, O. and Millet, G.P. (2004) Effects of the ground surface on the physiological and technical responses in young tennis players. In: *Science and Racket Sports III*. Eds: Reilly, T., Huges, M., Lees, A. London: E and FN Spon. 4, 43-48.

Gomes, R.V., Coutts, A.J., Viveiros, L. and Aoki, M.S. (2011) Physiological demands of match-play in elite tennis: A case study. *European Journal of Sport Science* **11(2)**, 105-109.

Gopher, D. (1992) The skill of attention control: Acquisition and execution of attention strategies. In: *Attention and performance, XIV: Synergies in Experimental Psychology, Artificial Intelligence and Cognitive Neuroscience*. Eds: Matthews, D.E. and S. Kornblum, S. Cambridge, MA: MIT Press.

Hogervorst, E., Riedal, W., Jeukendrup, A. and Jolles, J. (1996) Cognitive performance after strenuous physical exercise. *Perceptual and Motor Skills* **83**, 479-488.

Hornery, D.J., Farrow, D., Mujika, I. and Young, W. (2007a) Fatigue in tennis: mechanisms of fatigue and effect on performance. *Sports Medicine* **37 (3)**, 199-212.

Hornery, D.J., Farrow, D., Mujika, I. and Young, W. (2007b) An integrated physiological and performance profile of professional tennis. *British Journal of Sports Medicine* **41**, 531-536.

Janelle, C.M. and Hillman, C.H. (2003) Current perspectives and critical issues. In: *Expert performance in Sports: Advances in Research on Sport Expertise*. Eds: Starkes, J.L. and Ericsson, K.A. Champaign Illinois: Human Kinetics. 19-47.

Kovacs, M.S. (2006) Applied physiology of tennis performance. *British Journal of Sports Medicine* **40 (5)**, 381-386.

Marks, B.L., Angelopoulos, T., Shields, E., Katz, L.M., Moore, T., Hylton, S., Larson, R. and Wingo, J. (2006) The effect of a new sports drink on fatigue factors in competitive tennis athletes. *Journal of Sports Sciences* **24 (4)**, 344.

McGlynn, G.H., Laughlin, N.T. and Rowe, V. (1979) The effect of increasing levels of exercise on mental performance. *Ergonomics* **22 (4)**, 407-414.

McMorris, T., Gibbs, C., Palmer, J., Payne, A. and Torpey, N. (1994) Exercise and performance of a motor skill. *Research Supplement* **15**, 23-27.

Mendez-Villanueva, A., Fernandez-Fernandez, J. and Bishop, D. (2007) Exercise-induced homeostatic perturbations provoked by singles tennis match play with reference to development of fatigue. *British Journal of Sports Medicine* **41 (11)**, 717-722.

Mousseau, M.B. (2004) The onset and effect of cognitive fatigue on simulated sport performance. *Unpublished Masters Thesis*, University of Florida.

Noakes, T.D. (2000) Physiological models to understand exercise fatigue and the adaptations that predict or enhance athletic performance. *Scandinavian Journal of Medicine and Science in Sports* **10**, 123-145.

Novas, A.M.P., Rowbottom, D.G. and Jenkins, D.G. (2003) A practical method of estimating energy expenditure during tennis play. *Journal of Science and Medicine in Sport* **6 (1)**, 40-50.

Royal, K. (2004) Fourth quarter fade out – is it just an excuse? *Sports Coach* **27(3),** 27-28.

Royal, K.A., Farrow, D., Mujika, I., Halson, S.L., Pyne, D. and Abernethy, B. (2006) The effects of fatigue on decision making and shooting skill performance in water polo players. *Journal of Sports Sciences* **24(8),** 807-815.

Schwab, R.S. (1953) Motivation in measurements of fatigue. In: *Symposium on Fatigue*. Eds: Floyd, W.F. and Welford, A.T. London: H.K. Lewis.

Smekal, G., Von Duillard, S.P., Rihacek, C., Pokan, R., Hofmann, P., Baron, R., Tschan, H. and Bachl, N. (2001) A physiological profile of tennis match play. *Medicine and Science in Sports and Exercise* **33(6)**, 999-1005.

Szabo, A. and Gauvin, L. (1992) Mathematical performance before, during and following cycling at workloads of low and moderate-intensity. *Perceptual and Motor Skills* **75(3)**, 915-918.

Therminarias, A., Dansou, P., Chirpaz-Oddou, M.F., Gharib, C. and Quiron, A. (1991) Hormonal and metabolic changes during a strenuous tennis match: effect of ageing. *International Journal of Sports Medicine* **12(1)**, 10-16.

Torres, G. Cabello, D., Carrasco, L. (2004) Functional differences between tennis and badminton in young sportsmen. In: *Science and Racket Sports III*. Eds: Lees, A., Kahn, J-F. and Maynard, IW. Routledge: Taylor and Francis Group.

Vergauwen, L., Spaepen, A.J., Lefevre, J. and Hespel, P. (1998) Evaluation of stroke performance in tennis. *Medicine and Science in Sport and Exercise* **30(8)**, 1281-1288.

Wu, C., Shih, M., Yang, C., Huang, M. and Chang, C. (2010) Sodium bicarbonate supplementation prevents skilled tennis performance decline after a simulated match. *Journal of the International Society of Sports Nutrition* **7**, 33-40.

Key points

- Groundstroke accuracy under moderate-intensity fatigue is equivalent to performance at rest.
- Groundstroke accuracy declines significantly in both expert (40.3% decline) and non-expert (49.6%) tennis players following high-intensity fatigue.
- Expert players are more consistent, hit more accurate shots and fewer out shots across all fatigue intensities.
- The effects of fatigue on groundstroke accuracy are the same regardless of gender and player's achievement goal indicators.

AUTHORS BIOGRAPHY

Mark LYONS
Employment
Lecturer in Sports Science (Strength and Conditioning) at the University of Limerick, Ireland.
Degrees
BSc, PhD
Research interests
Field based performance testing. Strength and conditioning. Fatigue effects on sports performance.
E-mail: mark.lyons@ul.ie

Yahya AL-NAKEEB
Employment
Professor Emeritus, Graduate School, Newman University College, Birmingham, UK,
Professor, Research and Accreditation Consultant, College of Education, Qatar University, Doha, Qatar.
Degrees
BSc, MA, PGCE, PhD
Research interests
Psychophysiological aspects of Sports-performance; lifestyle, exercise and health-habits of young people and adults.
E-mail: y.al-nakeeb@newman.ac.uk.

Joanne HANKEY
Employment
Lecturer in Sport and Exercise Science at Coventry University, UK.
Degrees
BSc, MSc, PgCert
Research interests
Field based performance testing. Prolonged exercise and exercise-induced cardiac fatigue and damage. Caffeine on exercise performance.
E-mail: joanne.hankey@coventry.ac.uk

Alan NEVILL
Employment
Research Professor (biostatistics) in the School of Sport, Performing Arts and Leisure, University of Wolverhampton, UK.
Degrees
Cert Ed, Dip, BSc, PhD
Research interests
Investigating, analysing and modelling data recorded in sport, exercise and health sciences.
E-mail: a.m.nevill@wlv.ac.uk

✉ **Mark Lyons**
Department of Physical Education and Sport Sciences, University of Limerick, Ireland