



UNIVERSITY OF  
**STIRLING**

**A Physiological and Performance Comparison between a  
Traditional and Novel Tennis Grip**

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Research Thesis for the award of M.Phil

Word count 15,113

## Abstract

**AIM:** During tennis, the development of fatigue has been shown to induce performance decrements. However, it is not known specifically if the forearm muscles play a key factor in skilled performance. The aim of the current study was to investigate forearm fatigue following a tennis protocol and to determine the physiological and performance effects of a novel tennis grip on forearm muscle fatigue.

**METHOD:** 11 participants, 8 male and 3 female, regular tennis players completed a familiarisation session and then 2 trials, in a randomised cross-over design, separated by a minimum of 72 h. Each trial entailed of completing a tennis forearm fatiguing (TFF) protocol consisting of 7 sets of 120 cross-court forehand strokes. During the TFF protocol shot speed, accuracy and consistency were assessed. Pre- and Post-TFF, participants completed maximal voluntary contraction (MVC) tests of wrist extensor and flexor for force production, grip MVC and fatigue tests were completed surface electromyography (sEMG) examined the activity of extensor carpi radialis (ECR) and flexor carpi radialis (FCR).

**RESULTS:** There was a decrease in muscle function after the TFF protocol, with the novel grip causing a decrease in FCR muscle activity and force production. However, there were no changes in any performance measures during the TFF.

**CONCLUSION:** Our results indicate that an intense tennis protocol can induce forearm fatigue, however, the novel grip did not ameliorate the effects of fatigue on muscle function. The reduction in muscle function did not translate to changes in performance of the cross-court forehand stroke.

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## List of Abbreviations

Ach	Acetylcholine
ANOVA	Analysis of Variance
AP	Action Potential
ATP	Adenosine Triphosphate
CNS	Central Nervous System
E-C Coupling	Excitation-Contraction Coupling
ECR	Extensor Carpi Radialis
EMG	Electromyography
EMGrms	EMG Root Mean Square
FCR	Flexor Carpi Radialis
FCU	Flexor Carpi Ulnaris
FDP	Flexor Digitorum Superficialis
FDS	Flexor Digitorum Profundus
K <sup>+</sup>	Potassium
LITT	Loughborough Intermittent Tennis Test
MEP	Motor Evoked Potential
MU	Motor Unit
MVC	Maximal Voluntary Contraction
Na <sup>+</sup>	Sodium
NMJ	Neuromuscular Junction
Nov	Novel Grip
RPE	Rate of Percieved Exertion
SD	Standard Deviation
sEMG	Surface EMG

SR	Sarcoplasmic Reticulum
TFF	Tennis Forearm Fatiguing Protocol
Trad	Traditional Grip
t-tubules	Transverse Tubules
VAS	Visual Analogue Scale
Vm	Membrane Potential

## Acknowledgements

First and foremost I would like to thank my supervisor Ian Walsh for putting up with my consistent pestering and questioning. Without his input I would not have been able to complete this piece of work.

Secondly, I would like to show my greatest appreciation for everyone who helped out throughout the duration of the project; from helping with the trials on the court to aiding in teaching me the various techniques used throughout the protocol. I would like to thank Lewis Macgregor, Sophie Harrison, Evelina Kortzon, Grace Wilson, and everyone else who played a part in my time at the University of Stirling.

I would like to extend a special thanks to the participants that spared their time and effort to be part of the trials without the participants volunteering their time and effort none of this would have been achievable. So a big thank you to them.

Finally, I would like to thank my family and friends throughout my M.Phil, without their love and support I would have been unable to complete my work.



## Authors Declaration

I declare that the work contained within this thesis is of my own production. The work within this thesis has been submitted for only the award of M.Phil.

Name:

Signature:

Date:

# **Chapter 1**

## **Introduction**

Competitive tennis has been described as a prolonged activity which typically last between 2-4 h, however in special cases 5 h can be exceeded in duration such as Grand Slam events. Each match consists of bouts of high intensity exercise broken by short periods of rest (Mendez-Villanuevae et al., 2007; Fernandez-Fernandez et al., 2012; Reid and Duffield, 2014). Typically, a rally lasts between 5-10 s interspaced with short rest periods of 10-20 s during each game. The accumulation of maximal or near maximal periods interspaced with lower intensity rest periods cause a disturbance in the homeostatic equilibrium of the body imposing constraints on performance, resulting in development of such phenomena as fatigue.

Interventions that reduce the onset of fatigue during tennis matches can prove advantageous to tennis performance over the course of prolonged matches and competitions. Currently, the alteration in the grip are aimed at optimising the grip size whereas, there has been no research known to us of the use of a novel grip structure in tennis performance. The introduction of a novel grip structure that reduces stress upon the forearm may prove valuable in reducing the development of fatigue.

### *1.1 Muscle Fatigue*

The ability to produce complex, controlled, skilled performance relies on controlling muscle contractions accordingly, resulting in the desired muscular output. The neuromuscular system plays a key role in controlling this output; however under fatigue, the mechanisms controlling muscular output can alter. The mechanisms of voluntary muscle contraction rely on a network of physiological processes. An action potential (AP) is produced within the motor cortex of the central nervous system (CNS),

ultimately stimulating the movement of myosin and actin filaments resulting in muscle contraction.

The mechanisms of muscle contraction are outlined by Bagshaw (1993). Muscle contraction begins within the supra-spinal area of the CNS where the activation of the motor cortex during voluntary contraction results in the stimulation of motor neurons (Gandevia, 2001). An action potential (AP) is propagated along a series of motor neurons from the CNS innervating multiple muscle fibres; termed a motor unit (MU). At the neuromuscular junction (NMJ) the AP stimulates the release of neurotransmitters, such as acetylcholine (ACh), resulting in the transition of AP from the neuron to the sarcolemma of the muscle fibre. ACh stimulates the depolarisations of the sarcolemma membrane causing the AP to propagate through the transverse tubules (T-tubules) deep into the core of the muscle. The AP stimulates the voltage-dependent release of calcium ions from the sarcoplasmic reticulum (SR). Calcium influx from the SR causes a release of the inhibitory effect of tropomyosin by causing a change in the configuration of the troponin releasing the tropomyosin from the myosin active sites on the actin filament. The globular head of the myosin filament is able to freely attach to the active site causing cross-bridge formation. Tension is produced by the hydrolysis of ATP which causes the globular head to cock and pull the actin filament relative to the myosin filament. Providing calcium concentrations remain sufficiently high, the cross-bridge cycle will continue and tension will remain (Allen et al., 2008; Robergs and Keteyian., 2003). Repeated stimulus without sufficient rest will cause disturbances to the physiological pathways involved in muscle contraction. Ultimately, this will reduce the ability to form a contraction. Fatigue will then develop over the course of task performance leading to the temporary loss of force production.

Exercise induced muscle fatigue is a multifaceted phenomenon best described as a reversible exercise-induced reduction in muscle force through voluntary contraction, resulting in reduced expected power output and task performance (Bishop, 2012; Allen et al., 2008). The onset of exercise induced fatigue is dependent on a multitude of variants which include; intensity, duration and type of exercise, type of muscle fibre, muscle contraction type and trained status (Fitts et al., 1994). These factors influence the development of muscle fatigue which can be separated into two distinct types of fatigue: central fatigue, proximal from the neuromuscular junction (NMJ), and peripheral fatigue, distal to the NMJ. The mechanistic disturbances that lead to the development of central fatigue occur through excitatory input into the higher and lower motor centres and neurons, motor neuron excitability and neuromuscular transmission. Whereas, with peripheral fatigue the mechanistic disturbances are within the peripheral muscle and include sarcolemma excitability, excitation-contraction (E-C) coupling, contractile mechanisms and metabolic energy supply and accumulation.

### *1.1.1 Central Fatigue*

Mechanisms of fatigue do not always lie within the peripheral muscle. Fatigue during isometric contractions has provided evidence that central mechanisms are disturbed resulting in reductions involuntary activation of muscles. Bigland-Ritchie (1984) has characterised central fatigue as fatigue occurring within the CNS and peripheral motor neurons. Disturbances to the physiology with the CNS can lead to the development of fatigue and reduced muscle contraction. It has long been observed that with repeated bouts of sub maximal tasks, there is a decline in force production capacity of the muscle (Masso, 1904). Furthermore; ‘Masso’ was able to demonstrate that excessive mental work prior to the repeated sub maximal task caused further reductions in the force production capacity of the muscle. These studies lead to the idea that fatigue can occur

not only within the peripheral muscle but also within central mechanisms. This idea was further developed by Lombard (1892), Gandevia et al. (1996) and Fernandez-Del-Olmo et al. (2014) who showed that stimulation of the peripheral nerves leads to an increase in force production during a contraction under fatigue. These data demonstrate that disturbances proximal to the peripheral muscle are the result of fatigue that lies within the central regions.

There are numerous methodologies to evaluate the effects of central fatigue on performance of a muscle, which are most commonly used during isometric contraction. The most frequent indicator of the development of central fatigue is the assessment voluntary activation during a muscle contraction. Gandevia et al. (1996) shows that through stimulation of both a motor point in the peripheral limb and transcranial that the voluntary activation during a 3 min sustained isometric contraction was reduced. By the end of the sustained isometric contraction the additional evoked force by cortical stimulation had risen to 9.8% compared to 1% at the beginning of the isometric contraction. Similarly, during a 3 min isometric contraction Gandevia et al. (1996) shows a significant decline in the voluntary activation of the bicep brachii. This shows that central fatigue has occurred within all subjects over the course of the contraction.

Taylor et al. (1996) proposed that changes to the motor evoked potential (MEP) during sustained contractions occur within the neurons within the motor cortex. MEP is the response measured in the target muscle to a single stimulation. Taylor et al. (1999) provides further evidence that after a 2 min sustained contraction a difference occurred between the peripheral and central analysis of fatigue. Through comparison of MEP and m-wave, peripheral measure of the early response to stimulation, Taylor et al. concluded that changes within the m-wave are smaller than that observed in the MEP during the sustained contraction. These data suggest that as the peripheral measure is

unable to account for all the change in MEP, these changes lie within central mechanisms.

It is clear that central mechanisms play a role in the development of fatigue over the course of a sustained contraction. These mechanisms can lead to a decrease in the intensity of voluntary activation during muscle contraction which will result in the loss of voluntary muscle contraction and force. However, there are more than just central mechanisms that play a role in the development of fatigue during contraction.

### *1.1.2 Peripheral Fatigue*

Peripheral fatigue occurs distally to the NMJ, and is most commonly associated with altered levels of metabolites. Bigland-Ritchie (1984) has described the manifestation of peripheral fatigue as occurring through several factors including: sarcolemma excitability, excitation-contraction (E-C) coupling, contractile mechanisms and metabolic state.

An AP provides the stimulus for the efflux of calcium from the SR which initiates the formation of cross-bridges, termed excitation contraction (E-C) coupling (Rebbeck et al., 2014). Alterations in membrane potential ( $V_m$ ) will cause reduced stimulation for calcium release and therefore reduce force production. These physiological alterations are believed to act as a protective mechanism against the accumulation of calcium and inorganic phosphate, to maintain the homeostatic nature of the cell (Lindinger and Sjøgaard, 1991). Furthermore, propagation of sarcolemma AP is dependent on ionic concentrations within the muscle cells; therefore the concentrations of potassium ( $K^+$ ) and sodium ( $Na^+$ ) influence the propagation of an AP leading to reduced  $V_m$  (Hodgkin and Horowicz, 1959). Decreased  $V_m$  results in the cells ability to propagate an AP to become reduced. This is thought to occur as the ionic balance is disturbed through the

flux of  $K^+$  from the intracellular space (Sjøgaard, 1991). The altered ionic balances influence the ability of the AP to activate the L-type calcium channels (dihydropyridine receptors) causing the calcium release from the SR via the calcium release channels (ryanodine receptors) to be inhibited (Rebbeck et al., 2014). Disturbances within the electrical signalling pathways cause a reduced transmission of the AP during voluntary muscle activation which results in a reduced ability to maximally produce power.

The altered electrical properties of the muscle produce a myoelectric signal that can be observed through surface EMG (sEMG) analysis during contraction. This enables analysis of the EMG signal to determine the muscle activity of specific muscles during contraction. It has long been established that there is a relationship with force and sEMG analysis (Bigland and Lippold, 1954). This has been furthered by Hultman and Sjöholm (1983) who demonstrated that over course of 75 s contraction the reduction in force and EMG amplitude both followed the same proportional decrease. As the 75 s contraction was produced through electrical stimulation the decrease in EMG amplitude is said to be due to mechanisms with peripheral muscle. Thus the muscles ability to become active during this form of contraction is limited. Ming et al. (2014) has further shown that with voluntary fatiguing contractions the levels of muscle activity measured through sEMG changes. During 3 sustained 60% isometric contractions, the EMG amplitude increased. These data show that muscle activity changes during electrically stimulated and voluntary sustained contractions.

Due to the complexity of the manifestation of fatigue the reduction in force production may occur through various mechanisms such as changes in metabolite dynamics or accumulation. During high intensity activity lactate levels have been observed to increase through the anaerobic metabolism of glucose (Shei and Mickleborough, 2013). This association has been shown as an increase in exercise intensity results in increased

concentrations of lactate (Thorstensson and Karlsson, 1976; Bentley et al., 2001). Moreover, an increase in lactate levels during muscle contraction results in a decrease in pH of the muscle due to the production of free hydrogen ions. It is proposed that these free hydrogen ions are the force depressing agent during muscle contraction (Cairns, 2006; Sahlin et al., 1978). Acidosis in the cells can cause a reduction in force production and can be linked to alterations in cross-bridge formation (Fitts, 2008). These low pH values have also been shown to not only decrease force production but also have an influence on maximal shortening velocity (Nelson et al., 2014), relaxation time (Baker et al., 1995) and inhibit key enzymes in the glycolytic pathway (McCartney et al., 1986; Parolin et al., 1999). There are a multitude of metabolic based components that are associated with the development of peripheral fatigue such as; concentrations of inorganic phosphate (Allen and Westerbald, 2001), production rates of ATP, muscle glycogen depletion and blood glucose metabolism (Fitts, 1994).

Taken together, it is clear that both central and peripheral aspects account for the manifestation of fatigue, with disruption to the homeostatic mechanisms of muscle contraction specifically during high intensity contractions. Therefore, it is likely that the decrease in muscle performance can be extended to other forms of exercise, such as high intensity exercise with insufficient rest.

### *1.2 Fatigue in Intermittent Sport*

High intensity intermittent sporting activity can induce alterations in the muscles ability to produce force and alter muscle activity. These changes in force and muscle activity are thought to be brought on by the development of fatigue which effects overall performance (Bishop, 2012). To assess the effect of fatigue within intermittent skill based sporting activity, consideration should be taken to assess both force production



capabilities and sport specific skilled performance. Afman et al. (2014) used a self-validated simulated basketball test to determine the effects of duration and match intensity on lay-up performance. As time progressed, lay-up skill performance decreased through the simulated basketball test. Furthermore, during simulated soccer fatigue, McGregor et al. (1999) showed that there was an increase in 15 m sprint time at the end of the 6<sup>th</sup> set when compared to the 1<sup>st</sup> set. In other high intensity intermittent skilled based sports such as hockey, evaluation of the effects of fatigue by Duncan et al. (2012) have provided insight into sprint performance and skilled based alterations that fatigue can have on athletes. Both sprint dribbling performance and ball handling skills were significantly decreased after a bout of whole body fatigue at 90% of maximal capacity. The onset of fatigue has a detrimental effect on sporting performance after sport specific bouts of high intensity intermittent exercise.

### *1.2.1 Fatigue in Racket Sports*

Power and skill are desirable attributes in racket sports. Like many other sports, decrements in force and skill have been observed within the progression of fatigue. Bottoms et al. (2012) investigated the effects of fatigue on the deterioration of the badminton shot and long serve. Long service skill was taken before and after a simulated badminton match and showed a significant decrease in accuracy. Similarly Bottoms et al. (2006) has shown that in squash there is a decrease in skilled performance after a fatiguing protocol. Bottoms et al. (2006) implemented a protocol that simulated the demands of a squash match and measured skilled performance and a 50 s MVC fatigue test. Bottom et al. also demonstrated during the 50 s MVC that post exercise there is a loss of force production of the wrist flexor muscles, which is thought to play a role in racket head control. The decrements in skill and force production have a clear impact on overall performance in high intensity intermittent sports. These

decrements in performance can have major impacts during sporting activity that requires high levels of hand eye co-ordination.

### *1.2.2 Fatigue in Tennis*

Tennis relies heavily on a multitude of fitness and skilled based parameters. As fatigue is known to affect skill and force production during a variety of other sports, the onset of fatigue may reduce tennis performance. Therefore determining the effects of fatigue on tennis performance and interventions to reduce this detrimental effect may prove advantageous to improving tennis performance.

The high intensity nature of tennis match play has been demonstrated to effect neuromuscular function. Girard et al. (2006) have shown that after a 3 h tennis match play in 12 highly trained tennis players there is a reduction in MVC force production, leg stiffness, peak power in squat and countermovement jump performance. Furthermore, Girard et al. (2008) was able to show that after 3 h match play there was a reduction in EMG activity of the muscle in such a way that suggests there may be alterations in central activation during tennis match play. However, these alterations in muscle performance during tennis match play have been primarily measured in the vasti muscles of the legs, thus may not be representative of tennis fatigue in muscles within the upper limbs. To understand fully the effects of fatigue on tennis performance it is imperative that along with changes in physiological markers of fatigue, skill performance needs to be assessed.

In 2002, Davey et al. attempted to determine the effects of fatigue on tennis stroke performance by inducing fatigue using *The Loughborough Intermittent Tennis Test (LITT)*. The LITT consisted of 4 min of maximal ground stroke hitting interspaced with 40 s of seated recovery. A tennis ball serving machine was implemented to feed balls in

a random fashion at a frequency of 30 balls per min. Sets were repeated until the player missed 2 consecutive feeds or stopped voluntary, at this point volitional fatigue was said to have occurred. Skill tests for service and ground strokes were completed pre and post LITT. From pre to post skill tests, Davey et al. found that there was a significant decrease in service accuracy from the right hand side (69%), and a decrease in shot accuracy during the LITT. These data show that inducing fatigue results in marked decrease in skilled tennis performance.

A further study examining the effects of fatigue was conducted by Vergauwen et al. (1998), concluding that after a 2 h strenuous tennis session, service performance decreased by 7%, however no documentation of physiological stress was taken throughout the session, therefore data comparisons can be problematic. Both these studies considered the effect of whole body fatigue on skilled performance and were able to show that there is a decline in skill performance with the development of fatigue. However, there has been limited research into the effects of local muscle fatigue during tennis performance.

Recently, Rota et al. (2014) considered the influence of fatigue on the muscle activity of the upper limbs and tennis performance. A fatiguing protocol to mimic a rally was performed; the protocol consisted of 4 sets of 12 repetitions of a serve and 8 cross court forehand drives, with 20 s rests between each repetition and 90 s rests between each set. Rota et al. (2014) quantified training intensity by recording heart rate, blood lactate and Rate of Perceived Exertion (RPE) to determine the extent of physiological stress placed on the player. Skill tests and maximal force measurements were performed following the fatiguing protocol. Results showed there was a significant decrease in serve velocity and accuracy, and forehand crosscourt drive accuracy and consistency. Furthermore, it was shown that there was a significant decline in force production and EMG amplitude

of the Flexor Carpi Radialis (FCR) and Extensor Carpi Radialis (ECR) during the protocol. These data indicate that with the onset of fatigue there are significant reductions in tennis skill performance, possibly due to the reduction in muscle strength and activity of the FCR and ECR. Therefore, interventions that may reduce these losses could contribute in aiding to reduce the effects of fatigue on tennis performance.

### *1.3 Racket Technology*

Within the last 30 years tennis racket technology has changed dramatically due to advances in technology and materials. The greater understanding of the demands of tennis performance has allowed innovations in tennis racket technology and design (Miah, 2000). The handle component is vital to ensure efficient transmission of the force from arm to racket. An important factor of the handle is to reduce grip tension and local muscular fatigue. It is observed by Roetert et al. (1995) that during tennis stroke production muscle activation levels of the key forearm muscles can range from 40-70% of MVC. These high levels of activation over a prolonged duration may lead to reductions in performance with the onset of fatigue.

Currently, innovations in grip technology revolve around the alterations of grip size to decrease measures of fatigue. Ohguni et al. (2009) determined that the grip size that produced the highest force production was dependent on hand size and grip force production for a forehand stroke. This could suggest that for different hand size there is an optimal sized grip. Hatch et al. (2006) used the Nirschl recommended (Nirschl and Ashman, 2003) tennis grip size measure to determine if  $\frac{1}{4}$  inch alterations in grip size caused differences in muscle activity. Hatch et al. found no change in muscle activity with the  $\frac{1}{4}$  inch changes in grip size. These data suggest that the grip size does not alter muscle activity and force when small deviations are made from the recommended size.

However, change in grip structure may prove enlightening; the altered grip structure will force the players to change the positioning of their hands around the grip away from the traditional methods which include: Eastern and Western grips, in order to reduce the effects of fatigue. The type of grip greatly depends on the shot being played with the eastern grips having the index finger knuckle on the third bevel while the western is placed on the fifth bevel. Therefore, the suggestion can be made that an alteration in grip structure, an aspect previously overlooked, may reduce fatigue and aim to improve skilled performance during tennis.

#### *1.4 Novel Grip*

Altering grip shape to maximise the force production has been shown to be successful by Wonders et al. (2014). Furthermore; altering the shape of the handle enables the equal absolute work to be completed with a decrease in muscle activation (Emam et al., 2014). This is supported by previous work from Sanchez and Maklin (2008). Data from Sanchez and Marklin provide evidence that by altering the structure of a tool grip may allow more torque to be produced. These findings showed that torque production from a novel grip was double that of a traditional grip. Implementing more ergonomically effective grips for the same work capacity results with less stress placed on muscles within the upper limbs; this may lead to a reduction in the loss of force. Combined, it can be concluded that change in grip structure can play a pivotal role in reducing the mechanical stress placed upon a muscle while performing tasks in the work place. Thus, in tennis, by changing the structure of a tennis racket grip to a more ergonomically effective grip may decrease the onset of fatigue and maintain shot performance. Innovations in grip structure may prove promising in reducing muscle fatigue during tennis play.

Altering the grip structure may reduce the extent of fatigue on the key forearm muscles involved in gripping the racket which may enable greater performance in the latter stages of competition. Shih and Wang (1996) have demonstrated that the most ergonomically effective grip is comprised of flat edges, when compared to a more rounded grip. The authors aimed to determine the grip structure which produced the highest torque during maximal exertions. The results illustrate that a triangular grip was shown to produce higher torque values across both sexes against a hexagonal shape. By enabling a higher torque production with the triangular grip, at equal absolute torque levels the muscle activation should be less thus having a protective effect against the onset of fatigue. It is plausible that a novel tennis grip employing a flat edge will reduce the force required to produce a tennis stroke, thus protecting against the development of fatigue and enable the maintenance of skilled performance.

The aims of this study are twofold; firstly to investigate forearm muscle fatigue following an intense tennis protocol. Secondly; to determine the effects of a novel tennis grip on torque production and forearm muscle fatigue following a tennis fatigue protocol.

It is hypothesised that during the intense tennis protocol the novel grip will induce reductions in local muscular fatigue within the forearm muscles of the racket hand. The novel grip is proposed to allow the participants to produce higher torque production while ameliorating the effects of fatigue on muscle function and performance.

## **Chapter 2**

### **Pilot Study**

#### *2.1 Introduction*

Developing torque from a racket includes the interaction between the hand of the individual and the racket grip. This interaction is key in maximising the muscle force to be transformed into torque production. A novel grip has been designed to attempt to maximise this interaction between the hand and the racket. The structure of the novel grip is curvilinear in shape, providing a straight edge that is paced in the palm of the participant, curved into a point where the fingers reach round to (*Appendix 1*).

Previous research has provided evidence suggesting that torque production with this structure of grip is advantageous to allowing a higher torque production (Shih and Wang, 1996). It is hypothesised that with the flat edge producing a higher resistance during pronation higher torque production would be achievable.

This pilot study aims to determine if the novel tennis racket grip enables a greater torque production over a traditional tennis racket grip structure.

#### *2.2 Methods*

##### *2.2.1 Participants*

Eight participants, 6 males and 2 females, the mean ( $\pm$  SD) age, height and body weight were  $24 \pm 2.6$  years,  $178.6 \pm 8.2$  cm and  $78.6 \pm 13.7$  kg, respectively. All participants were recruited from the University of Stirling and reported no upper body musculoskeletal disorders or injuries within the previous 6 months.

### *2.2.2 Experimental Protocol*

Participants reported to the Neuromuscular Laboratory at the University of Stirling on the trial day. Participants were introduced to the two different types of grip and given instruction as to how each grip was to be held throughout the trial. The BioDex dynamometer (BioDex, US) was adjusted according to the height of the participant so that the grip is held with participants elbow fixed to their side and flexed at 90° with the wrist in neutral position, similar to the Eastern grip in tennis. A custom made support was designed and attached to the BioDex to allow the attachment of the grips to the BioDex. Participants were instructed to pronate the wrist during a 5 s maximal voluntary contraction (MVC) without the grip sliding in their hand using their dominant hand. The design of the experiment was randomised with each participant using both grip types.

Each participant completed a standardised warm up prior to the MVCs. The warm up consisted of 3 contractions at 50% of estimated MVC and 3 contractions at 75% of estimated MVC, with 60 s rest between each contraction. After a 120 s rest participants were instructed to perform 3 isometric MVCs with 60 s rest between each contraction and 5 min rest between each grip type.

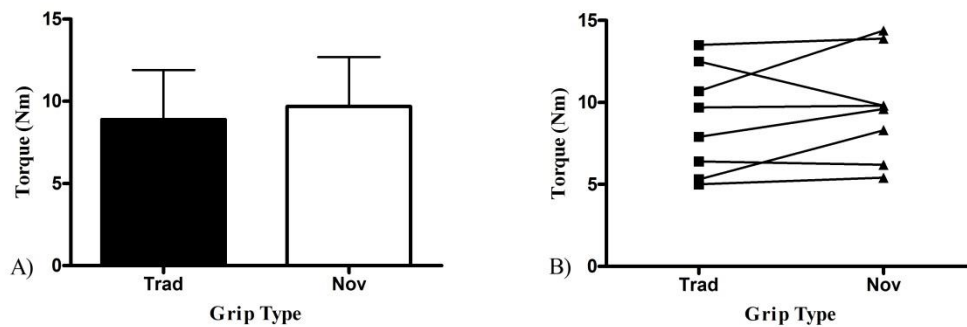
### *2.2.3 Statistical Analysis*

Peak torque was taken as the highest force achieved during the three MVCs. Data was checked for normality with the Kilmogorov-Smirnov test. The differences in peak force were analysed using a Paired Student t-test in SPSS with a statistical significance of  $p < 0.05$ .



### 2.3 Results

Mean Peak Torque Production is shown in Figure 1. There was no statistical significance between the two grip types for peak torque production ( $p= 0.3$ ). However, due to small sample size and heterogeneity of the sample the small increase in torque observed may allude to a trend for the novel grip to produce higher peak torque. It is observed not all individuals show a positive increase in torque production, there is one participant who showed a large decrease in their MVC.



**Figure 1. Torque Production of the novel and Traditional Grip.** Values are Mean  $\pm$  SD. Trad = Traditional Grip. Nov = Novel Grip. A) Mean Torque difference. B) Individual change between the Traditional and Novel grips.

## *2.4 Discussion*

The novel grip has a curvilinear structure; grips of similar structure have previously been shown to increase the torque production over other grip structures (Shih and Wang, 1996). We hypothesised that grips with longer and flatter edges would cause a higher resistance in the participants hand when a pronation force was applied to the grip. These data suggest that there is not a significant increase in torque production using the novel grip.

Although there is no significant difference in torque production between the novel grip and a traditional grip, relevance to tennis match play should be considered. During tennis play, wrist pronation is primarily used during ‘topspin’ shots, while not necessarily representing overall stroke performance. However, it has been shown that when balls are struck, there is an increase in muscle activity of the forearm muscles to enable the head of the racket to control the shot (Hatch et al., 2006). The novel grip may aid in reducing the grip strain required while striking a shot. Over a series of return shots, the novel grip may reduce the muscle force required to control the racket head upon ball impact which may prove advantageous to tennis match play. Therefore, as there is no data on the novel tennis grips ability during tennis play further studies are required to determine if the novel grip has an impact during tennis play.

## **Chapter 3**

### **Method**

#### *3.1 Participants*

Eleven participants were recruited from the tennis clubs at the University of Stirling and surrounding area. Participants' characteristics are outlined in Table 1. All participants were active to a minimum of the government recommended daily guidelines and were regular tennis players for a minimum of 2 years. Ethical approval was granted from the University of Stirling School of Sport Ethics Committee and written informed consent was gained from each participant prior to participation in the study.

**Table 1. Participant Characteristics**

	<b>Age (years)</b>	<b>Height (cm)</b>	<b>Weight (kg)</b>	<b>Left Handed</b>	<b>Right Handed</b>
<b>Male (8)</b>	23 ± 4	176 ± 5.5	73 ± 6.1	4	4
<b>Female (3)</b>	25 ± 5	174 ± 5.1	69 ± 4.0	0	3

Values are Mean ± SD. The characteristics of the participants

#### *3.2 Experimental Design*

The study was a randomised cross-over design with each participant completing a trial with each grip type, the novel grip and the traditional grip. All trials were completed at the same time of day. Participants attended the University Sport centre in the University of Stirling campus on three occasions. The first visit was the familiarisation trial where participants completed health screening questionnaires, were introduced to the laboratory settings for forearm strength and fatigue measures. The participants were then introduced to the court set up and the novel grip to become familiar with the tennis protocol. Participants completed ~40 min of forehand cross-court drives at a comfortable pace. Sets of 120 balls were completed with the next set commencing after

sufficient rest. Visual Analogue Scales (VAS) were completed after each set to assess the comfort of the grip and natural feel immediately following each set.

Participants returned to the laboratory a minimum of 24 after the familiarisation trial for the first of the experimental trials. There was a minimum of 72 hours between the two experimental trials. Both rackets had grip size of 12 cm in circumference and were strung with a tension of 254 N (57lbs·in<sup>-1</sup>). Prior to the first trial, a 3 day Food and Exercise Diary was completed by participants and replicated prior to the second trial. On trial days participants arrived at the University of Stirling Sport Centre Laboratory where they were prepared for the trial.

### *3.3 Surface Electromyography (sEMG)*

#### *3.3.1 sEMG Placement and Application*

Surface electromyography was used to assess the muscle activity of key forearm extensor and flexor muscles used while playing tennis, specifically the Extensor Carpi Radialis (ECR) and Flexor Carpi Radialis (FCR) (Hägg and Milerad, 1997 and Chow et al., 2007). Prior to skin preparation, the ECR was located two finger breadths distally from the elbows lateral epicondyle while the participants elbow was in an extended position. The location of the FCR was one third of the distance distally from the elbows medial epicondyle, on a line from the medial epicondyle to the distal head of the radius. The points of largest volume of muscle belly were found by palpitations to the skin prior to skin preparation. At these sites the skin was prepared by the removal of hair, abrasion and cleaned with alcohol swabs. Pre-gelled Ag/AgCl 11mm surface electrodes (Biopac, USA) were placed according to Mogk and Keir (2003). Electrodes were placed with 20 mm inter-electrode distance on the muscle belly in line with muscle fibre

orientation. EMG signals were collected using the PoweLab system (ADIinstruments, UK).

### *3.3.2 Extensor and Flexor Strength Test*

Strength tests were completed for extensor and flexor muscle groups using the Kin Com Dynamometer (Isokinetic International, UK). Participants were instructed to sit in a standardised position. Participants sat on the edge of the Kin Com seat with a straight back and knees at 90° at the edge of the seat. The dominant arm was flexed at the elbow at 90° with the wrist placed in the wrist support. Participants were instructed to remain in this position until the testing was completed.

Participants completed a standardised warm up for both extension and flexion consisting of three contractions at a perceived 50% effort, followed by three contractions at a perceived 75% effort; each contraction lasted 5 s. After the warm up was completed, participants rested for 2 min before they completed three 5 s maximal voluntary contractions (MVC) with 60 s rest between each MVC.

### *3.3.3 Grip Strength and Fatigue Tests*

Grip strength was assessed after a 5 min recovery period from the extension and flexion strength measures. Participants remained in the standardised seated position, the lever arm was removed and participants were provided with the hand grip dynamometer (ADInstruments, UK). Participants completed three 5 s grip MVCs with 60 s recovery between each MVC to assess grip strength, followed by a 2 min recovery. A 50 s fatigue test was then completed. For the 50 s fatigue test, participants were instructed to grip at maximal effort for 50 s constantly. The post-TFF values were normalised to the Pre-TFF MVC values for force and EMG root mean square (EMGrms).

Standardised verbal encouragement was provided by instructor for each MVC and throughout the 50 s fatigue test.

### *3.4 Tennis Forearm Fatiguing (TFF) Protocol*

The tennis forearm fatiguing (TFF) protocol employed a modified version of *The Loughborough Intermittent Tennis Test* (Davey et al., 2002). A standardised warm up were completed consisting of a warm up set of 120 balls, cross-court forehand drives were struck at a self-selected warm up pace. After the warm up, prior to the TFF protocol a 5 min active recovery was provided. After the standardised warm up participants completed 7 sets of 120 cross-court forehand drives from the baseline towards the target area. Participants were instructed to hit a cross-court forehand drives at maximal force and as accurately as possible towards the 1.5 x 1.5 m target which was placed at the opposing rear corner within the singles lines of the court. A tennis ball service machine (Lobster, UK) was placed 1 m from the singles side line along the baseline; balls were served straight to the participants' forehand at an initial speed of 80 km·h<sup>-1</sup>, with minimal spin, at a rate of 30 balls per min (Appendix 2). A radar gun (Stalker SPORT 2, US) was positioned in line with the cross-court shot to measure shot speed. Each shot was measured for accuracy and consistency (see section: *Skilled Performance Analysis*).

Each set lasted approximately 4 min with a 2 min passive recovery. During the recovery phases, participants completed visual analogue scales (VAS) to assess the natural feel and comfort of the grip, and complete Rate of Perceived Exertion (RPE) scores. Heart rate was recorded at the end of each set. Participants were allowed to consume water *ad libitum* during rest periods.

### *3.5 Skilled Performance Analysis*

Shot accuracy, consistency and velocity were measured during the TFF protocol as a measure of skilled performance. Accuracy was calculated as the percentage of balls that landed within the target area only. Consistency was scored as a ball that landed after the service line and to the target side of the halfway point between the singles lines. Consistency scores were calculated as a percentage of balls landing within this area of each set, including balls that land within the target area (Appendix 2).

After the TFF protocol was completed, participants returned immediately to the laboratory to perform the laboratory tests for the post measures (see *Flexor and Extensor Strength Tests*).

### *3.6 EMG Signal Analysis*

During the strength tests, EMG signals were collected at sampling rate of 2 kHz and range set to 20 mV, 50 mV and 1 V for EMG, grip force and Kin Com force recording, respectively. Raw EMG signals were visually inspected for signal/noise ratio and for baseline artefact with only high quality signals being used for analysis. The raw EMG signals were band-pass filtered between 10-500 Hz prior to the calculation of Root Mean Square (EMGrms). EMGrms were analysed in successive 5 s epochs for the 50 s fatigue test, and at 0.5 s epochs over the peak of each MVC for grip, flexor and extensor tests. EMG signal amplitudes were normalised to the maximal value gained during the Pre-TFF MVCs.

The force for the MVC was quantified over a 0.5 s period covering the peak signal. The peak value across the three MVCs for each muscle was chosen for further statistical analysis. During the 50 s fatigue test identical 5 s epochs were selected were peak force was quantified.

### 3.7 Statistical Analysis

Data are reported as Mean  $\pm$  SD. Data were tested for normality using the Kilmogorov-Smirnov test. The comparison of means of the tennis court data were completed using a repeated measures two-way Analysis of Variance (ANOVA) to determine whether any changes occur in ball speed, accuracy and consistency, with the interaction between the grip types from the first set to the seventh set of the TFF protocol. For the force and EMGrms data a repeated two-way ANOVA were used to determine whether any changes occurred in force and EMGrms, with the interaction between the grip types and from Pre- to Post-TFF. Where mean effects were found, a Bonferroni correction *post hoc* analysis were performed to determine where the statistical differences lie. Significance was set at  $p= 0.05$ .



## **Chapter 4**

### **Results**

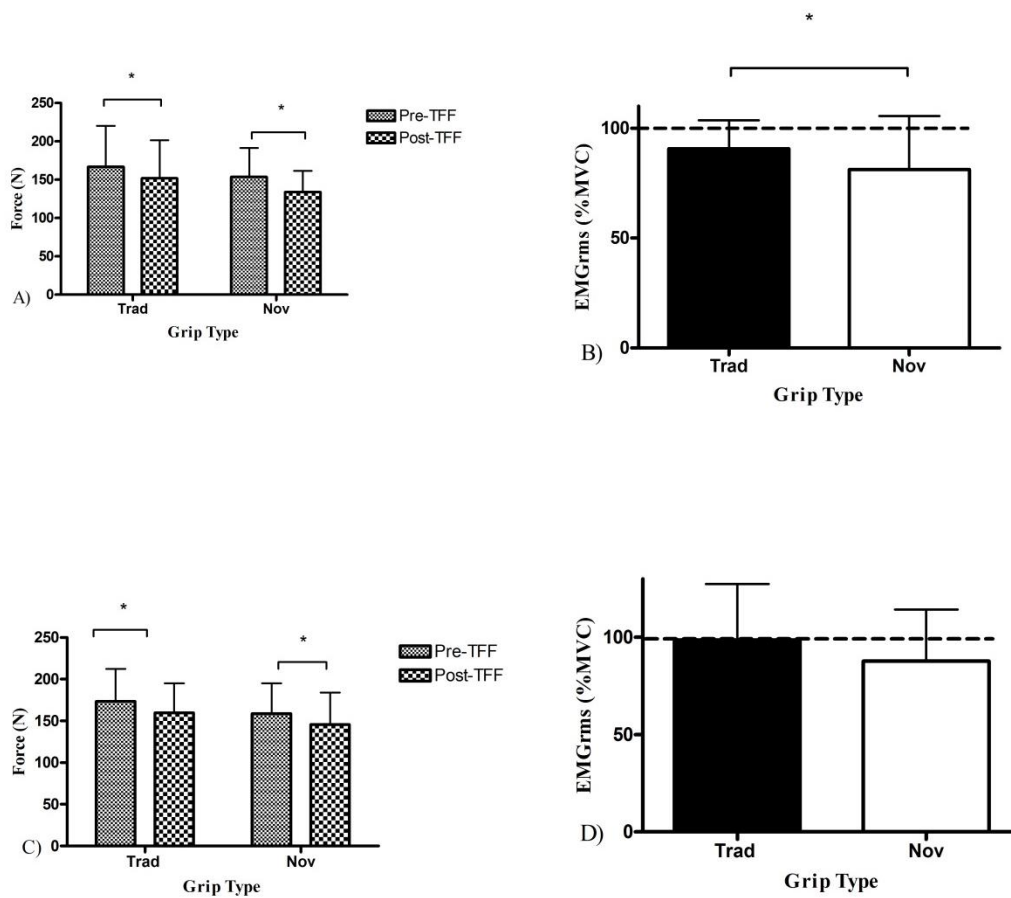
#### *4.1 Muscle Function*

##### *4.1.1 Extensor MVC*

There was a main effect of time for force production during the extensor MVC, where Post-TFF MVC had lower peak force production compared to Pre-TFF ( $p < 0.01$ ) (*Figure 2A*). There was no main effect of grip type on force production ( $p = 0.12$ ), neither was there an interaction effect between time and grip type ( $p = 0.12$ ). For muscle activity of the ECR there was a main effect of time ( $p < 0.05$ ) (*Figure 2B*), with no difference found for grip type ( $p = 0.49$ ) or an interaction effect ( $p = 0.49$ ).

##### *4.1.2 Flexor MVC*

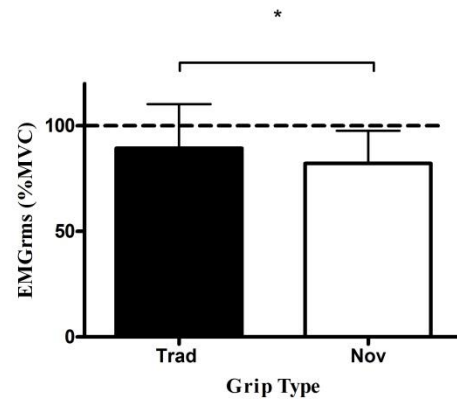
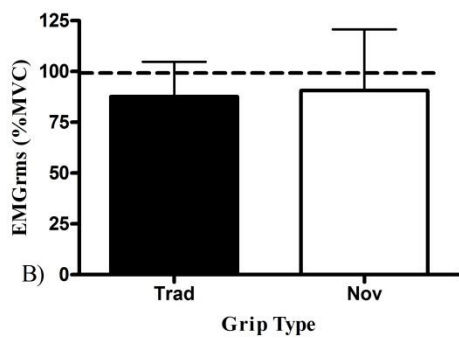
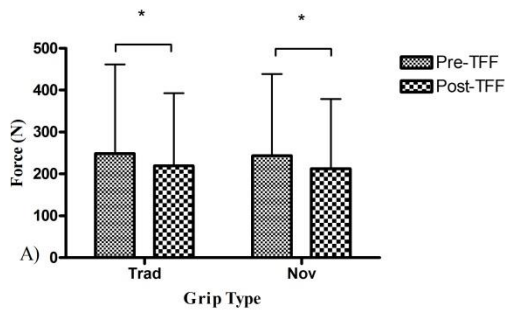
Force production for the flexor muscle group show similar outcomes to the force production for the extensor muscle group. A main effect of time was observed showing a decrease in force production Post-TFF protocol compared to Pre-TFF was shown ( $p < 0.01$ ) (*Figure 2C*). However, there was no difference in force production between the grip types ( $p = 0.72$ ) or interaction effect between time and grip type for flexor force production ( $p = 0.9$ ). No main effect of time was observed for muscle activity Post-TFF compared to Pre-TFF for the FCR during the MVC ( $p = 0.27$ ). Furthermore, there was no main effect found between the grip types ( $p = 0.43$ ) or an interaction effect of time and grip type ( $p = 0.57$ ) (*Figure 2D*).



**Figure 2. Extensor and Flexor MVC Force and Muscle Activity.** Values are mean  $\pm$  SD. Trad = Traditional Grip, Nov = Novel Grip. A) Post-TFF extensor force production normalised to Pre-TFF MVC. B) Post-TFF ECR EMGrms values normalised to Pre-TFF EMGrms. C) Post-TFF flexor force normalised to Pre-TFF MVC. D) Post-TFF FCR EMGrms values normalised to Pre-TFF EMGrms. Dashed line illustrates the Pre-TFF MVC values. \* represents a significant difference from the Pre-TFF value ( $p < 0.05$ ).

#### 4.1.3 Grip MVC

There was a main effect of time showing a decrease in grip force Post-TFF compared to the Pre-TFF grip MVC ( $p < 0.01$ ) (*Figure 3A*). However, there was no main effect found for grip type ( $p = 0.18$ ) or interaction between time and grip type ( $p = 0.67$ ) for grip force production. Muscle activity showed a main effect of time for the FCR ( $p < 0.01$ ) with no main effect of time in the ECR ( $p = 0.07$ ). There is no effect found for grip type for the ECR ( $p = 0.56$ ) or FCR ( $p = 0.39$ ) muscle activity (*Figure 3B and 3C*) with no interaction effect of time and grip type observed for ECR ( $p = 0.56$ ) or FCR ( $p = 0.37$ ).

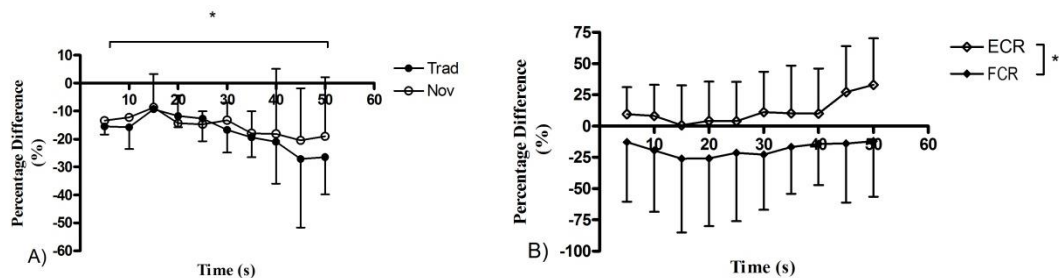


**Figure 3. Grip MVC and Muscle Activity.** Values are Mean  $\pm$  SD. Trad = Traditional Grip, Nov = Novel Grip. A) Grip force as % Pre-TFF force. B) ECR EMGrms values as % of Pre-TFF value. C) FCR EMGrms values as % of Pre-TFF value. Dashed line illustrates the Pre-TFF values. \* represents significant difference from the Pre-TFF value ( $p < 0.05$ ).

#### 4.1.4 Grip Fatigue Test

Force production during the Grip Fatigue tests is shown to have a main effect of time ( $p= 0.05$ ), with no grip type effect ( $p= 0.532$ ) or an interaction effect ( $p= 0.959$ ). The effect of time suggests that fatigue is occurring over the course of the contraction (Figure 4A).

The difference in muscle activity between both muscles is shown to have a main effect of muscle ( $p= 0.012$ ), where the FCR muscle activity is decreased compared to the ECR when the novel grip is used compared to the traditional grip. However, over the course of the fatigue tests there is no time effect ( $p= 0.1$ ) or interaction effect ( $p= 0.752$ ) (Figure 4B).



**Figure 4. Grip 50 s Fatigue Test Force and Muscle Activity.** Values are Mean  $\pm$  SD. A) Represents the percentage change in force between Pre-TFF and Post-TFF. B) Represents the percentage difference in muscle activity. \* represents a significant difference ( $p < 0.05$ ).

## 4.2 Performance and Physiological Stress Data

### 4.2.1 Skilled Performance

During each set of cross-court forehand drives there were no differences between the grip type for measures of average speed ( $p= 0.94$ ), accuracy ( $p= 0.83$ ) or consistency ( $p= 0.94$ ). Furthermore, there was no decline in speed ( $p= 0.25$ ), accuracy ( $p= 0.7$ ) or consistency ( $p= 0.68$ ) between each set (Table 2).

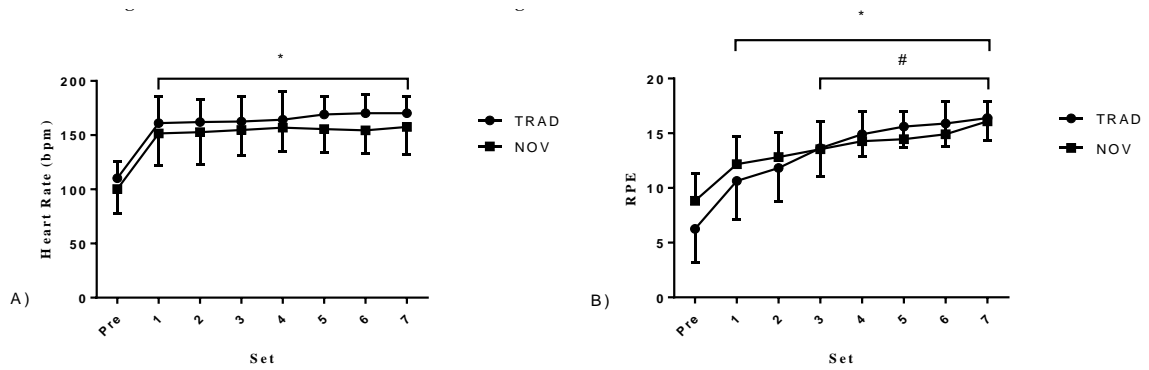
**Table 2. Performance Data**

		set 1	set 2	set 3	set 4	set 5	set 6	set 7
<b>Speed</b> ( $\text{km}\cdot\text{h}^{-1}$ )	TG	97.4 $\pm$ 8.0	97.9 $\pm$ 7.8	98.5 $\pm$ 8.8	97.0 $\pm$ 9.0	96.9 $\pm$ 9.4	97.6 $\pm$ 8.5	96.4 $\pm$ 10.1
	NG	98.4 $\pm$ 12.2	97.5 $\pm$ 12.4	96.1 $\pm$ 12.3	95.0 $\pm$ 12.0	95.4 $\pm$ 13.2	95.3 $\pm$ 13.5	93.6 $\pm$ 13.1 0
<b>Accuracy</b> (%)	TG	7.0 $\pm$ 4.3	7.0 $\pm$ 2.9	7.5 $\pm$ 5.6	6.5 $\pm$ 3.2	6.7 $\pm$ 4.6	7.0 $\pm$ 4.7	6.1 $\pm$ 3.8
	NG	6.5 $\pm$ 2.6	6.8 $\pm$ 3.1	6.6 $\pm$ 2.5	5.9 $\pm$ 1.9	5.7 $\pm$ 2.7	5.8 $\pm$ 2.5	6.7 $\pm$ 3.4
<b>Consistency</b> (%)	TG	40.9 $\pm$ 13.3	39.3 $\pm$ 9.3	40.4 $\pm$ 9.0	41.1 $\pm$ 13.7	44.3 $\pm$ 10.9	42.9 $\pm$ 12.7	41.3 $\pm$ 10.0
	NG	41.4 $\pm$ 11.7	42.4 $\pm$ 10.6	41.1 $\pm$ 10.3	41.2 $\pm$ 10.9	43.0 $\pm$ 10.9	43.0 $\pm$ 10.9	43.3 $\pm$ 9.8

Values are expressed as Mean  $\pm$  SD for the performance measures of shot speed, accuracy and consistency. Speed is the initial speed of the ball  $\text{km}\cdot\text{h}^{-1}$ . Both accuracy and consistency are of a percentage of total balls struck that hit the specific target areas.

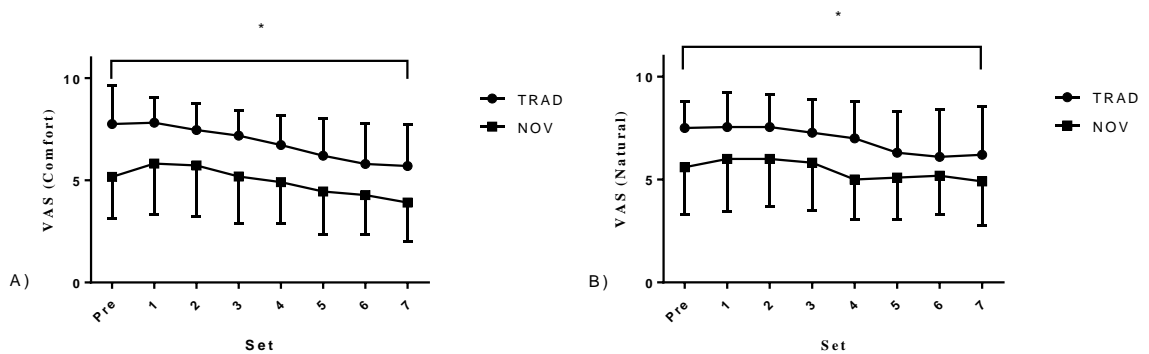
### 4.2.2 Physiological Data

Physiological stress was measured through heart rate (HR) and RPE immediately following each set. HR at the end of each set was greater than prior to the TFF protocol, taken just before initiation of set one ( $p < 0.01$ ). RPE increased during the TFF protocol and was greater during sets 3-7 ( $p < 0.01$ ) when compared to set one (*Figure 5A and 5B*).



**Figure 5. Heart Rate and RPE During the TFF Protocol.** Values are Mean  $\pm$  SD. A) Heart rate and immediately prior to, and at the end of each set of the TFF protocol. B) RPE at the end of each set and immediately prior to the TFF protocol. \* represents a significant difference from Pre ( $p < 0.05$ ). # represents a significant difference from set 1 ( $P < 0.05$ ).

Comfort and natural feel significantly decreased during the TFF protocol ( $p < 0.05$ ), indicating that the grips became more uncomfortable and felt less natural while performing the cross-court forehand stroke. The novel grip scores tended to be consistently lower scores than the traditional grip throughout the protocol, however this did not reach statistical significance (comfort ( $p = 0.07$ )) (natural feel ( $p = 0.21$ )) (Figure 6A and 6B).



**Figure 6. Visual Analogue Scales for Comfort and Natural Feel During the TFF Protocol.** Values are mean  $\pm$  SD. A) VAS scores for the comfort of the racket in the hand during the TFF protocol. B) VAS scores for the natural feel of the grip in the hand during the TFF protocol. \* represents a significant decrease across the sets ( $p < 0.05$ ).

## **Chapter 5 Discussion**

The aim of the present study was to determine the physiological effects of a tennis protocol on forearm muscle function and examine the effect of a novel grip structure on both muscle function and tennis performance. Our results have shown a reduction in forearm muscle function after the TFF protocol, in both extensor and flexor force production. However, no differences were observed following the use of either of the grip types. Furthermore, the loss in muscle function did not translate into impaired skill performance during the TFF protocol. Together, these data show that the novel grip does not ameliorate the loss of forearm muscle function following intense tennis play.

### *5.1 Muscle Function*

#### *5.1.1 Extensor MVC*

Muscle function was assessed for wrist extensor force production and muscle activity of the extensor carpi radialis (ECR) at baseline and immediately following the TFF protocol. We found that after the TFF protocol there was a reduction in muscle force production of the forearm extensors and reduced muscle activity. However, no differences were observed between the grip types, indicating that although the TFF protocol induced fatigue in the forearm extensors, the novel grip did not ameliorate the actions of fatigue.

The extensor muscles have previously been shown to fatigue during the performance of forehand stroke during a simulated tennis protocol (Rota et al., 2014). The simulated tennis protocol was an intermittent exercise consisting of 4 sets of the 12 simulated rallies which included of 1 serve followed by 8 cross-court drives. During this protocol EMG was recorded. Rota and co-authors were able to show that after the simulated tennis protocol, the activation of ECR was significantly decreased during the forehand



drive. We did not assess forearm ECR EMG activity during the TFF protocol as there is often high variance associated with EMG and non-stationary contraction (De Luca et al., 2010), however we were able to show similar results after the TFF protocol, with a reduction in muscle activity of the ECR muscles.

Previously, it has been shown that as the participants increase the returns of the ball at a greater speed, there is an associated increase in muscle activity of the ECR muscle (Rota et al., 2012). Specifically during the forehand stroke, the ECR is shown to be active immediately post-impact suggesting it is active to stabilise the joint during impact (Chow et al., 2007). Continued stress placed upon the muscle during the TFF protocol may cause a reduction in muscle activity during the Post-TFF strength measures. With the reduction in force generation during the extensor MVCs, it is plausible that the TFF protocol caused fatigue within these muscles.

There were no differences in functional muscle performance during the wrist extension MVC between the novel and traditional grips. These data suggest that the novel grip does not influence the effects on fatigue resistance of the ECR during the TFF protocol.

### *5.1.2 Flexor MVC*

Wrist flexor muscle function was also assessed through flexor force production with analysis of muscle activity of the FCR. Similar to the extensor MVCs there was a reduction in the force production following the post-TFF protocol. However, during the MVC, there was not a loss of muscle activation of the FCR. These findings illustrate that unlike the ECR the activity of the FCR shows no differences between the Pre- and Post-TFF test. In addition there were no differences between the novel and the traditional grips with both grips resulting in a loss of force but not FCR muscle activity.

After a simulated tennis protocol Rota et al. (2014) showed a decrease in wrist flexor isometric force production. However, Rota et al. (2014) also found that with the decrease in force production there was an associated decrease in muscle activation through EMGrms values. It is unknown why there are discrepancies between the studies, although we speculate the differences in FCR muscle activity are due to differences in strength measures for wrist flexion. Rota et al. implemented a wrist flexion test that involved a gripping action while our test was completed without a gripping action.

Gonzalez et al. (1997) have suggested the FCR provides a relatively small percent of total wrist flexion moment-generating potential in comparison to other wrist flexors. Therefore, we consider that the loss in force production during the flexor MVC test may be due to the loss of force production within synergistic muscles such as the flexor carpi ulnaris (FCU). Unfortunately, the muscle activity of these synergistic muscles was not assessed during this study therefore we are unable to state if changes within these muscles occurred. However, we propose that the loss in muscle function could be due to a number of wrist flexor muscles other than the FCR.

### *5.1.3 Grip MVC*

While performing a tennis stroke, both forearm extensor and flexor muscles play key roles in controlling the racket head (Hatch et al., 2006 and Elliott et al., 1989). Therefore, while it is important to examine muscles in isolation, it is also important to examine the interaction of an action which is applicable to tennis play. During the grip MVC task, force production and muscle activation of the ECR and FCR were measured. These data show that after the TFF protocol there is a decrease in both grip force production and FCR activation, however ECR activation shows little change after

the TFF protocol. In addition, the novel grip did not ameliorate the effects of fatigue on grip performance after the TFF protocol.

Gripping implements various muscles within the forearm, all to a different degree of activity (Kong et al. 2010). The FCR activity is observed during a maximal grip contraction is often less active than the flexor digitorum superficialis (FDS) and the flexor digitorum profundus (FDP). Di Domizio et al. (2008) have shown that the FCR during a maximal gripping task is active to around 25% of its maximal voluntary electrical activation in a neutral position. Although the primary function of the FCR is wrist flexion, the FCR has been shown to be active pre-impact of a forehand tennis stroke (Chow et al., 2007). Therefore, it is clear that the FCR plays a role in the grip of a forehand stroke. We speculate that the TFF protocol would induce fatigue within the FCR muscle which would be able to be observed during a gripping task. However, due to the low level of activation, it is questionable that a loss in muscle activation of the FCR is responsible for the reduction in grip force.

The absence of decreased muscle activity of the in the ECR may be explained by the role the extensors have during a gripping action. The extensor muscles play a role in stabilising the wrist joint by counteracting the torque produced by finger flexion (Snijders et al., 1987). Therefore during the gripping tests there is limited activation of the ECR muscles which may explain why we observe no change in ECR activity during gripping.

#### *5.1.4 Grip Fatigue Test*

Grip fatigue was assessed at baseline and after the TFF protocol to determine if the novel grip had an influence of the ability to maintain a maximally sustained contraction. Our results show that the decline in force over the 50 s test was similar between the grip

types. However, while there was no effect of grip type, the force produced over the course of the 50 s test decreased with both grips. This was accompanied by a reduction in the muscle activity of the FCR when using the novel grip.

The FCR was selected to measure activity during the strength and fatigue tasks as it has been shown previously to be a key muscle that is active while performing tennis forehand strokes (Chow et al., 2007 and Rota et al., 2012). During the forehand stroke, a gripping action is implemented, and over a prolonged period, reductions in the activation of the FCR have previously been observed (Rota et al., 2014). The novel grip resulted in a decrease in muscle activity levels after the TFF protocol compared to the Pre-TFF fatigue test. This would suggest that using the novel grip does not protect against the effects of fatigue during the grip fatigue test on force production and on the activation of the FCR. During a forehand stroke in tennis the FCR is shown to be active immediately pre-impact and immediately post-impact of the forehand stroke (Chow et al., 2007). This is likely due to the gripping action to control the racket head during ball impact. It is possible that the gripping action leads to a reduction in the FCR muscle activity that is not observed during the wrist flexion.

Our findings show that the novel grip does not protect against the effects of fatigue. Conversely, the novel grip appears to have a negative effect on the resistance to grip fatigue. It is unclear why the novel grip does not protect against the effects of fatigue. One reason may be due to the flat edge of the curvilinear structure of the novel grip. Holding a grip of this structure may cause the forearm flexor muscles to lengthen past the optimal length to control the racket. It is known that muscle length plays a role in the functional capacity of the muscle (Lieber and Friden, 2000; Gordon et al., 1966), which over a prolonged period may lead to fatigue. Therefore, we speculate that while a grip structure of this kind may be beneficial for torque production (Shih and Wang,

1996) this grip structure may also lead to increased grip stress while performing tennis strokes.

## *5.2 Performance and Physiological Data*

Although our data has shown a negative effect on muscle function after the TFF protocol, the loss in muscle function did not translate into a reduction in tennis performance. The results showed no decrements in cross-court forehand drive performance in terms of speed, accuracy or consistency throughout the protocol. However, it should be noted that with the novel grip for all 7 sets and sets 2-7 for accuracy and speed is consistently lower than with the traditional grip, respectively. This may be due to the discomfort and unnatural feel of the grip as observed during the VAS analysis for both these parameters. Figure 6A and 6B show that for both comfort and natural feel the novel grip is lower than the traditional grip.

The analysis of tennis stroke performance has previously been used as a measure of fatigue during simulated tennis protocols (Davey et al., 2002 and Vergauwen et al., 1998). However, these protocols have considered the effects of whole body fatigue on tennis performance through analysis of shot speed, accuracy and consistency. Furthermore; Rota et al. (2014) has been able to show a reduction in skill performance which is accompanied with a decrease in the muscle activity of the ECR and FCR while performing. We employed a protocol which allowed the participants to be relatively static in comparison to induce localised muscle fatigue in the forearm. Even though the participants were relatively static throughout the protocol fatigue occurred, this can be observed through the increase in Heart rate and RPE from Pre-TFF to the end of set 7 (Figure 5A and 5B). The reduced skill performance is likely due to whole body fatigue unlike the localised fatigue developed through the TFF protocol.

By minimising the movement throughout the TFF protocol the effects of fatigue would be minimised to muscles involved in the tennis stroke. Our data have shown that although we found reduced muscle function of the forearm, there was no effect on skilled and therefore did not influence stroke performance of the cross-court forehand stroke. However, as the TFF protocol was designed to induce fatigue locally within the forearm of the participant, this was accomplished a high volume of shots completed within a short time frame which does not represent tennis match play.

The loss of localised muscle function with no decrements in performance suggests some form of compensation. A forehand stroke involves the co-ordination of multiple muscles throughout the body from the lower extremities to the forearm (Elliott, 2006). Specifically, in the upper extremities, there are multiple muscles that are shown to be active during a tennis stroke including; biceps brachii, triceps brachii and pectorilais major (Rota et al., 2012 and 2014). Therefore, it is possible that activation of synergistic muscles may have compensated for the effects of fatigue in the forearm muscles allowing the maintenance of tennis skill performance during the TFF protocol. Unfortunately we did not measure the effects of the TFF protocol on these muscles and can only infer that the maintenance of skill performance is due to the increase of these synergistic muscles. During this study only the forearm ECR and FCR muscle activity was measured. Therefore any changes that may have occurred during the TFF within the synergistic muscle are not observed.

#### *5.4 Limitations*

The aim of this study was to determine the physiological and performance changes through the use of a novel tennis grip. However, as there was only the availability of one novel grip we were unable to change the size of the grip to suit each individual and

therefore tested both the novel and traditional grip across a similar size. As size of a traditional tennis grip is an important factor in optimal performance, by only having a single grip size for both the traditional and novel grip we were unable to account for participants' variation in hand size. Furthermore; the TFF protocol was designed to induce fatigue within the upper body, specifically of the forearm muscles. In order to do this movement was restricted and shot intensity was increased. This meant that the TFF protocol did not exactly simulate open tennis match play.

### *5.5 Future Research*

From this study it has become clear that much further research is required to tease out the differences between the novel and the traditional grips. Future studies should consider the effects of the novel grip structure over a protocol that simulates the demands of a tennis match more accurately than accomplished in this study. As various shots are part of tennis match play studies into the effects of the novel grip on various skilled shots are required. Furthermore; as size has been shown to influence tennis performance and muscle activity, determining the effects of both the novel grip structure and the size is key.

## *5.4 Conclusion*

In conclusion, the TFF protocol induced local muscular fatigue within the forearm muscles which lead to a loss of muscle function. The novel grip did not ameliorate the loss of muscle function and may have a negative effect on the flexor muscles during the fatiguing test. These data suggest that the novel grip does not protect against the effects of fatigue specifically on the flexor muscles and that the novel grip does not influence tennis skill performance of the cross-court forehand stroke. Furthermore, we have shown that the novel grip does not enhance the ability of the participants to produce more torque through a pronation MVC.

Further study is required to assess the full potential of the novel tennis grip; considerations should be taken at trying to increase the comfort of the grip along with the development of protocols that will simulate tennis performance effectively. The size of the novel grip should be investigated as within this study we aimed to determine the effect of shape. A combination of shape and size may prove vital to optimising the grips to reduce the effects of fatigue on skilled performance. This may have implications for players, improved performance and protect against injuries such as lateral epicondylitis.



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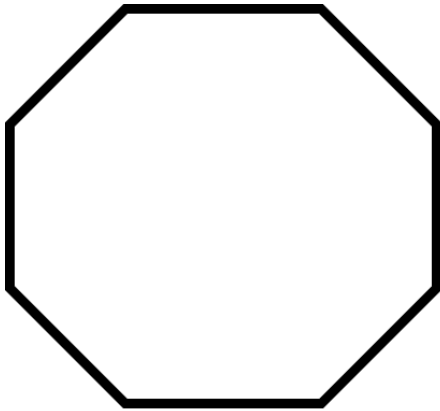
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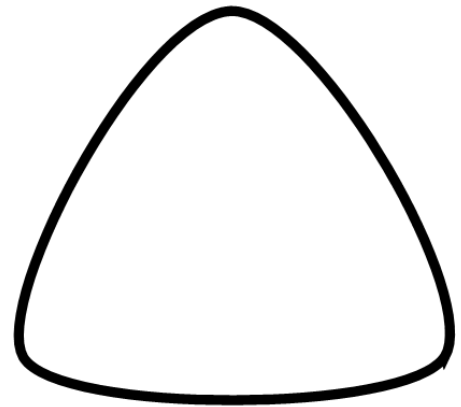
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## Appendices

### Appendix 1 Grip Structure



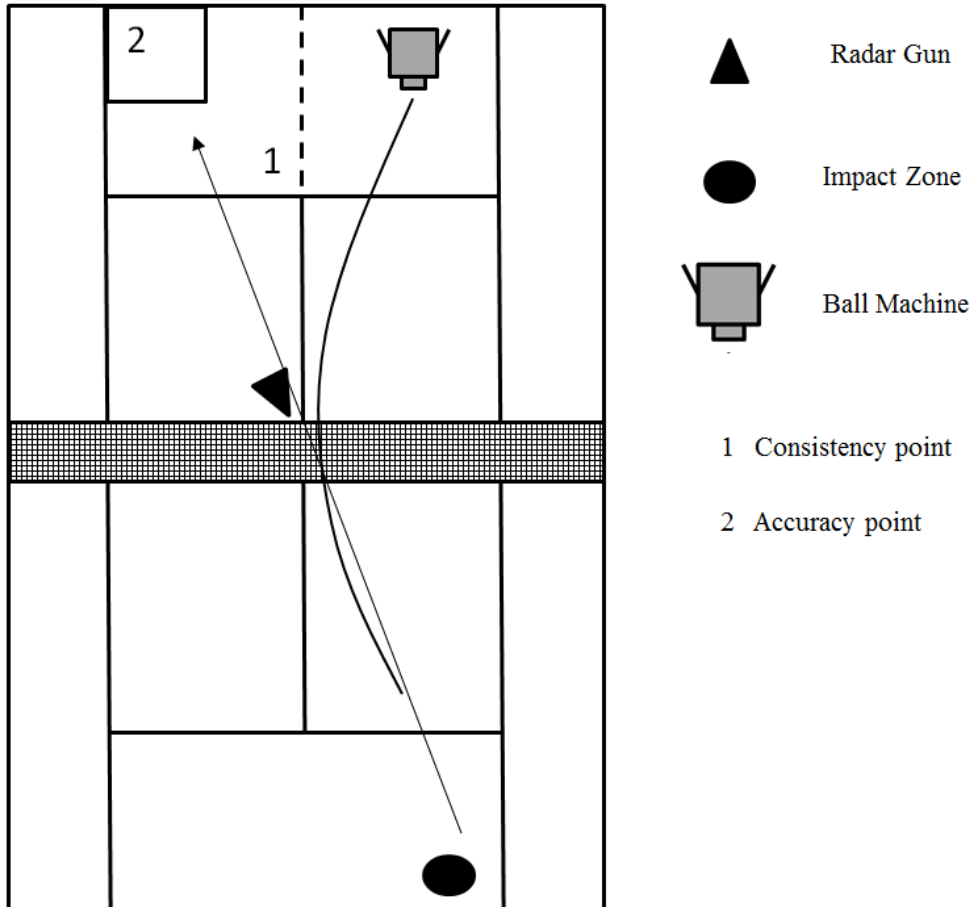
Traditional Grip



Novel Grip

Shown is a depiction representation of the structure of a traditional grip and that of a novel grip. It is clear that the novel grip differs in structure from the traditional grip. A traditional grip has 8 faces that allow the player to grip the racket. The novel grip is of a curvilinear shape with the bottom flat edge and top point being perpendicular to the face of the racket. The player would place the bottom flat edge in the palm of the hand while the fingers wrap round towards the point of the grip.

## Appendix 2 Court set up





## Appendix 3 Participant Information



UNIVERSITY OF  
STIRLING

Scotland's  
University for  
Sporting Excellence

Health & Exercise Sciences  
Research Group

**Study Title:** Comparison of the physiological responses using a novel tennis racket grip to a traditional grip.

I am currently looking for individuals who may be interested in participating in a tennis based research study. I would appreciate the time given to read this document fully which explains the details of the study and what would be required of participation within the study. Once you have read this document feel free to ask any questions that you may have about any part of the study and once done so take the time to consider whether you would like to participate or not in the study.

### **What is the purpose of the study?**

Tennis involves repetitive, high intensity efforts over a prolonged period. As the duration of a tennis match continues, fatigue is expected which can cause a reduction in skilled performance. Continual hitting for prolonged periods of time activates small muscle groups in the forearm which can lead to fatigue within these muscles and a reduction in grip strength thus having a negative impact on skilled performance.

To overcome this issue, previous research has attempted to alter the grip size of the tennis racket. Whilst altering grip size has shown limited potential, the design of the grip has not yet been researched. The aim of this research is to investigate if a more ergonomic grip design will reduce grip strain during match play and reduce forearm muscle fatigue.

The study is sponsored by: Innovation Voucher Scheme - Scottish Funding Council.

### **Am I eligible for the study?**

If you meet the following inclusion criteria then you are eligible to take part in the study:

- Healthy male or female aged 18-40 years
- An average of 30 min per day of moderate physical activity
- Have 2 years of tennis experience
- Have no recent history of upper body/limb injury

### **Do I have to take part?**

No, taking part in the study is entirely voluntary, if you decide you wish to be involved in the study you may withdraw at any time without giving a reason. Your decision to withdraw from the study will not affect how you are treated at any time. If you agree to becoming involved in the study you will be giving this information sheet to keep, asked to fill out a screening questionnaire and sign a consent form.

### **May I be excluded from the study?**

Yes, the investigators have the right to exclude you from the study if you do not meet the inclusion criteria or if you fail to comply with the requirements of the study.

### **What will happen to me if I take part?**

You will have to come to the University of Stirling on three occasions, one familiarising session and two trial days, each last no more than 2 hours. Total time commitment will be ~6 hours.

You will be asked to come to the National tennis centre and School of Sport Laboratories in the Gannochy Sport Centre. The first visit is a familiarisation visit where you will be introduced to the protocol the measures and the novel grip. The next two visits are trial days where you will complete the protocol once with each grip on separate days at least 3 days apart.

### **Visit 1: Familiarisation session**

Upon arrival for the familiarisation trial you will be asked to complete a Health Questionnaire and a Tennis Questionnaire.

During your first visit to the National Tennis Centre you will have time to become familiar with each of the tennis rackets (one with the novel grip design and one with the traditional design) and to select your grip size. Afterwards you will be introduced to the forearm strength and fatigue tests which will be completed.

After the familiarisation has been completed and you are happy with the protocols and any queries you may have are answered you will be given a 3 day food and activity diary, this should be filled out in your own time on the three days prior to trial day 1. You will be given guidance on how to properly complete the food and active diary and any questions will be answered. The food and activity diary are to ensure that your diet and physical activity are as similar as possible leading up to each trial.

### **Visit 2 and 3: You will complete the trials**

The trials will consist of the following aspects; pre-forearm measurements, service skill test 1, the tennis fatiguing protocol, service skill test 2 and post-forearm measurements. Each trial will be at least 5 days apart at the same time of day and you will use both racket designs in a randomised order.

### **Measurements before the tennis protocol**

Surface Electrodes will be placed on the forearm after the removal of arm hair, and the skin cleaned with alcohol. They will be placed on the skin above the forearm muscle groups of interest.

Firstly, forearm flexor and extensor muscles will be measured for strength and muscle activity through EMG readings.

Five minutes rest period will then be taken before a grip maximal voluntary contraction (MVC) is completed. Here you will be asked to grip a hand dynamometer and force produced and muscle activity will be measured.

Finally, after a further 5 minute rest period grip fatigue test will be completed. Here you will be asked to hold your Maximal Voluntary Contraction for a period of 50 seconds.

### **Tennis fatiguing protocol**

The tennis fatiguing protocol will take place on a tennis court in the National Tennis Centre. You will complete a standardised warm up before completing the protocol. The warm up will consist of 3 minutes of light jogging/running, 3 minutes of serving practice on both sides and 4 minutes hitting against the ball machine using forehand ground strokes at warm up pace.

The protocol call consists of 7 sets of 120 shots with a 60 seconds rest between each set. In-between each set your heart rate will be taken; blood lactate will be measured by a small volume of blood being extracted from the finger tip of the non-dominant hand and Visual Analogue Scale for forearm fatigue along with feel and comfort of the grip.

### **Measurements after the tennis protocol**

You will then return to the laboratory as quickly as possible after the tennis protocol has been completed. Here you will run through the identical tests as performed before the tennis fatiguing protocol.

### **What do I have to do before the trials?**

During the study it is important for you to maintain your normal lifestyle and not alter your diet or training within this time, this will allow the results to show changes in data from attributes of the study rather than changes within your lifestyle. You will be required to fast for 3 hours prior to the trials and refrain from strenuous exercise for 48 hours prior to trials. You will also be required to fill out 3 day food and exercise diaries prior to your first trial. In order for this study to be as successful as possible it is required that you comply with the requirements of this study.

### **What are the possible disadvantages and risks of taking part?**

There are minimal risks involved in this study. There may be slight forearm soreness from the fatiguing protocols. Blood collection from the fingertip may also leave minor bruising however this is normal and pain will be minimal.

### **What are the possible benefits of taking part?**

The benefits from participating in this study are that you will be amongst the first to experience the new grip type and use it. You will be able to receive information about the potential strength and fatigue rates of your forearms muscles relating to the tests completed in the laboratories, this may be used to design training programmes to improve strength and fatigue resistance of the forearm muscles. You will also get an indication of shot accuracy during a forehand rally.

### **Will my taking part in this study be kept confidential?**

To maintain anonymity individual participant codes will be used to identify each data set collected and storage of this data whether it be on computer, data storage units or on paper. These identification codes will to an extent be permitted by applicable regulations and laws and therefore will not be made available publically. Only the investigators will have access to the coding system which will be destroyed as soon as the study is completed, published data will be completely anonymous.

### **What will happen to the samples that are collected once the study is finished?**

The data gathered will all be stored on a computer system at the end of the trial from the last participant and will be destroyed in the correct manner 5 years after the last participant has completed the study.

### **What will happen to the results of the research study?**

The results of this study will be written up for my MPhil thesis, in the form of a journal article and submitted to a journal to be published. The results will also be written and presented to the inventor of the grip design. During the write up of the study you will not be able to be identified or at any other point.

### **Who has reviewed the study?**

The study protocol, this information document and the consent form all have been reviewed by the ethics committee of the school of sport at the University of Stirling.

### **What happens if something goes wrong during the trials?**

The procedures in the study are all covered within the University of Stirling Liability Insurance and if you are harmed during the study your normal rights apply and you may have the rights to take legal action. Prior to participation in the study you should check that your personal life or health insurance

policy is not affected by your participation in the study, you should contact Dr. Ian Walshe or Mr. Adam Wade immediately if this is the case. Your GP should be informed of your participation to ensure no health risks.

### **Complaints Procedure**

If you have any complaints regarding the way you have been treated or other aspects regarding the study you can write to Dr Angus Hunter who is independent from the research team and will investigate the matter fully.

Dr. Angus Hunter

Health and Exercise Sciences Research Group

School of Sport

University of Stirling

Stirling

Tel. 07706 586497

Email. a.m.hunter1@stir.ac.uk

### **Next step.....**

Once you have read this document, if you are still interested in participating in the study you have the opportunity to ask any questions you may have and only once you are satisfied you will be asked to sign an informed consent form. You will be given a copy of this information sheet and informed consent form for your own records. After this your first visit will be arranged.

Please also bear in mind that you are free to withdraw from the study at any point.

If you wish to have any further questions answered about this current research by an independent researcher who is highly experienced in this field of research then please contact Dr Angus Hunter (see above).

Thank you for taking the time to read this information sheet and if you have any further questions please do not hesitate to contact us.

### **Contact for Further Information**

Adam Wade

Health and Exercise Sciences Research Group  
Group

Office telephone:

Mobile (24 h): 07427695625

Room 3A54

Cottrell Building

University of Stirling

Stirling FK9 4LA

Dr Ian Walsh

Health and Exercise Sciences Research

Office telephone: 01786 466488

Mobile (24 h): 07745520939

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Email: [adam.wade@stir.ac.uk](mailto:adam.wade@stir.ac.uk)

Email: [ian.walsh@stir.ac.uk](mailto:ian.walsh@stir.ac.uk)

You may contact Adam Wade or Dr Ian Walshe 24 h in an emergency after contacting emergency services if required.

## Appendix 4 Informed Consent

### Consent Form

**Name of Patient/Volunteer:**.....

**Name of Study:** Comparison of the physiological responses using a novel tennis racket grip to a traditional grip.

**Principal Investigator:** Ian Walsh

I have read the patient/volunteer information sheet on the above study and have had the opportunity to discuss the details with Ian Walsh/Adam Wade and ask questions. The principal investigator has explained to me the nature and purpose of the tests to be undertaken. I understand fully what is proposed to be done.

I have agreed to take part in the study as it has been outlined to me, but I understand that I am completely free to withdraw from the study or any part of the study at any time I wish. I understand and agree that my participation in the study is entirely at my own risk.

I understand that these trials are part of a research or project designed to promote medical scientific knowledge, which has been approved by the Sports Studies Ethics Committee, and may be of no benefit to me personally. The Sports Studies Ethics Committee may wish to inspect the data collected at any time as part of its monitoring activities.

I also understand that my General Practitioner may be informed that I have taken part in this study if any unusual or surprising observations are made.

I hereby fully and freely consent to participate in the study which has been fully explained to me.

**Signature of Patient/Volunteer:** .....

**Date:** .....

I confirm that I have explained to the patient/volunteer named above, the nature and purpose of the tests to be undertaken.

**Signature of Investigator:** .....

**Date :** .....