The Workload Demands of Mixed Martial Arts

by

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ABSTRACT

Purpose: The current study was structured in two separate stages: study one aimed to determine the reliability of the Catapult Minimax x3 accelerometer in the assessment of isolated mixed martial arts (MMA) specific techniques; study two aimed to measure the workload demands of simulated MMA bouts.

Study One: Eight male MMA trained participants (age = 25.5 ± 4.5 yrs) performed a series of 10 standing striking techniques (5 occurrences of each), 6 ground striking techniques (5 occurrences of each) and 2 takedown techniques (5 occurrences of each) whilst wearing a Minimax x3 accelerometer. Intraclass correlation coefficients (ICC) (reliability threshold ≥ .700) found that all techniques showed intra-unit reliability for player load (PL) (ICC = .700 - .970) and accumulated player load (PL_{ACC}) (ICC = .794 – .984) with the exception of PL for left knee (ICC = .476) and right knee (ICC = .667). Offensive double leg takedowns caused the greatest PL_{ACC} (1.36 ± 0.40 au) whilst the greatest PL was caused by defending single leg takedowns (2.90 ± 1.46 au). Amongst the standing strikes, the cross punching technique caused the greatest PL (3.40 ± 0.53 au) and left body kick resulted in the greatest PL_{ACC} (0.69 ± 0.12 au) whilst right elbow caused the greatest PL_{ACC} (0.65 ± 0.15 au) and PL (3.89 ± 0.82 au) within the ground strikes. In terms of cardinal plane accelerations, all techniques with the exception of defending double leg and single leg takedowns displayed least acceleration in the Y axis (0.40 ± 0.29 - 2.45 ± 1.96 au) and the greatest acceleration in the X axis (0.99 ± 0.31 – 6.56 ± 0.73 au). Paired samples t-tests ($p \leq .05$) found the only techniques that demonstrated differences in PL between the left and right sides of the body was ground punches ($t_{(14)} = -4.201$; $p = .001$). No other significant differences were found.

Study Two: Six male MMA trained participants (age = 26.17 ± 5.04 yrs) took part in a single MMA sparring bout each (3 rounds of 5 minutes, 1 minute rest between rounds) whilst wearing a Minimax x3. The bouts were recorded in their entirety and time motion analysis (TMA) was completed through Longomatch 0.18. Capillary lactate samples were taken prior to warm up, post warm up, upon completion of each round and 5 minutes after the completion of the bout. Mean PL was recorded for each technique used in the bouts whilst mean PL_{ACC} and mean accumulated player load per minute ($PL_{ACC}.min^{-1}$) was calculated for each round and for the bouts in total. It was found that MMA participants had a PL_{ACC} of 224.32 ± 26.59 au and a $PL_{ACC}.min^{-1}$ of 14.91 ± 1.78 au. Three techniques used during the sparring bouts were found to have significantly different PL ($p < .05$) than the same techniques in isolation according to paired samples t tests, however seven techniques displayed moderate to large effect sizes (Cohen's *d*). The participants had a mean post bout lactate of 9.25 ± 2.96 Mmol.L and a delta lactate (ΔLac) of 3.87 ± 0.85 Mmol.L and MMA sparring causes a significant change in blood lactate concentration according to one-way ANOVA ($F_{(5, 30)} = 5.774$, $p = .001$). PL_{ACC} ($r = -.952$, $p = .198$) and $PL_{ACC}.min^{-1}$ ($r = -.939$, $p = .223$) displayed direct negative correlations to lactate prodcution by round according to Pearson's correlation ($p \leq 0.05$). The group was found to have a work to rest ratio (W:R) of 1.01:1 whilst a significant difference was found between bout winners and bout losers in terms of the amount of succesful takedowns according to paired samples t tests ($t_{(2)} = 5.196$, $p = .035$).

Conclusion: Study one confirmed the Minimax x3 is a reliable tool for measuring PL and PL_{ACC} in some MMA techniques whilst also revealing the sensitivity of the unit in highlighting the loss or changes of correct technique. Study two showed that the Minimax x3 is sensitive enough to monitor fatigue of the athletes during bouts whilst also giving a clear picture of how a competitor changes their technique or movement

due to facing a live opponent. In terms of energetics, it could be suggested that MMA sparring causes a similar amount of lactate production as muay Thai and Brazilian jiu jitsu competition. MMA competitors spend an equal amount of time during a bout engaged in physical exertion and actively resting. During the active phases, the participants spend a significant amount of time performing less explosive techniques, despite the bout winners being decided by achieving successful takedowns which produced the most load and greatest accelerations. Overall, the Minimax x3 was found to be a useful and reliable tool for monitoring the demands of MMA training and simulated competition alongside other assessment methods.

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TERMS AND DEFINITIONS

Accelerometry	The quantitative determination of acceleration and deceleration in the entire human body or a part of the body in the performance of a task.
Accumulated Player Load (PL_{ACC})	The total load of a participant's performance calculated by the accumulation of PL during performance.
Accumulated Player Load per Minute ($PL_{ACC}.min^{-1}$)	A participant's PL_{ACC} displayed as a per minute average of their full performance.
Body Kick	The technique of a fighter kicking an opponent to the torso.
Boxing	A sport of European and North American origin in which competitors are permitted to strike each other to the upper body with the fists only.
Brazilian Jiu Jitsu (BJJ)	A grappling based sport of South American origin in which the aim is to physically control an opponent and defeat them using joint locks and choke holds.
Cross	The technique of a fighter striking their opponent using their rear hand in a straight linear motion.
Delta Lactate (ΔLac)	The difference between a participant's lactate levels at the start of a performance and their lactate levels at the end of the performance measured in millimoles per litre (Mmol.L).
Double Leg Takedown	The technique of a fighter grappling both of their opponent's legs so that they are moved onto their backs in an inferior position
Grounded Knee Strikes	The technique of a fighter striking their opponent's torso with their knee whilst in a grounded position
High Kick	The technique of a fighter kicking an opponent to the head or upper torso
Hook	The technique of a fighter striking their opponent using either hand in an angular motion through the transverse plane.
Jab	The technique of a fighter striking their opponent using their forward hand in a straight linear motion.
Judo	A grappling based sport of Japanese origin in which the aim is to grapple an opponent and throw them onto their back and shoulders.
Lactate	Lactic acid that appears in the blood as a result of anaerobic metabolism when oxygen delivery to the tissues is insufficient to support normal metabolic demands

	measured in millimoles per litre (Mmol.L).
Leg Kick	The technique of a fighter kicking an opponent to the thigh.
Maximal Oxygen Uptake ($\dot{V}o_2max$)	The maximum amount of oxygen that can be consumed and used every minute. It is expressed as either litres per minute ($L.min^{-1}$) (absolute) or millilitres per kilogram per minute ($ml.kg.min^{-1}$) (relative).
Mount	A position within BJJ whereby one competitor assumes a dominant position by sitting on the torso of the opponent with their legs either side of the opponent's body.
Muay Thai	A striking sport of South-East Asian origin in which the competitors strike each other with their fists, elbows, feet and knees in standing positions only.
Pass	A group of techniques within grounded grappling where a competitor in a neutral position moves into a more dominant position
Player Load (PL)	The instantaneous load of a participant's movements calculated by combining the accelerations of their movements in the three cardinal planes of X, Y and Z.
Side Control	A position within grounded grappling where a competitor is holding their opponent's back and shoulders to the ground with their own body at a right angle to the opponent's torso.
Single Leg Takedown	The technique of a fighter grappling one of their opponent's legs so that they are moved onto their backs in an inferior position
Submission	An occasion in grappling where one fighter forfeits a contest due to their opponent holding them in a joint lock or choke hold from which they cannot escape.
Sweep	A group of techniques within grounded grappling where a fighter moves from an inferior position directly to a dominant one.
Time Motion Analysis (TMA)	A method of measuring activity and movement of a participant by quantifying how much time they spend performing a series of variables within a performance.
Wrestling	A sport of European origin where the aim is to pin an opponent onto the shoulders and lower back.

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CHAPTER 1

INTRODUCTION

1.1 Background of Mixed Martial Arts

Mixed Martial Arts (MMA) is a combat sport in which the competitors physically engage an opponent using strikes with the hands, feet, elbows and knees to the head, body and limbs with the aim of giving the referee due cause to intervene for the safety of the athlete or by causing them to give in or ‘submit’ to choke holds and joint locks. MMA bouts are performed within the confines of an octagonal cage (17 foot – 30 foot in diameter) or a boxing ring (Gentry, 2002). These conditions are set in place by the Unified Rules of MMA (New Jersey State Athletic Control Board, 2002) which were introduced as a single rule set to be used in each state of the USA in 2002, although prior to this, some organisations had introduced their own rules regarding prohibited techniques, rounds and weight classes, in that chronological order, periodically since 1993 (Gentry, 2002). This led to each state and country originally had its own set of differing rules, but the Unified Rules have become the accepted code of MMA across the world and prohibit illegal techniques such as eye gouging, groin strikes and kicks or knees to the head of a downed opponent whilst also defining the methods of victory, the weight classes and bout length. An international governing body, the International Mixed Martial Arts Federation (IMMAF), has recently been established to organise and govern the amateur side of the sport whilst also pursuing International Olympic Committee (IOC) recognition. This organisation uses a modified version of the Unified Rules with further prohibited techniques to increase safety and reflect the participant’s amateur status (IMMAF, 2013).

Male weight classes range from flyweight (below 56 kg) to super heavyweight (above 120 kg), although only the following classes are used by the premier international professional MMA organisation the Ultimate Fighting Championship (UFC): flyweight (below 56 kg), bantamweight (below 61 kg), featherweight (below 65 kg), lightweight (below 70 kg), welterweight (below 77 kg), middleweight (below 84 kg), light heavyweight (below 93 kg) and heavyweight (below 120 kg). The UFC also has a women's bantamweight division (below 61 kg) and a women's strawweight division (below 52 kg) (UFC, 2013). Professional bouts consist of 3 X 5 minute rounds, with world championship bouts being 5 X 5 minute rounds with a 1 minute rest period between each (UFC, 2013).

The movements of the sport itself are a combination of techniques from many different combat sports (Gentry, 2002). Within professional competition, participants are allowed to utilise punching, kicking, elbowing and kneeing techniques to the head, legs and body of their opponent in a standing position (determined as the soles of the feet being the only parts of the body in contact with the ground), traditionally displayed in boxing, kickboxing and muay Thai bouts. When one or both of the participants is in a grounded position, kicks and knees can only be applied to the body and legs whereas punches and elbows can be applied to the body, legs and head. In standing and grounded positions, competitors are also attempting to apply submission holds, which are grappling movements taken from Brazilian jiu jitsu (BJJ) and wrestling intended to choke the opponent or hyper extend their joints and limbs. Additionally, the competitors also engage in grappling movements from wrestling and judo designed to lift, trip or takedown the opponent to get them from a standing to a grounded position. The successful performance and application of these three skill areas is essential for success in high level competition (Ritschel, 2009).

To this end, the competitors at both amateur and professional level traditionally trained in one of these disciplines before moving into MMA. However, with the increasing popularity of MMA, more young male and female athletes are beginning to train in MMA as a single entity before any of the other combat sports (Bledsoe, 2009), a similar movement to that which has been noted in triathlon, whereby elite competitors are now ‘grown from the ground up’ rather than being selected through talent transfer (Shibli, 2012). Although comparisons have been drawn between MMA, the ancient Greek sport of pankration and the Brazilian vale tudo (no holds barred) contests of the mid to late 20th Century (Gracie and Danaher, 2003; Whiting, 2010), with little over a decade of competition with a legally enforced rule set and weight classes, relatively little peer reviewed academic work exists relating to the performance characteristics of the sport resulting in a clear lack of understanding of MMA competitor’s movement patterns and exertion during bouts. The only research to have used field based testing of MMA athletes to date are Amtmann et al. (2008) and Del Vecchio et al. (2011) who used lactate sampling and time motion analysis respectively to assess the load of competitive MMA. These studies are discussed in detail in Chapter 2.

For the athletes involved in competitive MMA to progress and improve, it is important that it is researched as a sport in its own right with its own needs, training protocols and physiological adaptations to ensure that coaching and training is geared towards the competitor’s specific needs. However, with the lack of controlled research regarding the performance of the athletes in competition, it is currently unknown as to what the physiological responses are to an MMA contest or what is the most viable method of measuring the loads involved in competition.

Lambert and Borresen (2010) highlighted the need for individual sports to have their own specific protocols for measuring training load and intensity to allow athletes and trainers to make the greatest gains whilst minimising injury rates, but Amtmann (2010) suggests that these protocols do not exist within MMA training due to a lack of scientifically supported knowledge of the movement and physiological parameters of a contest. This lack of baseline knowledge is an issue that is also reported by Lenetsky and Harris (2012) who discussed the current research into MMA and compared it to the available research from other combat sports, arguing that there are large gaps in MMA physiological knowledge across most levels of competition and that as MMA movement patterns and physiological responses may differ to other combat sports, using the measurement, training and testing modalities of these sports could be a mistake, a view supported by La Bounty et al. (2011).

To this end, it is important that research is undertaken to develop a measurement method for the MMA athlete's load in a field environment. This would allow the determination of whether training correctly mirrors the physiological intensity and workloads of an MMA bout so that competitors can be optimally prepared whilst ensuring injuries and overtraining are minimised. It is also vital that any method developed does not interfere with the athlete's natural movement patterns or provide any unnecessary risk of injury.

CHAPTER 2

LITERATURE REVIEW

2.1 Physiological and Anthropometric characteristics of Mixed Martial Arts Competitors

Several studies have provided mean data on MMA competitor's stature, mass and age, (Schick et al., 2010, age = 25.5 ± 5.7 years, stature = 174.8 ± 5.3 cm, mass = 77.4 ± 11.4 kg; Marinho et al., 2011, age = 30 ± 4 years, stature = 176 ± 0.05 cm and mass = 82.1 ± 10.9 kg; Alm and Yu, 2013, age = 29.6 ± 5.50 years, stature = 180.4 ± 9.07 cm and mass = 80.8 ± 11.08 kg), however, these studies did not differentiate between weight classes so large variations are to be expected. This is also reflected within other weight class based sports such as judo (age = 18.4 ± 1.6 years, stature = 177.4 ± 5.4 cm, mass = 74.9 ± 4.7 kg, Degoutte et al., 2003) and taekwondo (age = 18 ± 3 years, stature = 175 ± 9 cm, mass = 65 ± 10 kg, Machado et al., 2009) respectively.

Of the physiological testing that has been performed within MMA, Schick et al. (2010) showed that MMA competitors were most similar to judo participants based on their body fat percentages (MMA = 11.7 ± 4.0 %, judo = 11.4 ± 8.4 %, respectively) and one repetition maximum (1RM) bench press when expressed to body mass (MMA = 1.2 ± 0.1 kg/kg, judo = 1.2 ± 0.1 kg/kg, respectively). Whilst this reference provides a good overview of the capabilities of this group of athletes, it does not analyse how their body's physiological responses are affected by the type of training and competition engaged in, and more importantly, it has no discussion or analysis of field based responses.

Similarly, Marinho et al. (2011) used strength tests to show that MMA athletes had much lower strength in comparison to karate and judo practitioners (based on 1 repetition maximum squat: MMA = 73 ± 15 kg, karate = 128.6 ± 20.4 kg, judo = 104 ± 27 kg, respectively), which, according to Argura et al. (2003), classifies the MMA athletes as having low level strength for this lift, with 104 ± 27 kg being the acceptable range for a participant of a grappling inclusive activity. There is no discussion, however, as to whether this has an effect on the level of success in competition or the participant's abilities in the different areas of performance or how this range has been determined as being 'acceptable' for the movements and requirements of MMA. Additionally, whilst MMA does have a large grappling element, it also consists of a large amount of striking, which negates a like-for-like comparison with judo in this instance.

It has been hypothesised in Ratamess' (2008) comparison of the energy system usage in a number of sports, that MMA has high demands of the phosphocreatine (PCr) and glycolytic energy systems with moderate use of the aerobic systems. This informs the author's recommendations for the training programmes used in MMA. However, more detailed analysis of the metabolic processes of each stage of an MMA bout will be required for a specific performance profile, as Ratamess' (2008) conclusions were based on the length of time of a typical MMA bout rather than any specific research into the movements and intensities experienced by the participants. The fact that MMA coaches and athletes do not currently have a scientifically determined set of physiological data to compare performance to, or a valid and reliable method of assessing training and competition load, is a shortcoming that needs to be addressed in order to improve athlete performance. This would also allow any other currently existing studies to be viewed and evaluated in context as pointed out in Paillard (2011).

2.2 Quantifying the Physical and Physiological Demands of Performance

There are a variety of physiological testing methods that were considered for use in this study. Some are currently used within MMA, but have limitations to their use and value. The following section examines these methods and their limitations and explains why each was either rejected or accepted for use in MMA analysis.

2.2.1 Introduction to Maximal Oxygen Consumption Testing

Maximal oxygen consumption ($\dot{V}o_2max$) has been used as a method of measuring aerobic capacity and endurance for sports performance for several decades, allowing the determination of the upper limit of aerobic exercise tolerance for individuals (Davies, 2006). Whilst indirect methods of measurement have been developed such as multiple linear regression equations (Jones et al., 1985), heart rate extrapolation and step testing (Grant et al., 1999), it is highly recommended that direct testing through gas analysis be used as the basis of scientific analysis (Koutlianos et al., 2013) as this is a method that has been shown to be valid and reliable in commercially available desktop and portable formats (Macfarlane, 2001). Due to the ease of reproducing $\dot{V}o_2max$ testing in lab-based environments, it is often viewed as the 'gold standard' of measuring aerobic capacity (Gaskill et al., 2001), though it is unlikely to yield as much useful information as a functional field-based test (Carlson, 1995). Whilst there have been developments in the use of portable gas analysis in the field for some sports (Crandall, 1994; Keskinen, 2003), much of the direct testing in academic studies is limited to lab-based testing such as treadmill or cycling based research (James et al., 2008; Gocentas et al., 2009), thus reducing its application to making informed deductions about an athlete's performance in multi-skilled competition.

2.2.2 Maximal Oxygen Consumption in MMA

Of the $\dot{V}o_2max$ testing that has been performed in MMA, Schick et al. (2010) and Alm and Yu (2013) both used portable gas analysis during treadmill tests and reported mean $\dot{V}o2max$ values of 55.5 ± 7.3 $ml.kg^{-1}.min^{-1}$ and 60 $ml.kg^{-1}.min^{-1}$ respectively. Schick et al. (2010) used this information to compare MMA to other combat sports, for example wrestling (54.6 ± 2.0 $ml.kg^{-1}.min^{-1}$) and the results from both studies can be compared to boxing = 64.6 ± 7.2 $ml.kg^{-1}.min^{-1}$ (El-Ashker and Nasr, 2012), taekwondo = 57.09 ± 3.89 $ml.kg^{-1}.min^{-1}$ (Wheeler et al., 2012) and judo = 47.3 ± 10.9 $ml.kg^{-1}.min^{-1}$ (Sbriccoli et al., 2007). This puts MMA athletes in the middle to upper range for $\dot{V}o_2max$ amongst martial arts participants. Whilst these findings could allow for an estimation of how the fighters may perform during a bout, due to the lab based manner in which these studies were conducted, they do not give a true representation of the load within competition, as MMA is not a steady state running event.

Crisafulli et al. (2009) attempted to design a more ecologically valid method of measuring $\dot{V}o_2$ responses in combat sports by testing muay Thai athletes in a simulation bout. Participants took part in 3 X 5 minute simulation rounds consisting of a pre-determined series of strikes and defensive movements against a sparring partner using kick and punch pads whilst wearing a portable gas analyser. The results showed that on average, each of the participants rapidly approached $\dot{V}o_2max$ during the simulated bout. Additionally, each participant's minute ventilation (V_E) increased to a peak value of 117.5 ± 12.7 $ml.min^{-1}$ during the second round whilst their volume of carbon dioxide ($\dot{V}Co_2$) levels were recorded as 2685 ± 122.9 $ml.kg^{-1}.min^{-1}$ after the first round, 3166.4 ± 178.6 $ml.kg^{-1}.min^{-1}$ after the second round and 2939.1 ± 79.1 $ml.kg^{-1}.min^{-1}$ after the third round. Similar methods were used by Ghosh (2010) using amateur boxers taking part in 4 X 2 minute rounds of striking a punch bag wearing a portable gas analyser, finding that the participant's $\dot{V}o_2$ peaked at 59.3 $ml.kg^{-1}.min^{-1}$ in the fourth round. The results of both these studies, combined with the fact that none of the recorded values returned to a resting state in the one minute rest periods, demonstrates that the participants are making extensive use of the anaerobic energy systems, and the rest periods are not sufficient for the body to eliminate its exercise induced bi-products. Due to the similarities in bout format and round times, it could be expected that MMA fighters would share a more similar profile to muay Thai fighters than boxers.

2.2.3 Limitations of Maximal Oxygen Consumption Testing for MMA

There are some inherent problems with using portable gas analysis of $\dot{V}o_2$max to gain truly field reflective results for MMA. First of all, competitive bouts do not involve a pre-set number or order of strikes or movements as used by Crisafulli et al. (2009) and Ghosh (2010), so unless the mean occurrence of each technique used in a typical MMA bout is determined, this method would not provide a realistic overview of bout demands. Secondly, the opponent will not be working with the participant to allow them to execute their techniques or movements at the time they wish, and will indeed force them to do other movements as such this may increase or decrease the workload of the competitor being tested.

Finally, the wearing of a portable gas analyser for any type of combat sport would be a danger to both combatants due to safety concerns based on use of a face mask in a sport in which one of the key aims is to strike the opponent's face as well as the movement restriction issues that would arise during the grappling phases of a bout caused by the portable units being worn as a harness on the torso of the participant (Medbo et al., 2000). Additionally, the wearing of such equipment is more likely to cause actions not in keeping with the movements of the competition. So whilst

$\dot{V}o_2max$ measurement is seen as a ‘gold standard’ measurement of physiological performance and adaptation (Cooke, 2009), making use of this method would prove impractical for field based measurement of the workloads in MMA. This eliminates the use of gas analysis for the testing of in-competition load. In order to achieve this goal, a different method which does not have the inherent risks or aforementioned limitations of $\dot{V}o_2$ testing needs to be utilised.

2.2.4 Heart Rate Monitoring

Heart rate (HR) is viewed as one of the most informative yet simplest methods of measuring a person’s response to activity as it allows a direct measurement of the increased activity of the cardiovascular system (Wilmore et al., 2008) whilst also having a direct, linear relationship with oxygen uptake and a strong correlation with $\dot{V}o_2max$ (Eston et al., 1996). Due to these factors, field measurement of HR is widely used (Bosquet et al., 2008) and is conducted using portable HR monitors either worn as a wristwatch (Crouter et al., 2004; Lee and Gorelick, 2011) or as a chest strap (Brage et al., 2006).

Whilst HR has been measured at 160 - 163 beat.min^{-1} in wrestling (Barbas et al., 2011), 171 – 184 beat.min^{-1} in boxing (Chatterje et al., 2005) and 175 – 187 beat.min^{-1} in taekwondo (Bridge et al., 2009), there is currently no HR data existing for MMA competitors. Portable HR monitoring systems have been shown to be accurate in assessing HR during rest and moderate activity but less accurate when HR is increased to near maximum or at high levels of participant motion due to increased motion artefact affecting the signal being emitted (Terbizan et al., 2002; Lamberts et al., 2004; Lee et al., 2011; Lee and Gorelick, 2011). Considering that MMA movements involve a high level of motion throughout a contest, this creates a considerable chance of motion artefacts and inaccurate data being recorded, as does the high likelihood of contact between the skin and the HR monitor being broken during grappling. Similar artefacts can also be caused by the sensor being worn against synthetic materials causing static or testing being done near overhead power lines, mobile phones or wireless routers (Garmin, 2013).

Other issues with the use of portable HR monitors is their time lag responding to and recording HR changes (Barreira et al., 2009) as well as a person's HR having day-to-day fluctuations and changes which do not always respond the same to matching levels of intensity (Bosquet et al., 2008). These fluctuations can often be influenced by other non-controlled variables such as temperature and emotional state (Strath et al., 2000; Burnik and Jereb, 2007). As the current study aims to assess responses to specific actions, this is deemed to be an unacceptable level of inaccuracy for such purposes, as it is limited in the determining of demands of finer movement patterns.

2.2.5 Lactate Sampling

Lactate sampling has been used across many different sports and training methodologies to assess changes in aerobic and anaerobic fitness as well as to prescribe training protocols and assess an individual's responses to these different systems. It is mostly used to estimate a person's anaerobic contribution to energy reproduction via lactate (Pyne et al., 2000). It has also been shown that there is a relationship between loss of muscular power and the accumulation of lactate (Ahmaidi et al., 1996) as well as a correlation between endurance performance and the determination of the anaerobic threshold (Pfitzinger and Freedson, 1998). Each of these responses could have a significant effect on an MMA competitor's ability to perform effectively in the latter stages of a bout due to the fighters relying on explosive movements, such as strikes and takedowns, in order to achieve victory and the likelihood of the combatants beginning to make use of the aerobic energy systems.

The Lactate Pro Analyser (Arkray, Kyoto, Japan) has been shown to be accurate (r = 0.78 – 0.92) in measuring lactate production, blood lactate content and lactate clearance by Mamen et al. (2011) when using a maximal lactate steady state (MLSS) estimation of between 3.0 and 4.0 Mmol.L. Pyne et al. (2000) also showed the very high inter-unit reliability of the Lactate Pro Analyser (r = 0.99).   Although it has been demonstrated that blood lactate measurements can underestimate true muscle lactate (Bangsbo et al., 1996; Reilly, 1997), Foster and Cotter (2006) showed that for relatively long periods of exercise (≥ 5 minutes) there is a reasonably even ratio between muscle and blood lactate, meaning that measurements taken from the blood will give a good indication of the amount within the muscle during MMA bouts. It has also been demonstrated that peak lactate levels may be observed 3 – 8 mins post exercise (Maughan and Gleeson, 2004; Goodwin et al., 2007)

Currently, the only published data on the lactate production of MMA competitors found that four participants involved in sparring bouts had a mean lactate of 16.35 ± 4.74 Mmol.L and a mean lactate production of 19.7 ± 1.41 Mmol.L from full competitive bouts (Amtmann et al., 2008). However, their study was limited in that only the pre and post-bout lactate levels were taken, without any indication of what movements or specific actions were undertaken during the performance of these matches or at which point in the bouts they experienced increased lactate. This led Amtmann et al. (2008) to conclude that the findings can only be effectively used for generalised comparisons and should not form the basis of training methods or athlete classification.

2.2.6 Limitations of Lactate Sampling

The information that can be gained from lactate sampling is limited to displaying peak amounts of lactate at the time of sampling. It cannot distinguish whether a participant's result is displaying a certain concentration due to low lactate production, or high lactate clearance. Similarly, as samples are taken post exercise, it cannot detail when the most lactate was being produced, which within a multi-faceted event could be of high importance (Spurway and Jones, 2007). Another issue is the invasiveness of the sampling method, which would lead to the participants potentially grappling each other with blood droplets on their fingers and hands. Whilst this issue could be minimised by the use of the earlobe as a sampling site, Draper et al. (2006) demonstrate that in a sports performance that relies heavily on upper body movements and strength, lactate can be absorbed by non-active muscle fibres, leading to an inaccurate result. In spite of this, the ease of collecting these data in the field and lack of intrusion on the participant's movements or level of safety made this a useable method of testing for this study. Though there are some practical issues to lactate testing during competition, it still presents a useful indicator of exercise effort (Kreamer et al., 2001; Smith, 2006; Cappai et al., 2012; da Silva et al., 2013; Degoutte et al., 2013). However, to get a better understanding of in fight dynamics, more sensitive and less invasive methods are required.

2.2.7 Video Based Time Motion Analysis

The use of video analysis to track and assess sports performance has been used in sports such as football, basketball and judo to assess player contribution and tactical effectiveness in matches and in training, as it provides a more detailed, non-invasive means of match/bout analysis (Miarka et al., 2012; Lemmink and Frencken, 2013). In its most basic format, video analysis is combined with notational analysis to assess performance based on a set of pre-assigned key performance indicators

(KPIs) (Hughes and Franks, 2004). For example, Marandi et al. (2010) used video recordings and Quintic video analysis software to determine which techniques led to most points being scored in the 2006 Karate World Championships, finding that attacking was more successful than counterattacking (61.6% vs. 19.6% respectively) and the most scored 'area' was the head (66%). This could be useful information for a coach or competitor as it statistically highlights which movements and techniques have the highest points return and which are the least successful, thus giving a focus for tactical planning and training. Video analysis can also be used to provide a prediction of stages of increased energy expenditure, a process known as time motion analysis (TMA) (O'Donoghue, 2008). Using this information, an observer or coach can assign a work:rest ratio (W:R) to a performance or stage of play, a method that has been used to estimate levels of energy usage and physiological stress (Ballor and Volovsek, 1992; Reilly, 1996).

2.2.8 Time Motion Analysis of Combat Sports

Sliva et al. (2011) used TMA to demonstrate that muay Thai has a W:R ratio of almost 2:3, showing that more time is spent either observing the opponent for the next movement or resting whilst kickboxers, who are not permitted to use elbows or knees, have an W:R of 1:2. This indicates that kickboxers spend twice as much time at comparable rest than in effort. Del Vecchio et al. (2007) showed BJJ having an W:R of 13:1, indicating that a BJJ practitioner (only being permitted to grapple and submit their opponent without any kind of striking) has a far higher work rate in competition than a striking based athlete. Van Malderen et al. (2006) showed a similar pattern in judo (another grappling sport that does not include strikes) which has an W:R of 2:1. These three studies clearly show that athletes who spend more time attempting to physically hold and control their opponent will exert more physical effort than those who only attempt to strike, whilst amongst striking athletes, those who are permitted to strike with more areas of the body use most effort. As MMA is a combination of all of these techniques, the current study will determine whether MMA competitor's W:R is more similar to a pure striking sport or a pure grappling sport.

Del Vecchio et al. (2011) conducted a TMA of 52 MMA competitors in Brazil and reported a W:R of between 1:2 and 1:4 It was also noted that time spent in groundwork of low intensity was longer in the second round than in the third round. These findings were reached by categorising the periods of the contest as standing high intensity, standing low intensity, groundwork high intensity or groundwork low intensity. What was not defined is what was actually classed as "high intensity" or "low intensity", especially when the bout is conducted on the ground, where half of the matches in question were ended. Nor does it allow any analysis of which techniques were favoured the most or what affect these had on the workload of the participants.

Bridge et al. (2011) attempted to address this limitation of TMA within national level taekwondo tournaments and determined that the amount, intensity and frequency of activity varied between weight classes. The results showed that there were more kicks thrown by the +84 kg heavyweight (HW) participants (33 ± 6) than both the 67 kg featherweight (FW) (29 ± 7) and 54 kg finweight (FinW) (32 ± 8) categories, although these differences were not statistically significant. However, the main discussion point of Bridge et al. (2011) is the separation of the different phases of combat in taekwondo. The phases of combat were split into fighting activity (the competitors engaged in attempting to strike), preparatory movement (any movement leading to an attempted strike), non-preparatory time (the competitors moving around the ring, not engaging or attempting to engage) and stoppage time (referee separation, stoppage, knockdown or foul stoppage). This shows a good example of how to further break down the movement of a combat sport in a way that will allow more analysis and more detailed results. Such detailed TMA has not been performed in MMA to the knowledge of the researcher, so use of this method could provide a greater insight into what movements were performed and at which stage of the bout the participants are experiencing the greater load.

2.2.9 Limitations of Time Motion Analysis

A limitation of TMA is that it cannot directly measure differences in intensity for different performers, it can only allow a prediction or estimation as without an understanding of the participant's individual physical capabilities, the true energetics involved are unknown. Similarly, it cannot be used to explain why these changes in intensity take place as it does not detail whether the performer has altered their movements due to fatigue or choice (Lovell and Abt, 2013). However, the biggest limitation of TMA is that it is a more qualitative method of assessment, which could yield different results from different assessors who may differ in opinion of when a particular movement or technique has begun or ended, particularly when there is a lack of quantification of what is high and low intensity. To give TMA data an acceptable level of usefulness in scientific research, it should be used in conjunction with other validated methods of measuring workload.

2.2.10 Global Positioning Systems

Whilst the methods discussed so far can allow an indication of physiological demand and intensity of performance, they are not able to directly evaluate the external load of a particular event. Global positioning sytems (GPS) have been used to achieve this depth of analysis though the evaluation of the ambulatory movement of humans since the mid 1990s as they provide a lightweight method of measuring motion, acceleration, deceleration and effort. This is done via a wearable GPS unit being in communication with at least four Earth-orbiting satellites which then triangulate the position of the unit's wearer, using this information to calculate their displacement and velocity (Aughey, 2011). GPS has since been used to assess the success of training programmes, rehabilitation and in-game performance across a number of team and individual sports (women's football maximum speed travelled = 21.8 ± 2.3 $km.h^{-1}$, Vescovi, 2012; junior cricket fast bowlers cover a median distance of 7049 m in competition, McNamara et al., 2013; rugby union wingers average distance covered per minute = 78.2 $m.min^{-1}$, Reid et al., 2013).

2.2.11 Validity and Reliability of GPS Systems

There are several validated GPS units currently in use in sports research. An example of one is the Catapult Minimax x3 (Catapult Innovations, Melbourne, Australia), which is a 5 Hz GPS with a 100 Hz tri-axial accelerometer and gyroscope (Catapult Sports, 2012a). Originally designed for rowers, the Minimax x3's GPS is currently in use in elite level organisations across several sports (Catapult Sports, 2013). The recorded data is displayed as directional lines on a graphical output showing movements and velocities of individual players (Catapult Sports, 2012b). Several studies have shown that the Minimax x3 GPS is valid in tracking participant movement (r = 0.998) (Edgecomb and Norton, 2006), and reliable in tracking distance covered (CV = 4%) (Randers et al., 2010) and acceleration and deceleration (CV = 1.9 – 6.0%) (Varley et al., 2011) in Australian rules football, football and sprinting, respectively. It has also been shown to have inter-unit and intra-unit reliability in the field using Australian Rules Football players during competitive league matches where the units were shown to be capable of detecting differences in ambulatory physical activity, such as changes in accelerations from walking to running to sprinting (CV = 1.9%) (Boyd et al., 2011). Similarly, Varley et al. (2011) showed that the Minimax x3 has high validity (r = 0.98) and reliability (r = 0.98) in detecting and measuring changes in velocity, acceleration and deceleration during straight line running and suggested that the Minimax x3 could detect changes in performance in team sports. Despite the findings that there is some error in the accuracy of changes of velocity, it is accurate in the determination of whether or not an acceleration or deceleration has taken place (Varley et al., 2011).

The Minimax x3 has also been shown to be valid and reliable in measuring distance (r = .997) and velocity (Inter-unit CV = 2.03%) in non-linear cycling (Hurst and Sinclair, 2013). Although Gray et al. (2010) demonstrate that data generated by GPS units on repeated occasions was less concordant ($p < 0.05$), the level of agreement remained high (Intra-unit CV = 2.66%) during different velocities and non-linear movements. Due to this reliability and validity, several studies have used the Minimax x3 to assess performance across several invasion sports in order to inform the training and preparation methods within these sports (DeMartini et al., 2011; Johnston et al., 2012; Johnston et al., 2013).

Whilst each of the above named studies support the use of the GPS capabilities of the Minimax x3 in several sports, it has its limitations, as whilst it can show distances covered and how fast they were covered, GPS does not show how they were covered in terms of changes in intensity or contact with other performers. Another issue is that due to MMA being an indoor sport, the Minimax x3 units would not be able to access the satellite signal due to the lack of a direct line of sight. Whilst a newer version of the Minimax does support indoor use (Catapult Sports, 2014), it was decided that this function would be less suited to MMA, as success in this sport is not dependant on distance covered, or the control of a particular area of the competition surface. Equally, MMA does not utilise running movements in either linear or non-linear directions. However, as the Minimax x3 does include a tri-axial accelerometer, this may provide a more useful and useable means of determining MMA workloads in an indoor environment.

2.2.12 Accelerometry and Workload Assessment

Wixted et al. (2007) outlined the introduction of accelerometers for measuring the energetics of ambulatory movements and daily life. However, there has also been an increase in the study of accelerometry usage for analysing sporting movements by recording how often and how rapidly a performer or an object moves and changes direction in the three cardinal planes (X, Y and Z) in units of g. The Minimax x3 can also combine these measurements into two variables: player load (PL) to measure instantaneous load of a single movement or incident (determined by the rate of change of acceleration) and accumulated player load (PL_{ACC}) which measures the total increase in load over a period of time i.e., a full performance. Both PL and PL_{ACC} are displayed as arbitrary units (au). The unit is mounted in a harness on the participant's mid-thoracic vertebrae so is sensitive to any movement of the torso (Catapult Sports, 2012a).

2.2.13 Validity and Reliability of Accelerometry

Kelly et al. (2012) argued that accelerometry is an under-utilised tool in contact sports and assessed the validity and reliability of the SPI-Pro GPS (GPSports, Canberra, Australia) accelerometer unit's ability to detect collisions automatically in rugby. The units were found to have $r = 0.958$ over a total of 70 separate tackles in full competition with 5 false positives. This was, however, down to a post-hoc tackle-detection algorithm applied to the data provided by the unit. This involves manually labelling on the video-synched data when a tackle has been deemed to occur, and then using a series of signal filters and calculations to find other occurrences of the same or similar data trace. Without this algorithm, the GPSports unit's accelerometer is not valid at registering body-to-body contact or differentiating contact from ambulatory movement. Neither do Kelly et al. (2012) provide any information on the accuracy of the units in measuring the load caused by the contact. This is in contrast to the Minimax x3 which shows strong correlation between the collisions recorded by the Minimax x3 and video coding (r= .96, p< 0.01) in rugby league and rugby union and has been suggested to be the only currently available accelerometer unit capable of doing this (Gabbett, 2013).

The Minimax x3 accelerometer also displayed acceptable inter- and intra-unit reliability in laboratory settings (CV = 0.91 to 1.05%), demonstrated by attaching the units to hydraulic universal testing machines whilst reporting that the units have reliability in the field using Australian football players (CV = 1.9%) (Boyd et al., 2011). Montgomery et al. (2010) used the Minimax x3 to determine that the differences in PL_{ACC} between drills and competition in elite under-21's basketball have moderately different intensities and demands (1.17 ± 0.65 % increase in matches) and a match PL_{ACC} of 279 ± 58 au. These findings could have relevance to MMA competitors as basketball requires lateral movement more than straight line running whilst also being an intermittent sport.

A study that demonstrates the increased effort and movement intensity involved in grappling and body-to-body impact is provided by Gabbett et al. (2012a), who used the Minimax x3 accelerometer function to show that in small sided games of rugby league, the games that had a large proportion of tackles, scrummages and attempted takedowns had a significantly higher number of high intensity efforts and maximal accelerations (2.1 ± 0.2 efforts vs. 0.2 ± 0.1 efforts, p < 0.05). It was also noted that these differences did not affect the volume of successful skill applications and suggested that intermittent wrestling drills form part of all rugby league training, thus demonstrating that accelerometer data is a useful tool in designing training protocols. This use is mirrored by Wells and Hattersley (2013) who used the PL_{ACC} experienced by football players in training drills and training matches to ascertain the intensity of each session and inform the planning of future periodisation programmes. Young et al. (2012) also used the Minimax x3 and PL_{ACC} to assess the effects of performance on muscle damage by demonstrating that Australian rules football players who produced 42% (p. <0.05) more PL_{ACC} also had 119% (p. <0.01) greater creatine kinase levels after competitive matches.

In terms of combat sports, accelerometers have been used to assess differences in forces applied in kicking techniques in different martial arts (O'Sullivan et al., 2009; Witte, 2013) or to assess the impact of punches to and acceleration of the head during boxing competitions (Beckwith et al., 2007). None of these, however, use accelerometers to assess the athlete's workload or performance. Nor has there been any scientifically recorded attempt to apply accelerometers to MMA.

2.2.14 Placement of Accelerometer Units

Nien et al. (2004) demonstrated a design for using accelerometers built into a kicking and punching dummy for two groups of taekwondo competitors to assess their speed, reaction time and power. The results showed that even though reaction time for the higher level group was only 0.01 seconds faster (0.175 ± 0.025 s compared to 0.182 ± 0.009 s for the lower level group), the amount of force produced was markedly higher (71.83 ± 13.78 g for the higher level group and 43.01 ± 9.34 g for the lower level group). Nien et al. (2004) conclude that the speed at which the strike commences does not necessarily translate into a harder impact. Other factors must come into play, such as technique and body weight which is supported by Turner (2009) who states that the ability of a combat sports participant to produce force and power in their striking movements varies widely depending on their experience and mastery of technique. However, as the accelerometer used by Nien et al. (2004) was placed within the punch/kick dummy, the movement pattern and individual differences cannot be specifically highlighted, nor can it provide a tool for field based assessments, whereas a body worn accelerometer may be able to do this.

Trost et al. (2005) discussed the use of body worn accelerometers and highlighted the importance of choosing the optimum position on the body in relation to the task undertaken, finding that positioning on the lower back was the strongest predictor of energy expenditure (r = 0.92 – 0.97) with placement on the ankles and wrist being more affected by gravity. It was also noted that whilst there is an increase in reliability of measurement of energy expenditure from using multiple units at once, they are only slight (< 0.20 kcal.min^{-1}) whilst often causing a drop in performance due to the restriction of movement placed on the subject, a conclusion supported by Melanson and Freedson (1995) and Swartz et al. (2000).

Montgomery et al. (2010) placed the Minimax x3 on the lumbosacral region of elite junior basketball players to assess the different physiological demands between training and competition play as this position was deemed closest to the participant's centre of gravity. This was in response to the fact that the placing of the unit on the upper posterior torso can lead to the recording of a 'false acceleration' (Catapult Sports, 2012b), where an acceleration that did not occur, or occurred but not to that magnitude, is recorded due to excessive or rapid forward flexion of the trunk without actual movement taking place, thus potentially affecting the reliability of the results. This view is supported by Waldron et al. (2011) who argued that the further up the spine the unit is placed, the more 'noise' is registered by the unit. This was determined, however, using the GPSport's unit and harness, which Waldron et al.

(2011) admit does not hold the unit securely in place and so allows for more variation in accelerations recorded. There have been no such conclusions regarding the Minimax x3 harness and in addition, placement of the unit on the lumbar spine of an MMA participant is creating the risk of injury and movement alteration, especially during grounded or grappling sections of a bout, as a competitor is likely to spend some portion of a bout with their lumber spine in contact with the ground or the side of the cage, thus making this area unsuitable, if not dangerous, for placement of an accelerometer. To this end, mounting of the unit on the participant's upper posterior torso can be deemed the safest and most ergonomic solution.

The key limitation of using accelerometry and in particular the Minimax x3 unit, is that there is no existing research into the reliability of the system in measuring the workload demands of MMA training or simulated competition. Equally, as there has been no use of body worn accelerometry in combat sports, it is unknown whether any useful information or data can be gained from using such a method.

2.3 Workload Assessment Methods

In reviewing the available literature and evaluating the existing workload testing methods, it was concluded that the most practical and applicable methods of assessing the workload demands of training and competing in MMA were the Minimax x3 accelerometer used alongside video based TMA and supplemented by lactate sampling. These methods were chosen as they would allow field based testing to take place without placing unrealistic restrictions on movement or technique, therefore allowing for the greatest amount of ecological validity, which is to make experimental testing as applicable to the participant's real world environment as possible (Schmuckler, 2001).

CHAPTER 3

STUDY ONE: RELIABILITY OF THE MINIMAX X3 FOR MEASURING THE WORKLOAD OF MMA SPECIFIC TECHNIQUES

3.1 Introduction

As detailed in Chapter 2, there is currently limited knowledge available regarding the workloads of specific MMA movements either in competition or in training (Amtmann et al., 2008; Amtmann, 2010; Schick et al., 2010; Del Vecchio et al., 2011). Equally, there is no testing method that has been shown to have reliability in the measuring of this variable for MMA participants. There are also limited studies that attempt to determine the individual differences in movements and technique amongst combat sports participants (Filimonov et al., 1985; Turner, 2009). As such, it is currently unknown which movements produce the most load and therefore exertion, or how much variation there is in techniques used by different levels of performer. One of the methods that was chosen to assess the workload demands of the sport was accelerometry, measured using the Minimax x3, which has been shown to be reliable in measuring the movements and loads in several sports including rugby (Gabbett et al., 2012b), football (Casamichana et al., 2013) and Australian rules football (Mooney et al., 2013).

As the Minimax x3 is able to measure overall workload intensity whilst also displaying magnitudes of accelerations in the three cardinal planes, it was theorised that the Minimax x3 could be a valuable resource for the MMA competitor and coach to determine workload intensities and assess skill development. A severe limitation of utilising this system within MMA, however, is that there has been no peer-reviewed analysis of the Minimax x3's reliability or suitability for the measurement of workload in any combat sport. In order for the Minimax x3 to be an acceptable tool for use in

MMA research, it must be shown to have reliability in the measurement of the movements, accelerations and loads experienced by the participants.

3.1.1 Aims

Due to the lack of research on MMA and the workload demands required for successful performance, the aims of the current study were to:

1. Determine the reliability of the Catapult Minimax x3 for measuring the loads of MMA specific movements
2. Determine the physical loads of isolated MMA training movements

3.1.2 Hypotheses

Based on previous research conducted using accelerometry in other contact sports, it was hypothesised that the Catapult Minimax x3 would provide a reliable tool for assessing the load during repeated MMA sport specific movements. The null hypothesis was that the Catapult Minimax x3 would not provide a reliable tool for assessing the load during repeated MMA sport specific movements.

As data on MMA specific workloads is currently unavailable, it was difficult to make hypotheses based on previous research. As such, the second aim of this study was to provide descriptive data on the workload demands of isolated movement in MMA that may inform future research.

3.2 Methods

3.2.1 Participants

A group of male trained MMA competitors (n = 8, age = 25.5 ± 4.5 yrs, height = 176.4 ± 9.4 cm, mass = 74.9 ± 13.1 kg) who were all right hand dominant agreed to take part in the study and provided verbal and written informed consent prior to testing (Appendix A). Each participant was assigned a unique number for identification purposes upon completion of a PAR-Q, (Appendix B). The participants had all taken part in at least 4 professional or semi-professional MMA bouts at either regional or national standard and one of their bouts must have been in the 6 months prior to the day of testing. This was to ensure a high enough level of currently competitive participant to provide meaningful results. Prospective participants who did not meet these criteria were turned down, sacrificing a larger sample size for a better quality and more consistent skill level. All participants were allowed a familiarisation session prior to testing which consisted of a discussion and description about what would be involved in the testing and what would be physically required of them as well as a discussion about the use of their personal data. All participants were also instructed to refrain from alcohol for two days before and to eat a breakfast that would be typical for a competition day. Testing took place at a privately owned MMA training facility. Ethical approval was granted by the University of Central Lancashire Research Ethics Sub-Committee.

3.2.2 Materials

Participant's stature was measured to within 0.5 cm using a Leicester Height Measure stadiometer (Seca, Birmingham, UK) and their mass was measured to the nearest 0.5 kg using a standard manual scale (Seca, Birmingham,UK). Each participant was required to wear standard MMA competition shorts, a groin protector, gum shield and a t-shirt or rash guard. The participants were fitted with a single

Minimax x3 accelerometer each (8 units in total for the group) which was marked with their unique number and placed in a support harness on the participant's back around the T3-4 vertebrae. Whilst other positions on the body were considered, this was deemed the most practical placement to record all the different movements required of an MMA competitor whilst also ensuring the participant's safety during the grappling phases of testing and is also in keeping with the design of the Minimax x3 unit and harness. The harness was then secured in place using duct tape around the participant's torso. Each Minimax x3 was calibrated prior to testing using the protocol set down by Catapult Sports (2012b). Standard 45 kg heavy punch/kick bags were used during the isolation strikes and a padded floor area 5 m^2 was used for the isolated takedown testing. Each participant was also fitted with competition standard 142 gram MMA gloves (Figure 1.1). All isolated techniques were recorded using a tripod based Samsung HMX-F80 camcorder (Samsung, Seoul, South Korea). These recordings were imported into Kinovea 0.8.21 (Joan Charmont, France) video analysis software where still photos of key points during the techniques were created and technique angles were measured as Kinovea has been shown to be reliable for 2D movement measurement (Bowerman et al., 2013).

Figure 1.1 – Competition Standard 142 gram MMA gloves

3.2.3 Minimax x3 Variables

In pilot testing conducted prior to the commencement of the current study, it was decided that the most appropriate variables to record for the assessment of the workload demands of MMA competitors would be PL, PL_{ACC}. These were chosen as they allow measurement of instantaneous load of individual techniques whilst also the load of the entire performance. At the same time, the magnitude of accelerations in the three cardinal planes (X – left/right movement, Y – forwards/backwards movement and Z – up/down movement) were chosen as these could highlight differences in technique between participants whilst also allowing the assessment of which plane is most contributing to movement and workload demands.

3.2.4 Protocols

Prior to testing the participants were lead through a 10 minute warm up, consisting of a pulse raiser (10 lengths of the gym jogging), dynamic stretching and shadow kickboxing.

3.2.4.1 Isolation Strikes

Each participant stood in front of a 45 kg heavy bag in their natural fighting stance and their accelerometer was switched on. Each time the accelerometer was switched on, the participants were required to stand still in a neutral position until they were instructed to complete the following strikes on command from the researcher: 5 jabs (participant punches with their lead hand), 5 crosses (participant punches with their rear hand), 5 left hooks (participant punches in a transverse plane at head height with their lead hand), 5 right hooks (participant punches in a transverse plane at head height with their rear hand), 10 leg kicks (participant turning kicks the bag at their own thigh height, 5 left then 5 right), 10 body kicks (participant turning kicks the bag at their own body height, 5 left then 5 right) and 10 high kicks (participant turning kicks the bag at their own head height, or as high as they are able, 5 left then 5 right). All punches were aimed at the participant's own head height. Multiple occurrences of each technique were used to allow the determination of an average reading for each participant to be achieved, thus allowing for the effects of any technique inconsistencies to be negated.

The participants were given a 2 second rest between each strike and in between each set of five strikes the participants were instructed to stand still in a neutral position for 30 seconds to allow a clear distinction to be made between different sets of data during analysis. This time frame was chosen as this length of time resting allows most if not all of the person's phosphocreatine stores to be replenished, allowing near maximal exertion to continue (Maughan and Gleeson, 2004). In between every other set of strikes, the accelerometers were switched off and straight back on again. This was to allow clear distinctions to be made between each set of strikes when analysing the accelerometer data.

Figure 1.2 – Full mount position

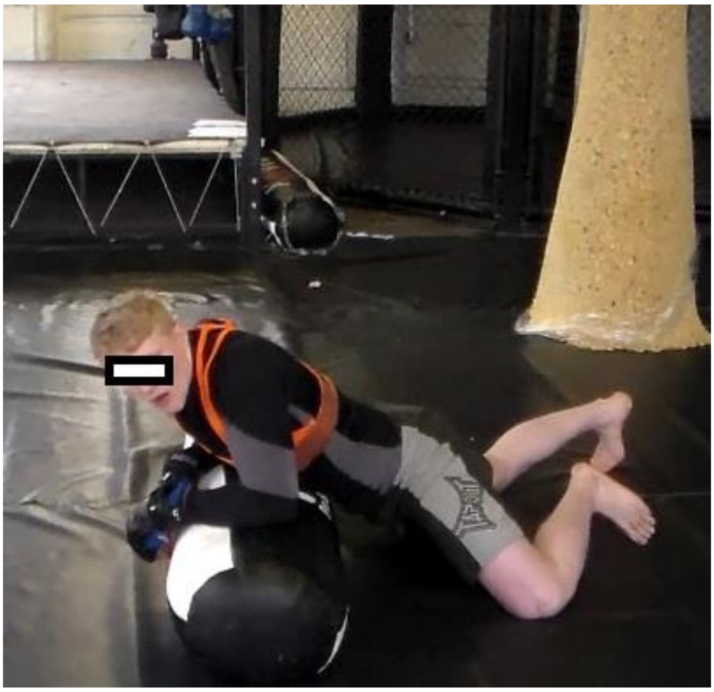


Figure 1.3 – Side control position

A 45 kg heavy bag was then laid flat on the ground and each participant in turn sat on the bag in a full mount position (Figure 1.2) and was then instructed to complete the following strikes on command: 5 left punches, 5 right punches, 5 left elbows, 5 right elbows. The participants were then asked to move into a side control position (Figure 1.3) and complete the following strikes on command: 5 left knees to the 'body', 5 right knees to the 'body'.

3.2.4.2 Isolation Takedowns

To assess the isolated accelerations of the wrestling and takedown movements of MMA, the participants were paired with another participant who was approximately the same weight on the day of testing. Both participants then took it in turns to complete the following takedowns (TD) on command: 5 double leg takedowns (Figure 1.4) and 5 single leg takedowns (Figure 1.5). Each takedown was a complete technique in that the offensive participant continued until their partner was flat on the ground. Each participant completed all 10 takedowns before the accelerometers were switched off and on again and the next participant completed their set of TD.

Figure 1.4 - Double leg takedown

Figure 1.5 - Single leg takedown

The reasoning behind not randomising the order of the isolated techniques was based on conducting study one as a strictly lab based test. Although repeating the same technique five times in succession could cause a small amount of fatigue and possibly affect the results, it is currently unknown which techniques are likely to cause fatigue and to which extent. Therefore it was decided that randomising the order of strikes could of caused some techniques to be performed with a greater amount of fatigue than others, which could affect the results greater. For this reason it was instead decided to have uniformed rest periods to ensure the greatest chance of gaining the true values.

3.2.5 Raw Data Organisation

The data collected from these tests was used firstly to determine the reliability of the Minimax x3 and secondly to determine the loads of each technique used. The accelerometer data was downloaded from the Minimax x3 units to Catapult Sprint 5.0.9 (Catapult Innovations, Melbourne, Australia). An example of how each individual technique was selected from the resultant graph can be seen in Figure 1.6. For each instance of the isolation strikes and takedowns, the peak values for X, Y, Z, PL and PL_{ACC} were exported into Microsoft Office Excel 2007 (Microsoft, Redmond, USA). For the takedowns, the above variables were recorded for both the participant performing the takedown (TD offensive) and the participant being taken down (TD defensive). Once all five instances of each technique were identified and recorded, the mean ± SD was calculated for the group and for each of the techniques.

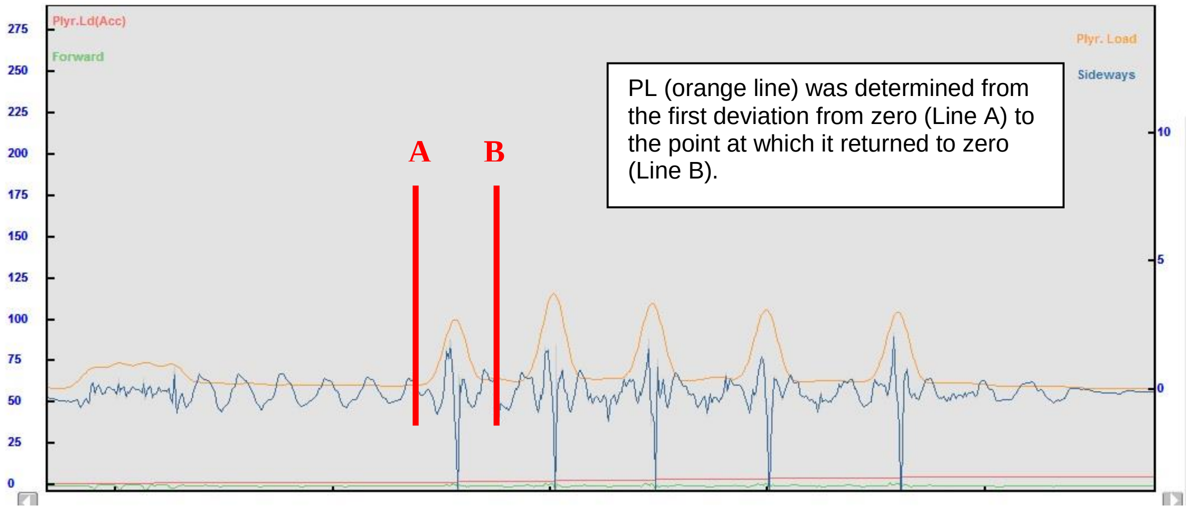


Figure 1.6 – Output showing how each separate technique was identified

During the isolated takedowns, the Minimax x3 units recorded two separate accelerations for the participants performing the takedown (Figure 1.7). The first acceleration (Acc1) indicating the participant moving to make contact with their partner, and the second (Acc2) represented the actual takedown. For the analysis of the data, Acc1 and Acc2 were recorded separately.

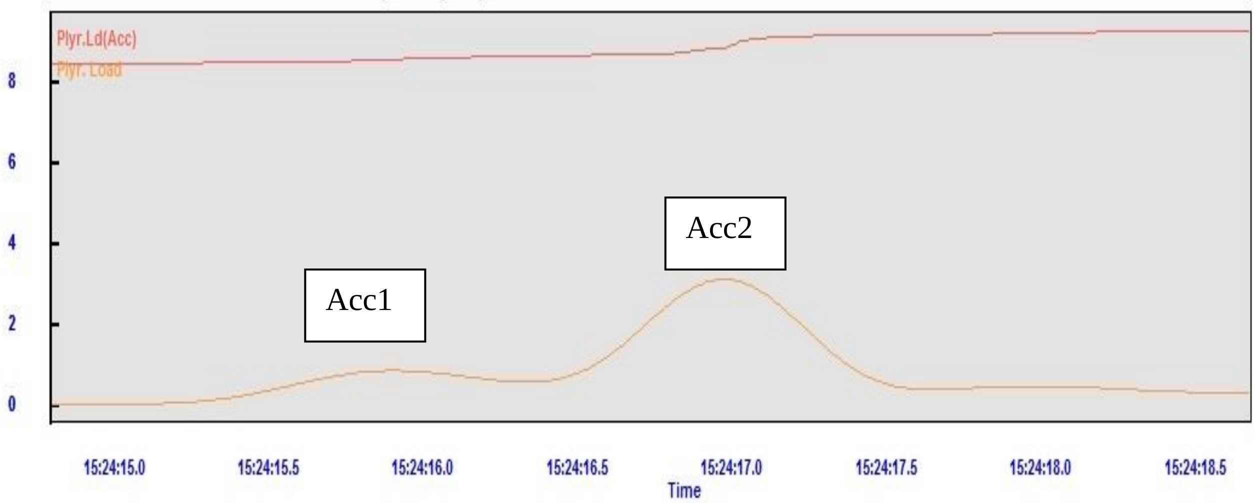


Figure 1.7 - Output showing the two separate peaks of PL during an isolated takedown

3.2.6 Statistical Analysis

3.2.6.1 Assessment of Reliability

Each of the following statistical procedures was performed using SPSS 20 (IBM, New York, USA). In order to ensure that the data for PL and PL_{ACC} was normally distributed, a Shapiro-Wilk test was performed for each variable ($p \geq .05$).

To determine the intra-unit reliability of the Minimax x3, two-way mixed intraclass correlation coefficients (ICC) were calculated using a reliability threshold of ≥ .700 for the PL and PL_{ACC}. The upper bound and lower bound ICC values were also calculated for each technique to allow evaluation of the spread of the results. A ≥ .700 reliability threshold was decided upon due to ICC being based on Cronbach's alpha, in which an alpha of ≥ .700 is used to indicate a satisfactory level of reliability (Nunnally and Berstein, 1994). During testing, some of the Minimax x3 units malfunctioned, either recording bad data or no data for a series of strikes. This may have been caused by the unit being inadvertently switched off due to contact during one of the techniques. Occasions when this occurred are identified with a ‡ in the results tables. In each instance, one unit malfunctioned, meaning these values were calculated from 7 samples.

3.2.6.2 Determination of Loads for Isolation Techniques

Descriptive statistics were determined for PL, PL_{ACC}, X, Y and Z with physical load data being reported as the mean ± SD of all five occurrences for each technique. In addition, differences between dominant and non-dominant sided strikes were analysed through paired samples t-tests with a significance level of $p \leq .05$ for each technique for PL. Data was entered in order of technique occurrence.

3.3 Results

All of the values for PL and PL_{ACC} were found to be normally distributed according to the Shapiro-Wilk test ($p \geq .05$). The p values of each technique for both variables can be viewed in Appendix C.

3.3.1 Instantaneous Player Load Reliability

3.3.1.1 Isolation Standing Strikes

As shown in Table 1.1, the PL for the standing strikes had a high reliability for each strike when calculated using ICC.

Table 1.1 – ICC of Isolated Standing Strikes.

Strike	ICC	Lower Bound	Upper Bound
Jab	.913	.759	.980
Cross	.942	.839	.987
Left Hook ‡	.834	.540	.962
Right Hook ‡	.840	.521	.969
Left Leg Kick	.933	.813	.985
Right Leg Kick	.918	.771	.981
Left Body Kick ‡	.966	.899	.993
Right Body Kick ‡	.822	.467	.965
Left High Kick	.970	.917	.993
Right High Kick ‡	.853	.559	.971

‡ indicates results were calculated from seven sets of data due to accelerometer errors

All standing strikes had a high ICC, however, four of the strikes lower bound values fell below .700, but did not affect reliability.

3.3.1.2 Isolation Ground Strikes

The ICC for the ground strikes PL are shown in Table 1.2. Whilst the punch and elbow strikes had high reliability, the knee strikes showed low reliability with very low lower bound values.

Table 1.2 – ICC of Isolated Ground Strikes.

Strike	ICC	Lower Bound	Upper Bound
Left Punch	.892	.700	.975
Right Punch	.906	.739	.979
Left Elbow	.990	.971	.998
Right Elbow	.923	.787	.982
Left Knee	.476	-.457	.880
Right Knee	.667	.101	.926

3.3.1.3 Isolation Takedowns

The ICC for both TD offensive and TD defensive for the double leg and single leg takedowns revealed high reliability.

Table 1.3 – ICC of Isolated Takedowns.

Strike	ICC	Lower Bound	Upper Bound
Double Leg TD Offensive ‡	.837	.512	.968
Double Leg TD Defensive	.960	.889	.991
Single Leg TD Offensive ‡	.700	.102	.941
Single Leg TD Defensive	.958	.882	.990

‡ indicates results were calculated from seven sets of data due to accelerometer errors

The only outlying technique was the single leg TD offensive. This has been highly affected by the lower bound value, but this technique still showed reliability for PL.

3.3.2 Accumulated Player Load Reliability

3.3.2.1 Isolation Standing Strikes

Each strike PL_{ACC} demonstrated a statistically high reliability. However, seven different strike's lower bound values fell below the .700 threshold.

Table 1.4 – ICC of Standing Strikes PL_{ACC}

Strike	ICC	Lower Bound	Upper Bound
Jab	.855	.598	.967
Cross	.947	.853	.988
Left Hook ‡	.895	.684	.979
Right Hook ‡	.890	.670	.978
Left Leg Kick	.886	.682	.974
Right Leg Kick	.794	.428	.953
Left Body Kick ‡	.854	.564	.972
Right Body Kick ‡	.909	.726	.982
Left High Kick	.940	.832	.986
Right High Kick ‡	.893	.680	.979

‡ indicates results were calculated from seven sets of data due to accelerometer errors

3.3.2.2 Isolation Ground Strikes

All ground strikes had high reliability (Table 1.5). Both the left knee and the right knee recorded lower bound values that fall below the reliability threshold, but still had high reliability. The right punch also revealed a sub-threshold lower bound value but was still reliable overall.

Table 1.5 – ICC of Ground Strikes PL_{ACC}

Strike	ICC	Lower Bound	Upper Bound
Left Punch	.913	.758	.980
Right Punch	.887	.686	.974
Left Elbow	.984	.957	.996
Right Elbow	.970	.917	.993
Left Knee	.839	.552	.963
Right Knee	.845	.568	.965

3.3.2.3 Isolation Takedowns

Table 1.6 shows the ICC values for the single leg and double leg takedowns for both TD offensive and defensive.

Table 1.6 – ICC for Isolated Takedowns

Technique	ICC	Lower Bound	Upper Bound
Double Leg TD Offensive ‡	.868	.606	.974
Double Leg TD Defensive	.871	.641	.971
Single Leg TD Offensive ‡	.882	.647	.977
Single Leg TD Defensive	.920	.778	.982

‡ indicates results were calculated from seven sets of data due to accelerometer errors

The Minimax x3 demonstrated high reliability for recording the PL_{ACC} for both the participant attempting the takedown and the participant being taken down despite three of the four techniques having lower bound values below the threshold.

3.3.3 Workload Demands During Isolated MMA Training Movements

3.3.3.1 Standing Isolation Strikes

The mean ± SD accelerometer load values for the standing isolation strikes are shown in Table 1.7.

Table 1.7 – Mean Accelerometer Values for the Standing Isolation Strikes

Strike	PL(au)	PL_{ACC}(au)	X(g)	Y(g)	Z(g)
Jab	2.88 ± 0.31	0.58 ± 0.08	1.88 ± 0.35	1.22 ± 0.39	3.08 ± 0.76
Cross	3.40 ± 0.53	0.67 ± 0.11	6.42 ± 0.38	1.89 ± 0.84	2.89 ± 0.59
Left Hook ‡	3.21 ± 0.33	0.67 ± 0.09	2.66 ± 0.81	1.52 ± 0.37	3.03 ± 0.30
Right Hook ‡	3.19 ± 0.51	0.61 ± 0.09	5.42 ± 1.30	1.70 ± 0.65	3.24 ± 0.43
Left Leg Kick	2.38 ± 0.57	0.64 ± 0.12	2.12 ± 0.81	0.99 ± 0.54	3.70 ± 0.80
Right Leg Kick	2.19 ± 0.59	0.59 ± 0.10	2.45 ± 1.30	1.48 ± 0.69	3.09 ± 0.61
Left Body Kick ‡	2.34 ± 0.71	0.69 ± 0.12	2.23 ± 0.56	1.06 ± 0.58	4.05 ± 1.14
Right Body Kick ‡	2.25 ± 0.29	0.67 ± 0.13	2.48 ± 0.63	1.35 ± 0.29	3.38 ± 0.64
Left High Kick	1.88 ± 0.66	0.58 ± 0.16	2.00 ± 0.51	1.01 ± 0.82	3.09 ± 1.02
Right High Kick ‡	2.10 ± 0.29	0.62 ± 0.11	2.02 ± 0.61	1.40 ± 0.35	3.31 ± 0.52

‡ indicates results were calculated from seven sets of data due to accelerometer errors

The highest mean PL of the individual standing strikes was produced by the cross whereas the lowest mean PL was produced by the left high kick. The highest mean PL_{ACC} value was produced by the left body kick with the lowest being the jab and the left high kick, respectively. For the Y variable, the peak value was cross and the low value was left leg kick. When looking at X, it can clearly be seen that cross and right hook involved far more sideways movement than the other strikes (next highest X value is left hook) whilst jab recorded the least sideways movement. Left body kick had the peak Z value whilst cross had the lowest.

3.3.3.2 Ground Isolation Strikes

As can be seen in Table 1.8, right elbow recorded the highest values for each variable with the exception of Z where right punch had the highest recorded mean value. Left knee and right knee recorded the lowest PL and PL_{ACC}. Left knee also resulted in the lowest Y and Z values whilst right knee recorded the lowest X value.

Table 1.8 - Mean Accelerometer Values for the Ground Isolation Strikes

Strike	PL(au)	PL_{ACC}(au)	X(g)	Y(g)	Z(g)
Left Punch	2.95 ± 0.45	0.54 ± 0.09	2.96 ± 0.95	0.98 ± 0.47	2.25 ± 0.86
Right Punch	3.05 ± 0.42	0.55 ± 0.09	6.03 ± 0.73	1.29 ± 0.71	2.54 ± 0.72
Left Elbow	3.52 ± 0.98	0.61 ± 0.17	3.26 ± 1.61	1.77 ± 0.94	2.33 ± 1.62
Right Elbow	3.89 ± 0.82	0.65 ± 0.15	6.56 ± 0.90	2.45 ± 1.96	2.45 ± 1.27
Left Knee	1.30 ± 0.20	0.37 ± 0.09	1.27 ± 0.36	0.40 ± 0.25	1.16 ± 0.45
Right Knee	1.30 ± 0.16	0.37 ± 0.06	0.99 ± 0.31	0.48 ± 0.29	1.42 ± 0.51

3.3.3.3 Double Leg Takedowns

Table 1.9 shows the mean ± SD acceleration values for double leg TD offensive and double leg TD defensive, separated into Acc One and Acc Two (representing the two separate stages of the technique).

Table 1.9 – Mean Accelerometer Values for the Double Leg TD Offensive Acc One and Acc Two

Technique	PL(au)	PL_{ACC}(au)	X(g)	Y(g)	Z(g)
Double Leg TD Offensive Acc One ‡	2.75 ± 0.87	0.96 ± 0.24	1.99 ± 0.69	0.85 ± 0.46	3.42 ± 0.95
Double Leg TD Offensive Acc Two ‡	2.54 ± 0.77	1.36 ± 0.40	1.80 ± 0.97	1.14 ± 1.60	2.13 ± 0.90
Double Leg TD Defensive Acc One	1.79 ± 1.60	0.58 ± 0.31	1.59 ± 1.81	0.87 ± 2.01	2.33 ± 1.83
Double Leg TD Defensive Acc Two	2.90 ± 1.46	1.12 ± 0.38	2.37 ± 1.65	3.12 ± 2.01	3.70 ± 1.54

‡ indicates results were calculated from seven sets of data due to accelerometer errors

During double leg TD testing, Acc One produced the highest PL whereas Acc Two resulted in higher PL_{ACC}. Acc One also resulted in a larger Z output than Acc Two. For the double leg TD defensive, Acc Two resulted in higher values across all variables, including PL.

3.3.3.4 Single Leg Takedowns

Table 1.10 shows the mean ± SD acceleration values for single leg TD offensive and single leg TD defensive, separated into Acc One and Acc Two.

Table 1.10 - Mean Accelerometer Values for the Single Leg TD Acc One and Acc Two

Technique	PL(au)	PL_{ACC}(au)	X(g)	Y(g)	Z(g)
Single Leg TD Offensive Acc One ‡	2.18 ± 0.66	0.86 ± 0.27	2.30 ± 0.79	0.87 ± 0.58	2.57 ± 0.92
Single Leg TD Offensive Acc Two ‡	2.28 ± 0.89	1.19 ± 0.46	1.98 ± 0.82	1.14 ± 1.99	1.87 ± 1.08
Single Leg TD Defensive Acc One	1.10 ± 0.59	0.52 ± 0.23	1.09 ± 0.23	0.19 ± 0.34	1.66 ± 0.24
Single Leg TD Defensive Acc Two	3.42 ± 1.32	1.09 ± 0.17	3.73 ± 1.69	4.36 ± 2.08	3.46 ± 1.12

‡ indicates results were calculated from seven sets of data due to accelerometer errors

For both the single leg TD offensive and defensive, PL_{ACC} was higher for Acc Two than Acc One. Similarly, the values for PL and Y increase from Acc One to Acc Two for both the TD offensive and the defensive. However, X and Z both decrease for the TD offensive whereas both variables increase for the TD defensive.

3.3.4 Comparisons of Left Sided and Right Sided Loads

In terms of PL, the only isolated strike that had a statistically significant difference in the load between left and right sides were the ground strikes ($t_{(14)} = -4.201$; $p = .001$). Neither standing punches ($t_{(14)} = -1.30$; $p > .05$) nor kicks ($t_{(21)} = .567$; $p > .05$) showed any significant difference, neither did grounded knee strikes ($t_{(7)} = -.1$; $p > .05$). For the PL_{ACC} values, there were no significant differences between any of the categories with regards to dominant and non-dominant sides of the body.

3.4 Discussion

This study is the first piece of research that applies wearable accelerometry technology to the specific movements and techniques of MMA. It is also the first study to assess the use of this technology with isolated sports techniques as other studies have tended to focus on complete performances or full training sessions (Gabbett et al., 2012b; Johnston et al., 2013). Of the two aims set in place in Chapter 4.1.1, the first was to determine the reliability of the Catapult Minimax x3 for measuring the loads of MMA specific movements whilst the second was to determine the physical loads of isolated MMA training movements.

The key finding of this study was that the Minimax x3 had high reliability in assessing the loads of most isolated MMA training movements when using PL and PL_{ACC}. However, this excludes the PL of the knee strikes, which only demonstrated moderate reliability for this particular variable (ICC = .476 – .667). In total, 18 techniques also had lower bound values that fell below the .700 threshold. Reasons for the absence of high reliability for these variables are discussed later on in this chapter. The results collected in this study are comparable to the CV = 1.9% recorded by Boyd et al. (2011) using tackles and movement in Australian rules football and the r = .96 (p = <0.01) reported by Gabbett et al. (2012b) for detection of tackles and body-to-body contact in rugby. Callaway and Cobb (2012) also support the findings of the current study when comparing accelerometry to video analysis (r = .94, p < .01). The current study also showed the Mininmax x3 to have greater reliability than other available accelerometer units that have been tested (ICC = .73 – .87, Nichols et al., 1999; CV = 6 – 25%, Powell and Rowlands, 2004). This supports the use of the Minimax x3 for assessing the workload of most MMA movements. It was also noted that isolated standing strikes showed more reliability than isolated ground strikes and takedowns with left high kicks being the most reliable technique overall and left knees showing the least reliability.

In terms of the loads of individual techniques, double leg TD offensive Acc two produced the most PL_{ACC} with single leg TD defensive Acc two causing the greatest PL. In terms of accelerations in the cardinal planes, Y demonstrated the least magnitude on all techniques with the exception of double leg TD defensive Acc two where it recorded the second highest acceleration and single leg TD defensive Acc two where it showed the highest acceleration. This study has also found that the Minimax x3 may be used to assess the efficacy of the isolated techniques of MMA performers. Whilst it has been clearly demonstrated that the Minimax x3 has reliability in the measuring of MMA technique's workload demands, it would be beneficial to discuss how the movements yielded these results and how they can be interpreted as a measurement of performance.

3.4.1 Use of Accelerometry in Assessment of Individual Technique

The results reveal the Minimax x3 to be a potentially valuable tool for assessing an individual's technique within MMA. This can be demonstrated by analysis and interpretation of the ICC values of each technique. As can be seen in Figure 1.8, a participant's trunk can alter position on each strike, either due to inconsistencies in their technique, fatigue, or progressive movement learning (Martens, 2004). This alteration in technique is registered by the Minimax x3 and in turn causes a lower or more widely spread ICC. Amongst the standing strikes, this could be seen in the right body kick and the right high kick, which both have ICC values below .900 and lower bound values below .560, demonstrating that there was a relatively high variation in movement and therefore recorded results. This was due to some of the participants changing body position or movement pattern on subsequent strikes due to differing experience levels, as the more deliberate practice that has taken place, the more perfected and repeatable a motor skill becomes (Ericsson et al., 1993).

For example, the most experienced participant had taken part in 18 competitive MMA bouts at the time of testing, whereas the least experienced had taken part in 4 bouts with the group having a mean ± SD of 7 ± 4.7 bouts. It is therefore likely that the more experienced practitioners demonstrated less movement and technique variation than the least experienced fighters due to improved accuracy and timing and performance becoming more automatic (Sharp, 2004). This is also evident in left hook and right hook, both of which recorded relatively low ICC values and had lower bound values below .540, again showing a higher variability than the other standing strikes due to trunk sway and rotation being altered on each subsequent strike (Figure 1.9). These findings demonstrate that not only is the Minimax x3 highly reliable, but it is also sensitive enough to detect subtle differences in technique and movement which can be displayed via the calculation of the ICC.

Figure 1.8 – The Difference in Torso Position on Two Subsequent Right Body Kicks

Figure 1.9 – The Difference in Torso Position on Two Subsequent Right Hooks

The same level of sensitivity can be seen in the PL of the knee strikes. When viewing Figures 1.10a and 1.10b, it can be seen that the same participant delivers the strike from a different angle and the knee is brought up at a different height from the ground, in spite of the participants being instructed to aim the strike to the 'opponent's ribs'. This results in the torso being at different angles each time, which leads to the Minimax x3 unit recording different magnitudes and directions of accelerations. The results showed that the Minimax x3 only had moderate reliability in measuring the knee techniques, however, as all other isolated striking techniques were found to demonstrate moderate to high reliability, it can be concluded that this is due to variations in participant movements on subsequent techniques rather than the unsuitability of the unit.

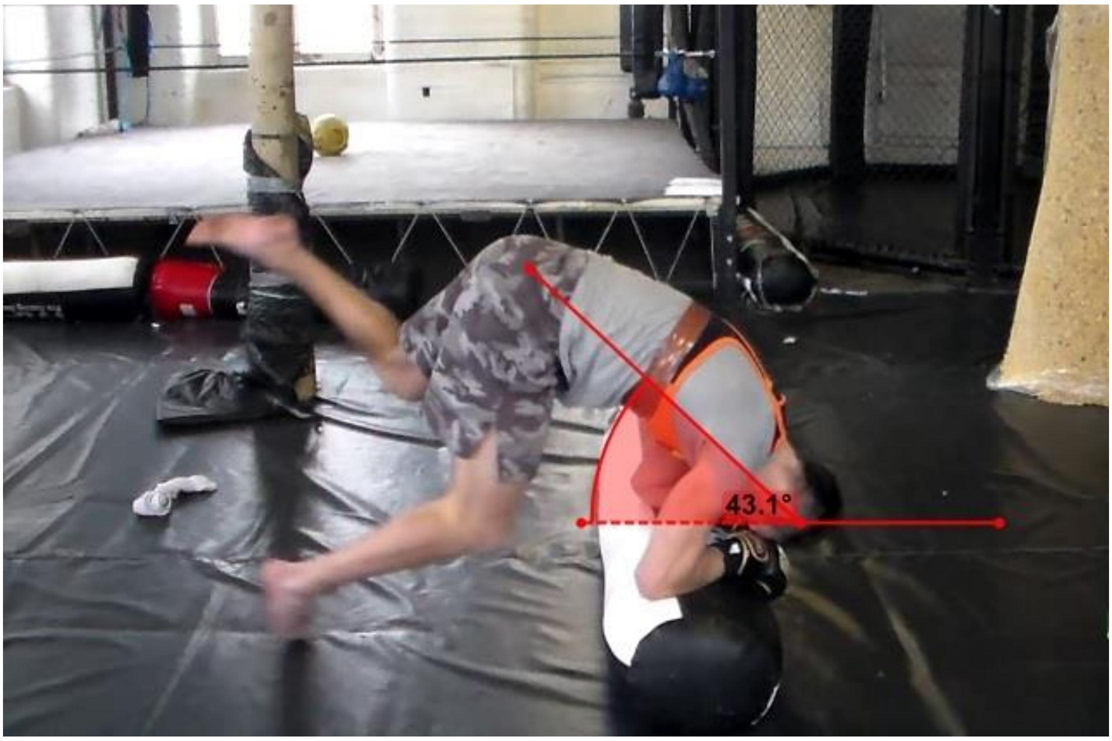


Figure 1.10a – Knee Strike Showing Torso at 43.1° to Ground

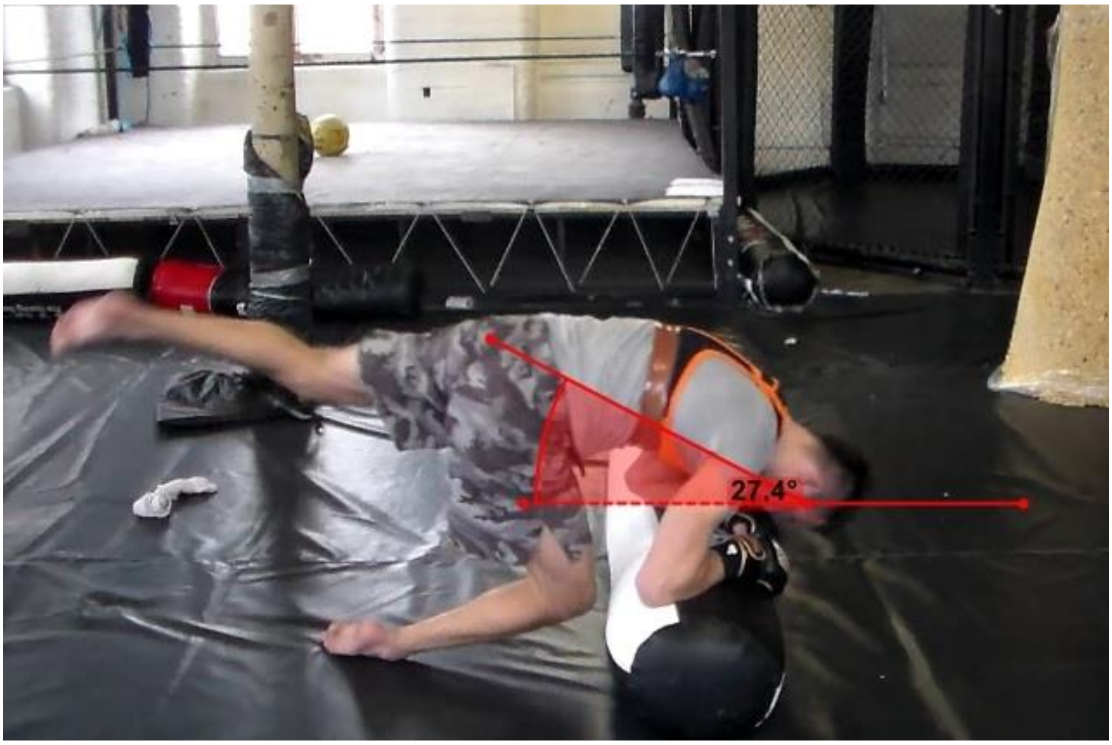


Figure 1.10b – Knee Strike Showing Torso at 27.4° to Ground

This conclusion can be supported when comparing the knee strikes to a technique with particularly high reliability, such as the left elbow (PL ICC = .990, p< .001; PL_{ACC} ICC = .984, p< .001). In Figure1.11, it can be seen that there is little opportunity for the participant to alter their trunk lean or rotation from strike to strike, as the pelvis and therefore the torso remains in a mostly unchanged position. This demonstrates that there is more chance of technique variation in whole body, rotational based strikes, or strikes where the angle of the torso to the floor changes by more than 90°. This demonstrates that the Minimax x3 is sensitive enough to pick up changes in the angle of movement and body position, even if only represented by a few degrees. This opens up the use of the Minimax x3 in measuring the participant's skill learning, technique performance and movement efficiency, a feature that has not previously been explored in the literature. This is discussed further in Chapter 6.

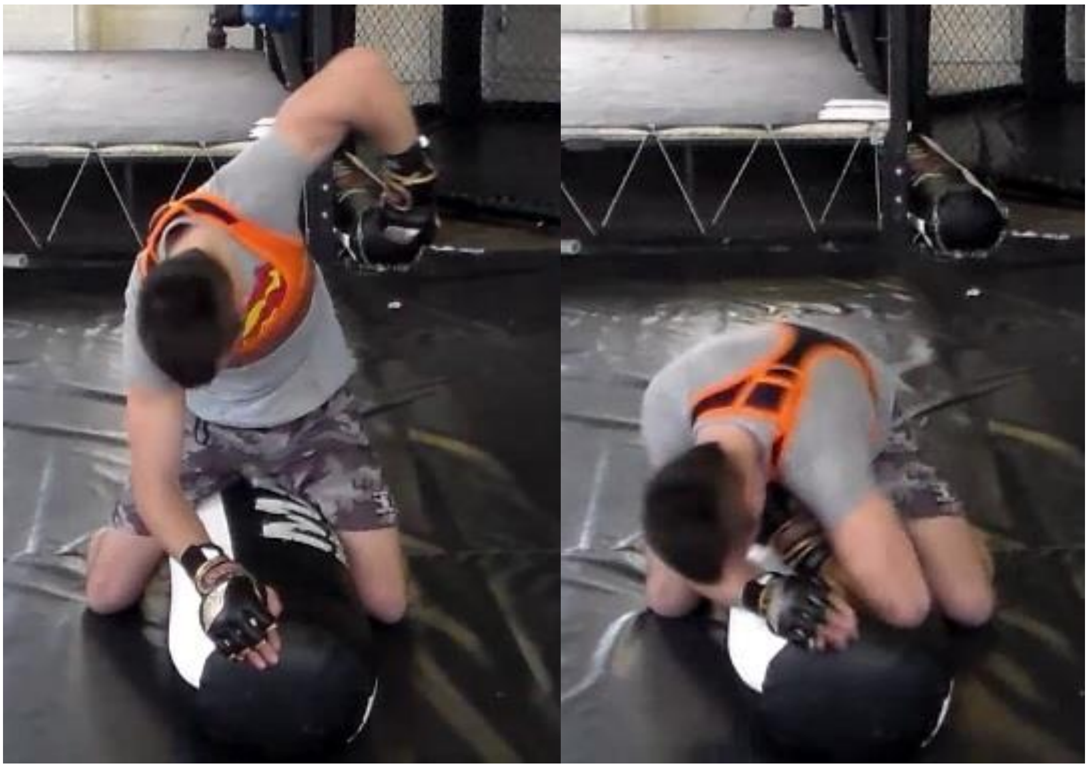
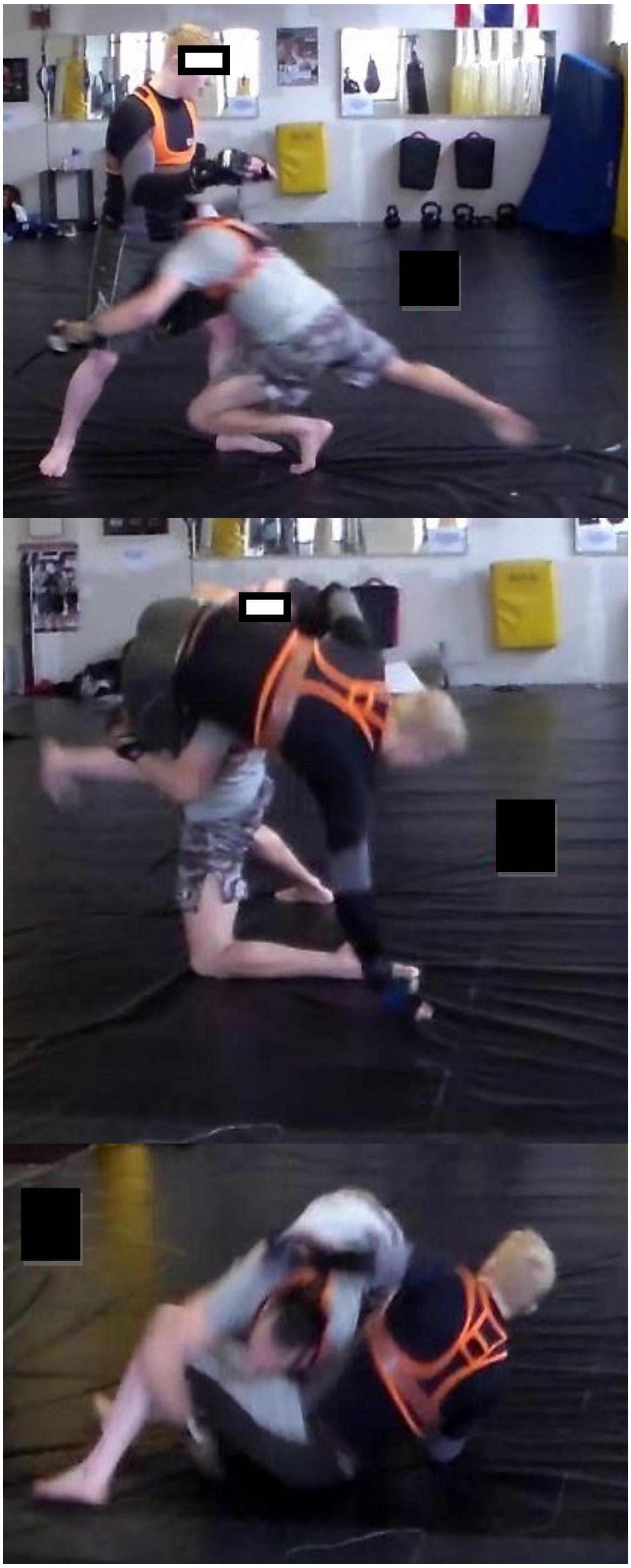


Figure 1.11 – Left elbow strike showing little opportunity for variation of torso movement on subsequent strikes due to fixed position of pelvis and relatively low range of movement required

Another aspect that could have had an effect on the results is the lack of strictly defined target areas during the isolated striking tests. Participants were not given a specific target on the bag to strike, rather they were asked to imagine the anatomical area of the opponent and aim for that area. In future testing, using tape or chalk to mark a cross or target area on the bag could yield results with even higher reliability than seen here.

When evaluating the ICC of the takedowns, it is important that the Minimax x3 is shown to be reliable in recording the loads of TD defensive movements, as during a sparring bout or training drill, a participant may be taken down many times and it would be useful to be able to reliably determine whether changes in load are due to attacking movements or defensive. As the results show, the Minimax x3 is more reliable for the TD defensive than the TD offensive for both variables, but both demonstrate high reliability. This contrasts with the results of the isolated strikes, where the greater the movement, the greater the opportunity for variations in values recorded. As can be seen in Figure 1.12, performing a takedown requires a great deal of movement in all three planes and whilst it could be assumed that this would lead to a lower reliability, what actually occurs is a higher level of reliability overall, despite the low lower bound values for the TD offensive techniques. This leads to the conclusion that when using gross skills, the Minimax x3 is less affected by technique alterations or movement changes. This would have implications for field assessments of workload as during a bout a participant may be unlikely to use single strikes or movements and would be more likely to perform large movements and combinations of gross motor skills. The fact that the Minimax x3 has been shown to be highly reliable in measuring the workloads of two of these gross motor skills, both for the person performing the TD and the person being taken down, is promising for the collection of reliable data in the field.



Point A

Point B

Point C

Figure 1.12 – Key Accelerations of TD Double Leg

3.4.2 Comparison between PL and PL_{ACC} Reliability

There was more variation in the accelerations recorded for the PL_{ACC} of the standing strikes than in the accelerations recorded for the PL of the standing strikes, which had four lower bound values fall below the threshold. What this potentially demonstrates is that the participants began to perform slower or more inconsistent movements during each set of techniques, resulting in less PL_{ACC} on each subsequent strike. This may highlight the ability of the Minimax x3 unit to the fatiguing effect of repeated MMA techniques and movements, giving the coach and performer a usable tool in the monitoring of coaching sessions, both in the long and short term.

What is also evident is that whilst many of the techniques analysed have relatively large variations in the magnitude and direction of instantaneous accelerations (PL) (based on the spread between the lower bound and upper bound values), they generally have uniformity in the total amount of load required to perform the technique (PL_{ACC}) showing that even if a technique is not performed perfectly, it requires the same overall effort. This could have an impact for both the training and competition aspects of MMA. For example, if a competitor is attempting striking techniques without using consistently correct movement, then the success of each strike could be compromised, whilst still placing the same load and therefore requiring the same exertion of the competitor.

If used as part of a competitor's training programme, this information can provide both knowledge of performance and knowledge of results at the same time which will enable skill learning at a faster and more efficient rate (Knudson and Morrison, 2002). This insight could only be achieved by a combination of the accelerometry data and visual analysis of movements allowing the objective data to be examined alongside the context provided by said visual analysis (McGarry, 2009). To this end, further study into different isolated MMA movements and different levels of performance will be required to establish any existing differences in PL or PL_{ACC} between competitors of different experience or levels of performance.

3.4.3 Measurement of the Accelerations and Workload of Individual Techniques

Measurement of the differing magnitudes of accelerations in the three cardinal planes during MMA movements allows the evaluation of movement patterns and provides a quantifiable measurement of which technique and movement will cause the greater load to be produced. Across all techniques, with the exception of TD double leg defensive and TD single leg defensive, Y (forwards/backwards acceleration) recorded the least acceleration. This is reflected in the mean Y value and the mean X value of the cross technique in the present study, where the participant's sideways acceleration was much higher that their forward acceleration during the same strike. This difference is similar across all standing strikes, with the X value being greater than the Y value for each. This is to be expected as all strikes attempted in MMA (or any other combat sport) commence from the same starting position. Also of note is the fact that only the jab displayed an X value of less than 2 g whilst the left high kick had an X value of 2.00 ± 0.51 g. Additionally, it was these two strikes that resulted in the two lowest PL_{ACC} values suggesting that the less sideways movement involved in a technique, then the less overall load is placed on the participant.

To explain the reasons behind this, it is important to highlight what a 'sideways' movement represents in MMA. As Figure 1.13 shows, striking in combat sports is not performed in a direct forward-backwards motion. In the figure, a boxer is throwing a cross punch to their opponent. As can be seen in the bird's eye view, the boxer actually has a diagonally side-on stance to their opponent, meaning that their body's movement is more sideways than forward. So whilst a person running in a linear fashion would presumably be producing more forwards acceleration, due to an MMA participant's initial stance and body angle, most acceleration is found in the X, sideways plane. Thus any technique that yields greatest acceleration in the Y axis would most likely result in the technique missing its target, so any attempted strike is going to result in a high amount of sideways movement and the more effort a participant uses in a strike attempt, the higher the resulting PL_{ACC}.

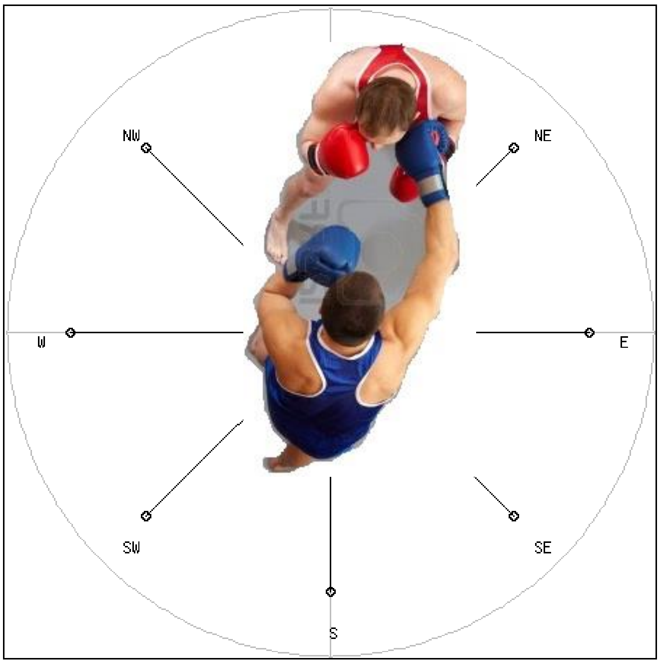


Figure 1.13 – Diagram Showing the Direction of Movement of a Cross

The same result can be seen in the ground isolation strikes, where the lowest X value strikes also displayed the lowest PL_{ACC} values. A difference is seen, however, in looking at the ground strikes with the highest X values (right punch = 6.03 ± 0.73 g and right elbow = 6.56 ± 0.90 g). For each of these strikes, the PL_{ACC} is almost equal to the left handed counterpart, whilst the X value is more than 1 au lower for the left handed strikes (Left Punch = 2.96 ± 0.95 g and Left Elbow = 3.26 ± 1.61 g). As each participant in this study was right hand dominant, this could demonstrate some body asymmetry when it comes to the direction of acceleration and therefore force of a ground strike.

When comparing standing strikes in terms of Z, all strikes have a relatively high mean value, with the lowest being cross and the highest being left body kick. Amongst all other g measured accelerations, only two other values (cross and right hook X) were recorded as being higher than 3 g. This shows that the majority of the acceleration experienced by MMA competitors during standing strikes is in the up-down plane. This could be an area of technique comparison between MMA trained competitors and muay Thai, kickboxing and boxing trained competitors, as this could possibly have an effect on the efficacy of the techniques. It could be that if more of the participant's effort and force is moving in an upwards trajectory, rather than a sideways or forwards direction, then less force is being applied to the target (the opponent). When comparing the ground strikes, the Z value is generally uniform across techniques with the exception of the knee strikes, both of which had values below 2 g. This is due to the specific movement of the body around the torso as can be seen in Figure 1.10a and 1.10b, where the torso does not elevate or depress as much as the other strikes. Rather, the participant's body tends to rotate around the torso in this movement. Whilst it would prove difficult to find comparisons from another sport for the ground striking techniques, as MMA is the only sport which contains these types of movements, the Minimax x3 could still be used as a tool for the measurement of internal skill consistency.

In conclusion, in terms of PL the most load inducing standing strike technique seen in this study was the cross, whilst the least was the left high kick. When this is compared to the values for PL_{ACC}, however, it is the left body kick which was shown to make the most impact on overall load whilst the left high kick and jab caused the least amount of overall load. For standing strikes in isolation, the amount of forwards or upwards movement is the main cause of increased PL_{ACC} experienced by participants. Amongst the ground strikes, the highest PL and PL_{ACC} were recorded by the left elbow and the right elbow. The individual variables for each technique, however, are very different, with the Y, X and Z values for the right elbow all being higher than the left elbow. This shows that once on the ground, elbow strikes could be the most physically taxing technique to use whilst use of the participant's dominant side can lead to more overall load due to the increased acceleration and movement in all three axes.

3.4.4 Isolated Takedowns Accelerations and Loads

The analysis of the accelerations of the takedowns elicits few surprising results, in that for both the single leg TD and double leg TD, Acc Two (the stage at which the TD offensive proceeded to takedown the TD defensive) caused the biggest increases in PL_{ACC} and PL, with the exception of double leg TD offensive in which Acc Two PL was slightly lower than the Acc One PL. Perhaps the most revealing information that can be gained from the isolated takedowns is that there are similar amounts of load being placed on both the person attempting the takedown and the person being taken down. The key difference is that for the TD offensive, this load is evenly spread over both stages of the takedown, whereas for the TD defensive, fewer loads are experienced on the first stage in comparison to the second. For the double leg TD defensive, Acc Two produces more than 1 au of PL more than Acc One whereas for the single leg TD defensive, Acc Two is more than 2 au of PL greater than Acc One. In practice, what this means is that if a defender was to stop a takedown by preventing the offender from commencing Acc Two, then the offender would experience less load than if they were able to complete the takedown. However, as the offender has experienced an increase in their PL_{ACC} without achieving a positional advantage, then this would be an overall negative result. So whilst takedowns lead to a similar increase in PL_{ACC} for both participants, the offender is benefitting the most from this increase by gaining an improved position, whereas the defender is placed in a potentially inferior position with an increased PL_{ACC}.

Where the dissection of the results for the isolated takedowns differs from the results for the isolated strikes is in the studying of individual technique. As demonstrated in Figure 1.14, there is more opportunity for individual variation of a takedown technique such as the TD single leg, in comparison to a striking technique, particularly as the offender makes contact with the defender (Point A) and they transition to the takedown (Point B) where the offender must flex their spine and rotate (Point B and Point C) in order to complete the single leg TD technique. This shows that the single leg TD allows more opportunity for the participant to alter their torso position on each subsequent takedown. When taking into account the changes in movement that will be caused by the defender, it is clear that there will be increased variations in the magnitude of accelerations in each plane. In contrast, the defender in both takedown techniques maintains an almost straight torso throughout until the takedown is complete. Even then, there is little change in their torso sway or rotation. To this end, it could prove difficult and counter-intuitive to use the Minimax x3 as a method of assessing takedown technique. Where it could be applied, however, is as a measurement of overall technique efficiency by tracking the accelerations of individuals over a series of sessions and comparing each set for differences and changes whilst also comparing them to ‘perfect model’ values which could be determined from further study.

Point A

Point B

Point C

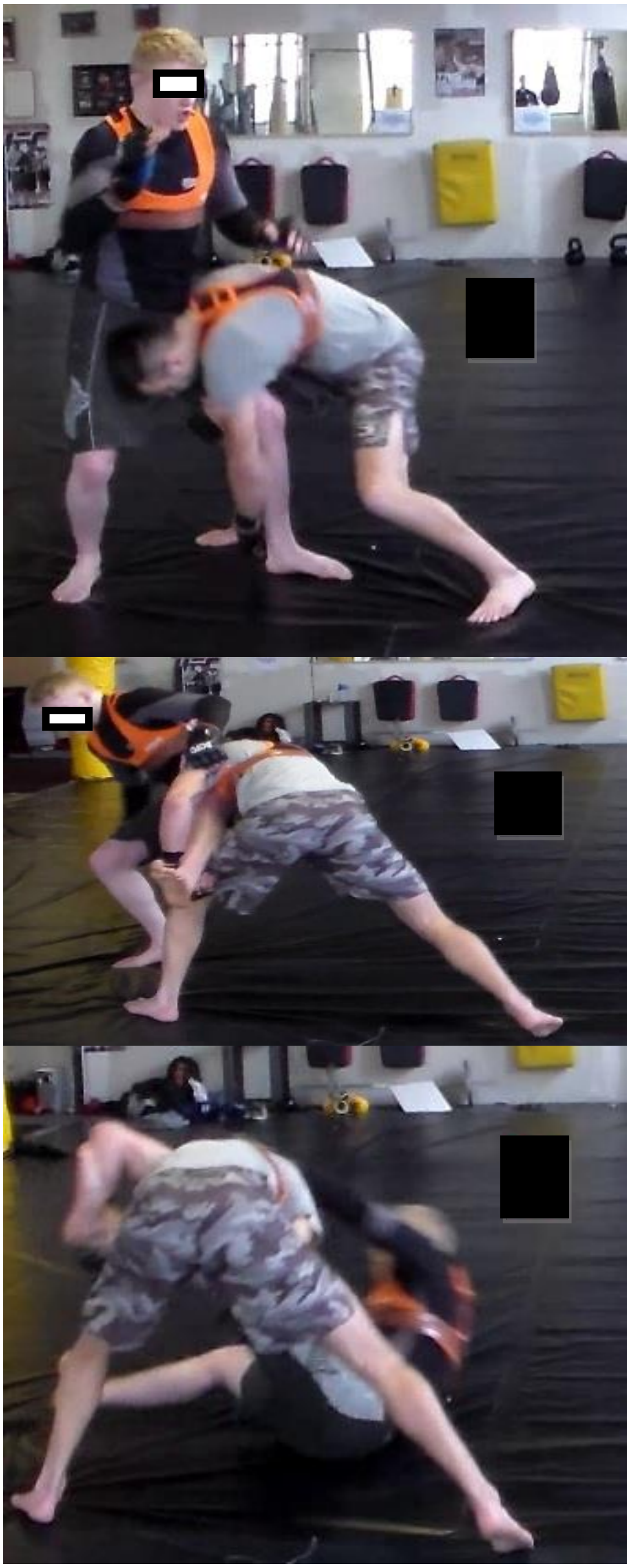


Figure 1.14 – Key Accelerations of TD Single Leg Offensive

3.4.5 Dominant and Non-Dominant Sided Differences

In the current study, the Minimax x3 found no difference between the loads of the participant's dominant side or non-dominant side with the exception of the ground punches and elbows. Body side dominance has been an increasing source of research in terms of its effect on performance and injury rates. Using a dominant side of the body in sporting tasks leads to asymmetries in the musculature of the torso and the lower limbs, which in turn can cause a greater risk of injuries due to overuse and overloading (Negrete et al., 2007; Everett et al., 2008). Cular et al. (2010) used taekwondo practitioners to determine that male participants display a strong correlation between body side dominance and technique performance and success. Similarly, Neto et al. (2012) showed that within martial arts, dominant hand strikes can exert up to 50% more force than the weak hand. For grappling based sports, however, Stradijot et al. (2012) found that judokas and wrestlers have bilateral symmetry in strength, balance and power fitness tests.

This could demonstrate that an MMA participant's body symmetry has been affected by the grappling aspects of their training more than the striking aspects, however, further research with a larger sample size and using participants from purely grappling sport and purely striking sports would be needed to make a firm statement either way. Also, from a statistical viewpoint, as the t values for these tests fell below the critical value, it cannot be said with any certainty that the observed differences were due to the treatment (left or right sided strikes). It could also be concluded that the increased accelerations of the right sided ground strikes could be caused by an increase in the muscular force of the left sided trunk muscles, as these would be the muscles that create the movement of these strikes and this therefore demonstrates asymmetrical differences in the participant's physical makeup. However, the current study found no evidence that this has affected the participant's performance outside of a single specialised technique. These findings are supported by statistical analysis of elite level MMA fighter's win-loss records in relation to their dominant side by Baker and Schorer (2013), who also concluded that there are no significant differences in performance success due to lateral preference.

3.5 Conclusion

Following isolated testing of the Minimax x3 across 8 units, 17 MMA specific techniques and 5 trials of each technique with each unit, the variables of PL and PL_{ACC} were found to be reliable for most of the isolated MMA techniques and the null hypothesis can be rejected. Whilst PL can have lower reliability on techniques where the movements are greater or have more room for individual variation, such as grounded knee strikes, where PL was not reliable, the PL_{ACC} has high reliability across all techniques although techniques that demonstrate small lower bound values may suggest a lower reliability across a larger sample size. This demonstrates that the Minimax x3 is a useful tool for tracking and monitoring of load over the course of a skills-based training session, but caution must be used when attempting to measure the loads of individual techniques using PL, as the amount of load incurred depends on the skill being implemented and the participant's skill uniformity. From a practical use standpoint, the results within this study show that the Minimax x3 could also be used to determine the efficiency and variability of skill repetition amongst MMA competitors. Finally, these results support the use of the Minimax x3 in measuring the workload demands of simulated MMA competition. Study two undertook this by assessing the loads experienced during live simulated competition and comparing them to isolated training techniques to determine the complete workload demands of MMA.

CHAPTER 4

STUDY TWO: MEASURING WORKLOAD DEMANDS DURING SIMULATED MMA COMPETITION

4.1 Introduction

Study one concluded that the Minimax x3 is a reliable tool for measuring the loads of most MMA specific movements in isolation, it also found that the Minimax x3 is sensitive enough in the measuring of PL and PL_{ACC} to reflect the changes in movements and techniques of repeated skill attempts. What has not been reported are the effects of MMA competition on the participant's workload or physiology.

As detailed in Chapter 2, there are currently no studies looking into the use of body worn accelerometry to measure the workload of combat sports, although other contact sports have used the Minimax x3 for this purpose, reporting PL_{ACC} accrued per minute of performance ($PL_{ACC}.min^{-1}$). These include Australian rules football (15.65 au, Mooney et al., 2013) and football (4.38 – 5.33 au, Domene, 2013), which demonstrate the greater workload required of sports that include a high degree of physical contact.

Amtmann et al. (2008) and Del Vecchio et al. (2011) are the only previous studies that attempted to ascertain the workloads of MMA fighters in a competitive environment. Amtmann et al.'s (2008) main limitation was the small sample size available due to some of their participant's bouts not lasting more than a single round meaning that a complete picture of their physiological requirements could not be gained. Del Vecchio et al. (2011) calculated a W:R result of 1:2 – 1:4, but included no discussion as to how this affected the participant's physiology or performance.

This lack of evidence based research regarding the requirements of MMA performance has repercussions for the preparation of the athletes which was highlighted by Lenetsky and Harris (2012) who discussed the current research into MMA and compared it to the available research from other combat sports. They argued that there are large gaps in MMA physiological knowledge across most levels of competition and that as MMA movement patterns and physiological responses may differ to other combat sports, using the assessment, training and testing modalities of these sports could be a mistake.

This view is supported by Lambert and Borresen (2010) who promoted the need for individual sports to have their own specific training assessment techniques to allow athletes and trainers to make the greatest gains whilst minimising injury rates, a key aspect that is missing from MMA according to Amtmann and Berry (2003) who suggested that the training methods used by MMA competitors are not necessarily specific or relevant to their needs and as a result performance, health and career length may be adversely affected. Despite this, a group of studies (Sanders and Antonio, 1999; Mackin, 2011; Schick et al. 2012; Tack 2013) have discussed and planned out possible training protocols for MMA athletes, making reference to variables such as energy system usage and overtraining. However, it has not been scientifically established which is the predominant energy system used in MMA competition, or what their movement patterns or workloads actually are, meaning that these training protocols are not based on measurable data and may be contributing to poor athlete development and increased susceptibility to injury.

To this end, it is important that research using the Minimax x3 was undertaken to establish the physiological intensity and workloads of an MMA bout so that competitors can fully prepare themselves for competition whilst ensuring injuries and overtraining are minimised. Study two led on from the findings of study one and measured the workloads of simulated MMA competition using the Minimax x3 whilst also reporting the effect of live MMA competition on PL and PL_{ACC}.

4.2 Aims

After reviewing the available literature and establishing the reliability of the Minimax x3 for the measurement and assessment of isolated MMA specific training techniques, the aim of this current study was to record and evaluate the workload demands of simulated MMA competition.

4.2.1 Hypothesis

Though there is a lack of research using accelerometry for the measurement of workloads in MMA, based on the nature of the sport, in that another competitor will be working against the participant to resist their movements, it was hypothesised that the workload during simulated competition would be greater than in isolated training movements.

4.3 Methods

4.3.1 Participants

Six male MMA trained participants (age = 26.17 ± 5.04 yrs, stature = 176.50 ± 5.86 cm, mass = 73.33 ± 7.84 kg, number of competitive bouts = 8 ± 5.02 bouts) took part in this study and completed the same pre-testing preparations detailed in Chapter 3. Ethical approval was again granted by the University of Central Lancashire Research Ethics Sub-Committee.

4.3.2 Materials

The participants were equipped with 198.5 gram MMA sparring gloves (Figure 1.15), kickboxing shin and instep pads and the equipment listed in Chapter 3.2.2 (Catapult Minimax x3 secured in harness, competition standard shorts, gum shield and either a t shirt or rashguard).

Figure 1.15 – 198.5 gram MMA Sparring Glove

4.3.3 Protocols

Within MMA training, participants take part in sparring bouts, which are friendly matches generally performed under modified rules in order to improve match fitness and aid preparation. Whilst these are not generally considered ‘open’ bouts, they are used in training as being as close to a competitive bout participants can perform without unduly putting themselves at risk. The participants took part in a single sparring bout in a 17 foot competition standard MMA cage under MMA rules modified for the participant’s safety (3 X 5 minute rounds, 1 minute rest between rounds, no elbows or knees to the head) against the same partner they worked with in the isolated takedown tests from study one. If at any point a submission occurred or either participant was considered to have been placed in an inescapable, indefensible position, both participants were to return to their feet and immediately continue the bout. The bouts were recorded in their entirety using a tripod based Samsung HMX-F80 camcorder (Samsung, Seoul, South Korea).

4.3.3.1 Lactate Sampling

Prior to a warm up, the participant’s middle finger of their left hand was cleaned using an anti-bacterial alcohol wipe before being pricked using a Accu-Chek Safe-T-Pro Plus Lancet (Roche Diagnostics, Basel, Switzerland) whilst they were in a seated position. The first blood droplet was wiped away using an alcohol wipe before taking a capillary blood sample using a Lactate Pro Analyser (Arkray, Kyoto, Japan) in keeping with the guidelines of Maughan et al. (2009). The results were recorded in Mmol.L. Their lactate levels were also recorded upon completion of the warm up detailed in Chapter 3.

Lactate samples were then taken at the end of each round of MMA sparring, each time with the participants in a seated position. Samples were taken in between rounds as these are the natural breaks in performance of a bout and would not result in the movements or positioning of the participants being affected. Upon completion of the bout, the participants remained in a seated position for 5 minutes and their lactate levels were recorded again once this time had elapsed. This time frame was chosen as muscle lactate has shown to peak 3 – 7 mins post exercise (Maughan and Gleeson, 2004) whilst for exercise ≥ 5 mins there is a relatively even ratio of blood to muscle lactate (Foster and Cotter, 2006). For each stage of lactate sampling, each participant was tested using a separate Lactate Pro. In order to avoid cross contamination from the blood sampling and to ensure the health and safety of the participants, each wore a surgical glove underneath the MMA sparring glove on their left hand. This was removed directly before each sample and was immediately replaced following the taking of the sample and a plaster being placed over the test area.

4.3.3.2 Video Based Time Motion Analysis

Once the testing had been completed, the sparring bouts were viewed in their entirety and TMA was completed for each participant individually using LongoMatch 0.18 (Andoni Morales, Madrid, Spain) tagging software. The following variables were recorded:

High activity striking (3 or more strikes per exchange whilst standing), clinch defending (the participant did not instigate the clinch or is not controlling the clinch), takedown attempt (participant attempts to takedown opponent), takedown successful (participant successfully gets opponent to a grounded position), sprawl (participant drops their bodyweight rapidly forward to prevent a takedown), inferior position (participant is put into an inferior position either standing or on the ground), high activity ground strikes (3 or more strikes per exchange in a grounded position), submission attempt (participant attempts a submission), successful submission (participant submits opponent), submission defence (participant defends a submission attempt), sweep (participant moves from an inferior position on the ground directly to a dominant position), to standing (participant moves from a grounded position to standing whilst clinched), scramble (participants are both moving rapidly on the ground with neither having a direct advantage), low activity striking (no more than 2 strikes per exchange whilst standing), clinch aggressor (the participant instigates or is controlling a clinch), lockdown (both participants are grappling in a grounded position and are holding each other so neither can advance or strike), pass attempt (participant attempts to pass from a neutral position into a more dominant position on the ground), pass (participant moves from a neutral position to a dominant position on the ground), dominant position (participant secures a dominant position in either standing or grounded), low activity ground strikes (no more than 2 strikes per exchange in a grounded position) and clinch striking (striking within a clinch).

These categories were chosen in keeping with the phases of combat and key skills most associated with and taught within MMA competition and training (Gracie and Danaher, 2003; Plyler and Seibert, 2009; Ritschel, 2009). Whilst this TMA system has not been tested for intra or inter-rater reliability, the analysis was completed alongside an independent MMA coach and an agreement was reached about time spent in each category for each participant.

The reasoning behind completing traditional TMA alongside the accelerometer data collection was the wide variety of skills utilised within an MMA competition. This necessitates the video-based tracking of which movements and techniques were performed during the bout so that the accelerometer data can be fully understood and applied to a live performance in a way which is not necessary in a sport such as rugby or football, where the variation and differences in movements that cause accelerations is not as great. To ensure the video and Minimax x3 were data were synchronised, the participants each performed three stationary jumps immediately prior to the start of the sparring bout to create a clear marker on the output graph to synchronise the video to.

4.3.4 Raw Data Organisation

4.3.4.1 Descriptive Statistics

Within Catapult Sprint 5.0.9, the data from the sparring bout for each participant was split into 15 separate periods. The $PL_{ACC}.min^{-1}$ for each round and the total bout and the total PL_{ACC} at the end of each round was calculated for each participant and from this, the group as a whole. The mean ± SD PL for each type of punch, kick, takedown and grounded punches within the sparring bouts was also calculated for the group. When viewing the accelerometry data from the sparring bouts, on occasions where more than one punch or kick was attempted in quick succession, it was not possible to determine which punch or kick contributed to PL increases the most. For these occurrences, the PL was recorded under the variables of punch combinations and kick combinations.

The frequency of standing punches, kicks, standing knees, clinch strikes, ground punches, ground knees, takedown attempts and successful takedowns were also recorded and the mean ± SD for each variable was calculated. TMA results were reviewed and verified by a second, independent MMA coach and an agreement was made between the researcher and the coach about who would have been declared the winner of each sparring bout if it had been a competitive bout. The total amount of time (s) each participant spent performing each variable was entered into Microsoft Office Excel 2007 and values for each participant's total active time(s) and total inactive time (s) were calculated along with the mean ± SD for the whole group. The work:rest Ratio (W:R) was also calculated for each participant and the group.

The mean ± SD lactate for each participant at each stage of testing was calculated as well as delta lactate (ΔLac) for each participant, post warm-up levels being used for the participant's baseline value. The mean ± SD of the ΔLac for the whole group was then calculated.

4.3.4.2 Statistical Analysis

Each of the following procedures was performed in SPSS 20 (IBM, New York, USA). To assess the normal distribution of the sparring data a Shapiro-Wilk test was performed using $p \geq .05$ as the level of acceptance. This was completed for the values for $PL_{ACC,}$ $PL_{ACC}.min^{-1}$ and lactate for each round, the PL of each technique used in the sparring bouts and the total number of each technique used in the sparring bouts per participant.

Pearson's correlation coefficient was calculated, significance being accepted at $p \leq .05$, to determine any relationships between the variables of lactate, PL_{ACC} or $PL_{ACC}.min^{-1}$ in the sparring bouts. To ascertain if there were any differences between the variables of lactate, PL_{ACC} or $PL_{ACC}.min^{-1}$ between the three rounds of sparring, a repeated measures one-way ANOVA was calculated for each with significance being accepted at the $p \leq .05$ level. Repeated measures one way ANOVA was also used to find any differences between lactate produced across all six sampling points. Due to the small sample size, effect size (ES) was also calculated using eta^2 (η^2) with a small $\eta^2 \geq .10$, a moderate $\eta^2 \geq .25$ and a large $\eta^2 \geq .40$ (UCLA, 2014).

To discover any differences in the PL of the isolated techniques reported in study one and the PL of the same techniques in the sparring bouts, each variable was compared in paired samples t-tests with significance being met at the $p \leq .05$ level.

Again, due to the small sample size, ES was calculated using Cohen's *d* (Salkind, 2011), with a small $d \geq .20$, a moderate $d \geq .50$ and a large $d \geq .80$ (UCLA, 2014).

To calculate any significant differences between the determined winners and losers of each bout the means of the total number of standing punches, kicks, standing knees, ground punches, attempted takedowns and successful takedowns were compared in paired samples t-tests. Significance was met at the $p \leq .05$ level.

4.4 Results

The values for $PL_{ACC,}$ $PL_{ACC.}min^{-1}$, PL, numbers of techniques attempted and lactate for the sparring were found to be normally distributed according to the Shapiro-Wilk test (≥ .05). The p values of each variable can be viewed in Appendix D.

4.4.1 Workloads of Sparring

The participants had a mean ± SD PL_{ACC} of 224.32 ± 26.59 au for the complete bout (range = 189.86 - 269.53 au) and a mean ± SD $PL_{ACC}.min^{-1}$ of 14.91 ± 1.78 au over the full bout. As shown in Table 1.11, both PL_{ACC} and $PL_{ACC}.min^{-1}$ decreased with each successive round, however, it was found that there were no significant differences in the PL_{ACC} recorded by round as determined by one-way ANOVA ($F_{(2,15)}$ = 2.532, p= .113). The ES for this analysis (η^2= 0.25) exceeded the convention for a moderate effect (moderate $\eta^2 \geq$ 0.25), but not for a large effect (large $\eta^2 \geq$ 0.40). Neither was there recorded any significant differences in $PL_{ACC}.min^{-1}$ according to one-way ANOVA ($F_{(2,15)}$ = 7.899, p= .136), η^2 = 0.23.

Table 1.11 – Mean ± SD PL_{ACC} and $PL_{ACC.}min^{-1}$ of Each Round of the Sparring Bouts

	PL_{ACC} (au)	**$PL_{ACC}.min^{-1}$ (au)**
Round One	77.61 ± 9.92	15.37 ± 1.71
Round Two	71.48 ± 10.56	14.30 ± 2.11
Round Three	65.39 ± 8.61	13.08 ± 1.72

4.4.2 Accelerometer Values of Individual Sparring Techniques

Table 1.12 shows the PL for each of the individual techniques used in the sparring bouts and how they compare to the PL of the same technique in isolation from study one. There were no occurrences of knees on the ground.

Table 1.12 – Comparison of PL of Individual Techniques Used in Sparring Bouts and in Isolation

Technique	PL of Techniques in Sparring (au)	PL of Techniques in Isolation (au)	Effect Size Cohen's *d*
Jab *	2.04 ± .29	2.88 ± .37	*
Cross *	2.25 ± .26	3.37 ± .54	*
Left Hook *	2.48 ± .31	3.18 ± .40	*
Right Hook	2.54 ± .65	3.21 ± .41	*
Left Leg Kick	1.86 ± .04	2.38 ± .63	*
Right Leg Kick	1.93 ± .24	2.19 ± .65	
Left Body kick	1.72 ± .27	2.34 ± .72	
Right Body Kick	1.95 ± .42	2.25 ± .38	*
Left High Kick	1.98 ± .75	1.88 ± .67	
Right High Kick	1.61 ± .41	2.10 ± .35	*
Left Ground Punch	1.25 ± .22	2.10 ± .35	
Right Ground Punch	1.62 ± 0	3.00 ± .44	
TD Double Leg Attempt (Attacker)	3.85 ± .86	N/A	
TD Double Leg Successful (Attacker)	3.81 ± .80	5.29 ± 1.15	*
TD Double Leg Attempt (Defender)	2.66 ± .50	N/A	
TD Double Leg Successful (Defender)	4.95 ± 1.71	4.69 ± 1.43	*
TD Single Leg Attempt (Attacker)	7.50 ± 0	N/A	
TD Single Leg Successful (Attacker)	4.66 ± 0	4.46 ± 1.20	
TD Single Leg Attempt (Defender)	3.73 ± 0	N/A	
TD Single Leg Successful (Defender)	4.72 ± 0	4.53 ± 1.08	
Punch Combination	2.85 ± .35	N/A	
Kick Combination	2.10 ± .47	N/A	

Nb. Techniques with a ± SD of 0 displayed had only one occurrence in the sparring bouts and were not used in the paired samples t test. Variables marked with a * symbol showed significant differences (p ≥.05) in the paired samples t test. Variables with a large ES (large *d* ≥ .80) are marked with a * symbol and variables with a moderate ES (*d* ≥ .50) are marked with a * symbol.

Amongst the takedowns, the highest mean PL was recorded by the defender during successful double leg takedowns, though the only unsuccessful single leg attempt by an attacking participant recorded the largest PL value overall amongst measured movements.

The paired samples t-tests found that only the following categories had significant differences: jab ($t_{(5)}$= 4.105, p= .009); cross ($t_{(5)}$= 3.599, p= .016); left hook ($t_{(5)}$= 2.611, p= .048). However, the following variables had high ES: jab d = 2.12; cross d = 1.57; left hook d = 0.92; right body kick d = 0.92; right high kick d = 1.41; left punch d = 2; TD double leg offensive d = 3.54. The following variables had moderate ES: right hook d = 0.78; left leg kick d = 0.75; left body kick d = 0.72; TD double leg defensive d = 0.58. All other variables demonstrated low ES.

4.4.3 Lactate Sampling

Table 1.13 demonstrates a clear and steady increase in lactate throughout the bouts and decrease of 2.25 Mmol.L after the 5 minutes of passive rest. The group was found to have a ΔLac of 3.87 ± 0.85 Mmol.L from the end of their warm up to the end of round three. The highest ΔLac for an individual participant was recorded as 4.90 Mmol.L whilst the lowest ΔLac for an individual participant was 2.80 Mmol.L. There were no significant differences in the lactate produced by round as determined by one-way ANOVA ($F_{(2, 15)}$ = 1.670, p= .221), whilst the ES for this analysis (η^2= 0.18) demonstrated a small effect only (small $\eta^2 \geq 0.10$). There were significant differences found between the lactate produced across all six sampling points as calculated by one-way ANOVA ($F_{(5, 30)}$ = 5.774, p= .001) with the ES (η^2 = 0.49) showing a large effect (large $\eta^2 \geq 0.40$).

Table 1.13 – Mean and Range of Blood Lactate

Testing Stage	Mean Lactate (Mmol.L)	Max (Mmol.L)	Min (Mmol.L)
At rest	2.7 ± 1.46	4.90	1.20
After warm up	5.43 ± 2.74	8.90	2.2
End of Round 1	6.6 ± 1.99	9.20	3.60
End of Round 2	8.67 ± 2.86	11.60	5.40
End of Round 3	9.25 ± 2.96	13.10	5
After 5 minutes Rest	7 ± 2.09	10.60	5.20

4.4.4 Lactate and Accelerometer Relationships

Pearson's Correlation calculated that there was a direct negative non-significant correlation between $PL_{ACC.}min^{-1}$ by round and lactate (r= -.939, p= .223). It was also found that there was a direct positive, but non-significant relationship between mean lactate and mean PL_{ACC} for the complete sparring bouts (r= .985, p= .185) and a negative, but non-significant relationship between the mean PL_{ACC} change by round and mean lactate by round (r= -.952, p= .198). This can be seen in Figure 1.16, where as lactate increased with each successive round, PL_{ACC} and $PL_{ACC.}min^{-1}$ had linear reductions.

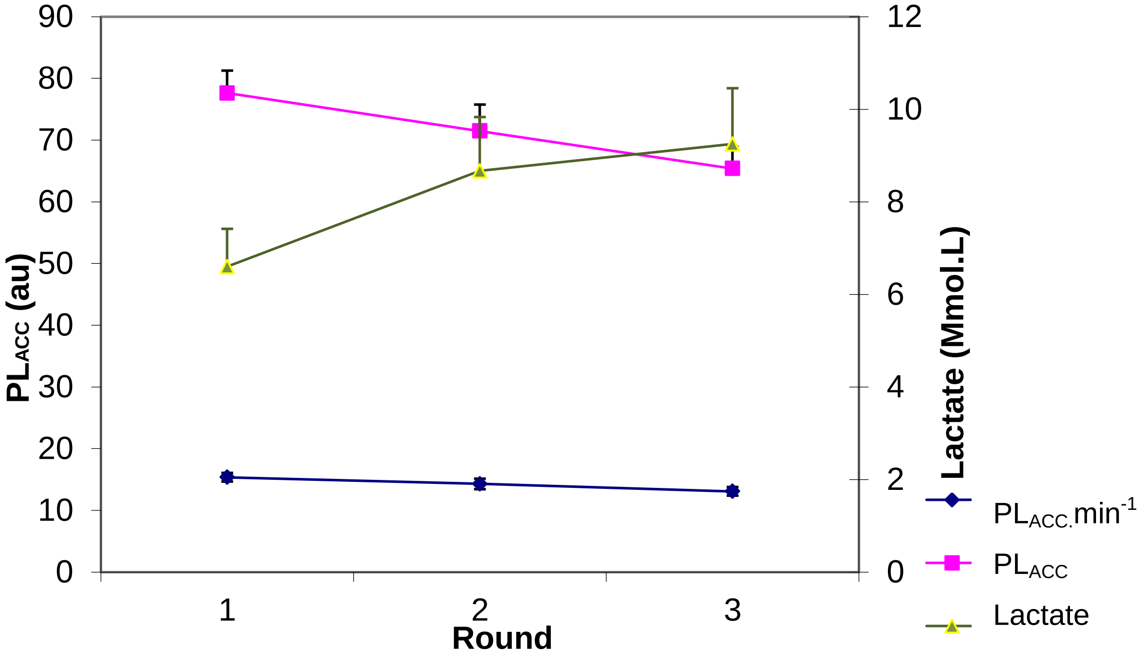


Figure 1.16 – Relationships Between Lactate (Mmol.L), PL_{ACC}.min^{-1} (au) and PL_{ACC} (au)

4.4.5 Time Motion Analysis

The participants in the sparring bouts were found to have an average W:R ratio for the total bout of 1:1.01 from a mean time of 447.67 ± 48.65 : 452.33 ± 48.65 s. The most active participant had a W:R of 1:0.76 whilst the least active participant had a ratio of 1:1.27. The participants spent most of their active time in the clinch aggressor category. The lowest amount of time was spent attempting to pass and sweep. There were no occurrences of pass attempt, submission attempt or submission defence. However, 0.50 ± 1.22 s was spent in the successful submission category. In terms of striking, the group had a larger mean striking low activity in comparison to striking high activity, striking clinch, ground striking low activity and ground striking high activity. More time was also spent attempting takedowns than actually attaining a successful takedown. Once in a grounded position there were very few positional changes, with the participants spending more time in either a dominant position or an inferior position in comparison to sweep, returning to standing position or in a scramble. All time motion analysis results can be viewed in Table 1.14.

4.4.6 Differences between Bout Winners and Bout Losers

The paired samples t-tests found that the only variable that demonstrated a statistical difference between the bout winners and losers was the number of successful takedowns ($t_{(2)}$= 5.196, p= .035). The bout winners achieved a mean of 3 ± 1 successful takedowns where as the bout losers didn't achieve any takedowns despite having an attempted takedown mean of 2 ± 2 (bout winners mean attempted takedown = 4 ± 2). No other significant differences were reported.

Table 1.14 - Mean and Total Time(s) of each Time Motion Analysis Category

Category	Mean Time per Participant (s)	Total Group Time (s)
Striking Low Activity	95.50 ± 12.63	573
Clinch Aggressor	100.33 ± 65.87	602
Lockdown	3.67 ± 5.68	22
Pass Attempt	0	0
Pass	0.33 ± 0.82	2
Dominant Position	50.5 ± 55.35	303
Ground Strike Low Activity	4 ± 3.85	24
Striking Clinch	12 ± 9.7	72
Striking High Activity	15.33 ± 11.22	92
Clinch Defensive	95.5 ± 58.48	573
Takedown Attempt	7.5 ± 6.53	45
Takedown Successful	2.5 ± 3.21	15
Sprawl	2.17 ± 2.86	13
Inferior Position	50.33 ± 55.32	302
Ground Strike High Activity	1.67 ± 3.2	10
Submission Attempt	0	0
Submission Successful	0.5 ± 1.22	3
Submission Defending	0	0
Sweep	0.33 ± 0.82	2
To Standing	4.33 ± 4.46	26
Scramble	1.17 ± 1.33	7

4.5 Discussion

The aim of study two was to use the Minimax x3 and video analysis to monitor the physiological workloads and movements patterns of simulated MMA competition and compare these workloads against those recorded during training movements detailed in study one. This is the first time this has been done within combat sports and it is the first time the physiological workloads and movements of MMA have been studied in this detail. The key findings of this study were that the PL recorded during isolated strikes were either similar or higher than in competition strikes whereas the PL of takedowns during simulated competition is higher than during isolated training movements. Therefore, the hypothesis can neither be rejected, nor accepted, as both isolation movements and simulated competition movements had greater loads. The greatest loads were caused by takedowns whilst the smallest loads resulted from ground strikes, and though MMA competition produces a high PL_{ACC}, this reduces as lactate production increases. Although this relationship was not found to be significant it was noted that MMA sparring does cause a significant increase in the amount of lactate present in the blood. The participants spent most of the sparring bouts in the clinch and performing two or less strikes in succession and the least amount of time attempting submissions, sweeps or pass attempts. Finally, it was found that the deciding factor in winning or losing the sparring bouts was the number of successful takedowns achieved.

4.5.1 Accelerations and Loads of Sparring Bouts

When analysing the accelerometry data of the sparring bouts in relation to exertion, it can be seen that there are differences in the magnitude of PL during training and competition. The PL values of the strikes from the isolation tests of study one were either higher or comparable to the values recorded for the same strikes during sparring, with the exception of left high kicks, which were comparable between the two testing stages. Similarly, the fact that PL for the takedowns in sparring were much higher than the takedowns in isolation, some more than 2 au higher, demonstrates that whilst the load experienced by the participants during competition for some grappling movements will be higher than that experienced during training drills, for striking techniques, PL will be lower in sparring than in isolated training. This, alongside the fact that five strikes and the double leg takedown showed significant differences between isolation and sparring is a strong indication that facing a resisting opponent is a key factor in this change in magnitude.

These differences could be caused by several components. The first is that during isolation drills, the participants do not have to move in response to an external stimuli i.e., their opponent's movements, so they are free to choose at which point, which angle and with how much force they attempt their technique. Also, they will not have to adjust their technique to counter or dodge an opponent's strike or grapple attempt. Each of these aspects may have led to greater accelerations generated and a greater PL. A second factor is that the accelerometer values take into account the deceleration effect of the participant striking another object, in this instance, the difference between striking a heavy bag and an opponent. The PL incurred by striking a heavy bag or taking down a non-resisting partner may not be equal to the change in load experienced when striking, pushing or taking down a resisting opponent. This is evidently clear when viewing the greater PL required to complete a takedown against a resisting opponent who is actively pushing back against the participant as opposed to a training partner who is allowing the participant to perform the technique without resistance.

A final point is that the means for punch combinations and kick combinations are similar in magnitude to single punches and single kicks in sparring. This is evidence that against an opponent, MMA participants are not able to produce a full movement or as effective a movement when attempting several strikes in succession. Similar findings were recorded by Gabbett et al. (2012b) who found that the loads experienced by rugby league players in training did not match or equal the loads experienced in games, which could have strong implications for the efficacy of the player's training as if a competitor's training movements and exertions do not match their competition levels, then their preparations will be insufficient.

The PL_{ACC} experienced by the participants in the current study shows that MMA is a physically demanding competition that requires a great amount of movement and workload. The PL_{ACC} recorded in this study (224.32 ± 26.59 au) can be compared to football players who experienced PL_{ACC} of 789 ± 224.9 au in 90 minute training sessions (Casamichana et al., 2013). In this instance, football players experienced 3.5 times more PL_{ACC}, but in 6 times the duration. This could be used to argue that in an equal amount of time, MMA participation would elicit more load than football as if an MMA session lasted 90 minutes, the theoretical PL_{ACC} could be 1,344 au. This would be an unrealistic comparison to make, however, as it is not truly reflective of the nature of these sports. As such, it would make more sense to use $PL_{ACC}.min^{-1}$ as a means of comparison and based on Casamichana et al's. (2013) findings, football players have a $PL_{ACC}.min^{-1}$ of 13.15 au. In contrast, Mooney et al. (2013) demonstrated Australian Rules football players experience $PL_{ACC}.min^{-1}$ of 15.65 au during match performance. Based on the findings of this study, an Australian Rules football player would experience more $PL_{ACC}.min^{-1}$ than an MMA competitor (14.91 ± 1.78 au), however, as highlighted by Mooney et al. (2013), Australian Rules football does allow the participants more rest and recovery periods during a game, allowing for less fatigue of the anaerobic energy systems and therefore more force production and greater accelerations.

To allow a fuller contextualisation of how body-to-body contact affects $PL_{ACC}.min^{-1}$, Cormack et al. (2013) showed that elite level netball players have a $PL_{ACC}.min^{-1}$ of 9.96 ± 2.50 au. This is a clear demonstration that the greater amount of bodily contact involved in a sport, the greater the workload demands on the participant. This is the key difference between MMA and the three other sports mentioned here, in that MMA involves a greater amount of bodily contact and no periods of running or jogging, which are an integral part of the other sports. How these differences affect the PL_{ACC} and $PL_{ACC}.min^{-1}$ variables cannot be fully explained by this study, however; Domene (2013) recoded defenders in football having a $PL_{ACC}.min^{-1}$ of 4.38 – 5.33 au, far lower than Casamichana et al. (2013) who used a full range of positions. As defenders in football are traditionally seen to perform less running movements during a performance, this could demonstrate a key difference in PL_{ACC} registered by body-to-body contact and ambulatory movements that could warrant further research.

As the participant's $PL_{ACC}.min^{-1}$ dropped by at least 1 au with each subsequent round, this could be evidence of the fatiguing effect of MMA competition on movement and muscular output, although more research into the causes and affects of this would be required. The fact that the decreased values were not found to be significantly different to each other in each round of sparring could also demonstrate that whilst there is clearly a reduction in movement and exertion on the part of the participants, this is not enough to significantly affect their performance, further highlighting the Minimax x3's capability in tracking performance output and fatigue with enough sensitivity to note the difference between the two. This result is supported by Mooney et al. (2013) who showed that the $PL_{ACC}.min^{-1}$ of an Australian Rules football player was seen to decrease with each successive quarter of play.

A final point to note about the use of acceleromery in MMA is that PL_{ACC} and $PL_{ACC}.min^{-1}$ has been shown to have a direct correlation to lactate, however, this does not necessarily demonstrate causality in this instance as it cannot be determined whether the increase in blood lactate caused less movement or if greater movement caused increased lactate. In spite of this, considering that Casaminchana et al. (2013) correlated PL_{ACC} against rate of perceived exertion (RPE) and Mooney et al. (2013) correlated PL_{ACC} against distance travelled, it can be stated that accelerometry and the PL_{ACC} variable is a relevant and useful tool to demonstrate that MMA competitors are engaged in a fatiguing activity that requires explosive movements throughout. The longer performance continues, however, the less able it seems the participants are of achieving these movements. To this end, it can be stated that the Minimax x3 can be effectively utilised to accurately measure the workloads demands of simulated MMA competition.

4.5.2 Lactate Sampling

When analysing the results from the lactate samples, as mean lactate steadily rose throughout the bouts, the findings reaffirm the important role of anaerobic metabolism in MMA performance (Maughan and Gleeson, 2004), though it is not possible to make assumptions about the relative metabolic contributions from these data. There were, however, large disparities between the highest and lowest values with there being a difference of 5.6 Mmol.L at the end of the first round, 6.40 Mmol.L at the end of the second round and 8.1 Mmol.L at the conclusion of the bouts. This could be largely affected by the peak resting value which was in excess of the generally accepted anaerobic threshold value of 4.0 Mmol.L (Foster and Cotter, 2006) and upon completion of the warm up, was already more than double the anaerobic threshold (8.90 Mmol.L). This, in addition to the large differences in maximum and minimum ΔLac results, indicates that MMA competitors have a large variance in lactate buffering capabilities. These variances cannot be explained from these results, however, it could theoretically be caused by the differences in experience and training age as the body's ability to manage its pH through lactate clearing has been shown to improve with increased physical activity over time (Castanga et al., 2007; Juel, 2008; Saraslanidis et al., 2011). Another explanation could be that the participants with lower lactate results were involved in bouts of lower intensity or difficulty.

During the one minute rest period when samples were taken, the participants were in a seated position, in keeping with the position that they would take between rounds in full competition. This is despite it being shown that an active recovery period would allow more lactate clearance than a passive recovery period, especially if the exercise being performed is of a high intensity (Menzies et al., 2010). This means that the participant's ability to sustain muscular force production during the proceeding round could be positively affected by spending what time they do have in between rounds engaged in some type of active recovery, whilst also allowing them to replenish most, if not all, of their phosphocreatine stores in time for the opening stages of the next round (Maughan and Gleeson, 2004).

The only other published data on the lactate production of MMA competitors is Amtmann et al. (2008) which found that two participants involved in sparring bouts had a mean lactate of 16.35 ± 4.74 Mmol.L and a mean lactate production of 19.7 ± 1.41 Mmol.L from full competitive bouts. Whilst these values are far higher than those detailed within the current study, they were collected from a very small group, too small for any significant comparisons, but it does bring about a question of what differences there would be between the lactate production of MMA competitors during a sparring bout and during full competition.

4.5.3 Comparison to Lactate Production in Related Combat Sports

The continually increasing lactate levels recorded at the end of each round of sparring indicate that MMA performers make substantial use of the anaerobic energy pathways, although not as much as competitors from more grappling based combat sports such as BJJ (10.4 ± 3.6 Mmol.L, da Silva et al., 2013), judo (12.3 ± 0.8, Degoutte et al., 2013) or freestyle wrestling (20 ± 0.7 Mmol.L, Kreamer et al., 2001). In these grappling sports there is little to no opportunity for disengagement once the competitors have made contact with each other, meaning that the participants are continuously engaged in forceful muscular contractions. A further comparison suggests that wrestling takedown techniques require more explosive, anaerobic contractions to achieve the desired result of getting the opponent onto their backs, again resulting in a higher lactate production than BJJ and judo, the techniques of both of which allow for more measured, finer contractions to achieve success. Due to these comparisons, it may be possible that MMA competitors use less explosive grappling movements than wrestlers resulting in lower lactate concentrations, but again, further research will be required to substantiate this proposition.

In comparison, some striking sports allow for more 'disengagement' from the opponent than grappling sports, as competitors will back off and plan their next movements and attacks and therefore have lower or similar lactate values to MMA. Examples of these sports are taekwondo = 7.5 ± 3.8 Mmol.L (Matsushigue et al., 2009) and muay Thai = 9.72 ± 0.6 Mmol.L (Cappai et al., 2012). Contrastingly, boxers have been shown to have higher lactate production than MMA fighters despite only using punches and having limited clinching (13.5 ± 3.0 Mmol.L, Smith, 2006; 14.5 ± 0.6 Mmol.L, Ghosh, 2010; 11.8 ± 1.6 Mmol.L, Davis et al., 2013). This could be due to the boxers having shorter rounds and not having to consider as many varied attacks as MMA competitors (such as kicks or takedowns). This could lead to more attacking movements and flurries of punches being attempted, causing a higher lactate overall.

These findings can be used in conjunction with the TMA results, which show the MMA participants spent most of their time in either striking exchanges involving punches and kicks or in clinch positions with very little time spent attempting explosive, wrestling based takedowns. Therefore, MMA fighter's energy usage and lactate production appears to most closely mirror that of muay Thai and BJJ practitioners and is lower than boxing and freestyle wrestling. Interestingly, the lactate studies involving wrestlers that most closely match MMA are Callen et al. (2000) who recorded lactate values of 10.6 ± 0.2 Mmol.L via laboratory based testing and Karnincic et al. (2009) reporting 8.60 ± 2.15 Mmol.L from field based testing that pitted elite level competitors against club level competitors. This seems to suggest that MMA competitors will share a similar physiological profile with wrestlers only under laboratory based testing or when put against inferior competition therefore requiring less strenuous activity.

This information could be further extrapolated to suggest that MMA training sessions could utilise boxing and wrestling based drills to further tax and therefore improve their lactate resistance in preparation for the greater lactate production of these techniques in competitive bouts.

4.5.4 Time Motion Analysis

Participants were found to have an almost equal ratio of time spent working to time spent resting. This is in contrast to the W:R of 1:2 to 1:4 as calculated by Del Vecchio et al. (2011). This result shows that an MMA competitor's TMA profile sits between those of a striking based sport such as muay Thai (Silva et al., 2011) and grappling based sports such as BJJ, judo and wrestling (Nilsson et al., 2002; Van Malderen et al., 2006; Del Vecchio et al., 2007; Miarka et al., 2012, Andreato et al., 2013) as the MMA participants engaged in less rest time than a pure striking sport, but less work time than a purely grappling sport. This is understandable when linking the results to the lactate production of the different sports, as MMA produced similar amounts of lactate to the striking sports of taekwondo and muay Thai, but less than the grappling sport of BJJ and much less than wrestling.

When looking at the MMA participant's active time in the current study, the data shows that when the participants did engage, they were more likely to engage in relatively low activity work, such as one or two strikes or holding within a clinch, leading again to the conclusion that MMA competitors spend less time attempting explosive movements. This can be seen more when comparing the results for total amount of time spent attempting takedowns (45 s) and gaining successful takedowns (15 s) against the total amount of time the bout lasted (900 s), showing it to be a very small amount of time engaged in the most explosive, load inducing technique observed. Similarly, once the bouts entered a grounded position, there was very little activity (90 s), with a relatively high occurrence of participants 'locking down' their opponent to simply hold position (22 s). These factors show that MMA competitors are more likely to attempt to defeat their opponent via measured, fine movements rather than high activity, explosive movements.

This approach does not seem to lead to success, however, as despite the small amount of time spent attempting and succeeding in attaining takedowns, the paired samples t-tests showed that the only key difference between the assigned winners and losers of each bout, was the number of successful takedowns. The conclusion that can be drawn from this is that the ability to control whether a bout remains standing or goes onto the ground, determines who controls the pace and activity of a bout and therefore controls the outcome. However, as can be seen from the studies of lactate samples in different sports as well as the accelerometry data from this study, using a grappling dominant approach to a bout could lead to much higher lactate production and therefore more fatigue. Also, as the bout winners attempted more takedowns than the losers, this could show that the bout winners had a higher resistance to or clearing rate of lactate, so they could therefore attempt more takedowns with more explosiveness and have a better chance of being successful. This is an area open for further research with a larger sample size and within competitive bouts to fully assess the importance of these techniques in winning and losing.

4.6 Conclusion

Study two represents two advances in the literature and study of MMA as a sport. The first is that this presents the first time that accelerometry data has been used to track and measure live MMA performance. The second is that this is, to the author's knowledge, the most detailed study of the loads and exertions of competitive MMA fighters in a field based environment, which also demonstrates the usefulness of the application of micro technology, physiological markers and subjective movement analysis to inform the practices of a combat sport. The findings demonstrate that MMA is an exertive sport that causes greater workloads than non-contact sports such as netball and comparable workload to contact team sports such as Australian Rules football and association football. It has also been shown that MMA fighter's energetics more closely match those of striking based athletes as opposed to grappling based ones, whilst MMA's W:R ratio sits in between the two ends of the striking and grappling spectrum. Striking done in isolation against a heavy bag causes more instantaneous exertion than that done in live sparring whereas takedowns in competition elicit significantly more exertion than in isolation due to the different interactions between competitors and training equipment. Finally the detailed relationship between PL_{ACC} and lactate is evidence of the affect workload has on the fatigue of MMA competitors and vice versa.

The key application of this study, however, is the demonstration of how the Minimax x3, in particular the PL and PL_{ACC} variables, could be used to track load and exertion in MMA training sessions and sparring. Further research is required if fully quantified values and training guidelines are to be developed, but as a general tool for the tracking of loads, the Minimax x3 shows promise for use in MMA, especially when used in conjunction with currently used measurements.

CHAPTER 5

EPILOUGE

5.1 Synthesis

This study set out to achieve two key aims: determine the reliability of accelerometry in measuring MMA specific movements and record the loads during simulated MMA competition and training. Study one confirmed the Minimax x3 as a reliable tool for measuring most MMA techniques whilst also revealing the sensitivity of the unit in highlighting the loss or changes of correct technique which allowed study two to detail the overall loads caused by simulated competition. This showed that the Minimax x3 may also be sensitive enough to monitor the fatigue of the athletes during bouts whilst also giving a clear picture of how a competitor changes their technique or movement due to facing a live opponent, however, more focussed research will be needed to substantiate these applications. In terms of the energetics recorded, it could be suggested that MMA fighters derive a significant amount of their energy from anaerobic means although it is not possible to make firm assumptions regarding the proportions of the respective metabolic contributions. Finally, the participants spent an equal amount of time during a bout engaged in physical exertion and actively resting. During the active phases, the participants spend a significant amount of time performing less explosive techniques, despite the bouts being decided by achieving successful takedowns which produced the most load and greatest accelerations. This information allows some future practical applications of accelerometry within MMA to be outlined.

5.2 Practical Applications

The PL and directional acceleration data taken from isolation movements can be used both as an assessment of exertion and efficiency of technique performance.

The values recorded could be tracked during training over a few weeks or months of a periodised training programme, to assess the success or otherwise of the learning of a particular skill. For this to be achievable further research must be carried out to record the accelerometer values of each technique using high standard model MMA practitioners, to attain a 'gold standard' value for each. Once this has been done, a testing schedule can be devised and monitored using the Minimax x3 to track how close to the 'perfect model' an MMA competitor is. Similarly, this process could be done with high level performers from each of the component sports of MMA to discover any differences in the techniques used by practitioners of each sport, i.e., use wrestlers to assess the PL and PL_{ACC} values of takedowns, muay Thai competitors to assess the values of kicking techniques and boxers for punching techniques. The values recorded by MMA practitioners could then be compared to these and be contextualised in terms of differences in workloads of techniques.

Once this has been done, then the values of the isolated techniques for MMA competitors reported in this study can be fully evaluated in terms of the participant's efficacy, technique learning and overall movement and load requirements. It must be stressed, however, that this could only be successfully achieved in conjunction with expert coaching and the knowledge of what construes the 'perfect model'. Simply matching numbers between samples would not provide usable performance indicators, especially for a low-level or novice performer. A key reason for this would be that providing such intricate detail of a gross motor skill would more likely lead to confusion and lack of skill learning on behalf of the participant (Masters, 2008).

Similarly, the Minimax x3 could be used to record PL_{ACC} throughout sparring or training sessions to determine which types of sessions and training methods contribute most to the loading of MMA fighters, thereby allowing the construction of guidelines and structures for planning training sessions and programmes with different aims at different times of the calendar. This would mirror the unit's usage in other studies into training intensity and athlete management in team sports such as football (Castellano and Casamichana, 2010; Casamincha et al., 2013; Wells and Hattersley, 2013; Scott et al., 2013), basketball (Montgomery et al., 2010), rugby league (Varley et al., 2011; Gabbett et al., 2012a; Gabbett et al., 2012b; Johnston et al., 2013) and Australian rules football (Boyd et al., 2012; Mooney et al., 2013). This could potentially negate the issues with training and conditioning planning and injuries suffered in training detailed in Chapters 1 and 2, thus informing the work of coaches, trainers and competitors within MMA. Where the unit cannot be used is in full competition itself, due to the prohibition of competitors wearing anything on their upper body (females can wear breast protectors and sports vests only) (New Jersey State Athletic Control Board, 2002). This means that field testing of PL and PL_{ACC} is limited to simulations and sparring.

This is not necessarily a negative aspect, however, as it has been suggested by Foreman et al. (2012) that the use of the Minimax system to assess in match performance in real-time has little relevance in performance management, due to the difficulty in arranging and assessing large amounts of data quickly enough to make an informed decision on the spot and the cost associated with enabling a single unit to be used exclusively by a single athlete. The latter point is much easier to work around in a solo sport such as MMA as a training centre will not be working with the same number of competitors as rugby or Australian rules football clubs will be, thus allowing a single athlete to use a single unit exclusively during a training camp.

5.3 Further Study

In terms of skill proficiency, research needs to be undertaken into the workloads and accelerations experienced by high level MMA participants as well as the sports that make up the skills utilised in MMA. This will give a set of reference points for how much or how little individual skill learning is taking place. On a similar note, the question of the effects of training on body side dominance could be answered by the use of the Minimax x3 in conjunction with other biomechanical analysis techniques such as video based kinematics analysis, which as Vieten (2010) discussed, is limited within martial arts research to descriptive analysis. Performing these techniques together could elicit much more informative data regarding asymmetry and force production amongst MMA practitioners, as well as participants of other combat sports, than the data presented here or kinematic data could alone.

Two areas of MMA that have not been studied in as much detail here is in the ground grappling phase and the movement phase between techniques during competition. Seeing how these two important facets of performance affect the PL_{ACC} of the participants would provide even more insight to their physiological conditions. What could also not be determined and may also provide a basis for future study is how much the PL and PL_{ACC} variables are affected by receiving strikes from a resisting opponent in the same way this study has recorded the differences experienced when attempting a takedown compared to suffering a takedown.

Finally, it should be researched how much load is experienced by a participant within a standard MMA training session and how this affects the performance of the athlete in the long term to help with the design of training programmes that maximises athlete preparation whilst minimising overtraining and injuries.

5.4 Limitations

The main limitation of this study is the small sample size. Eight participants for Study One and six for Study Two are very small groups and could be an explanation for the lack of statistical significance in some of the data analysis. This may have had an effect in the comparison of the PL of isolated techniques and sparring techniques, where there were large disparities in the sample sizes for each technique. It could also have affected the significance of the Pearson's correlation of PL_{ACC} and lactate from the sparring. In terms of the capillary blood samples used to measure lactate, a great deal more information could have been gathered by taking venous blood samples from the participants, however, this would have been extremely invasive and time consuming to do six times during one testing session. For this reason, capillary blood samples were deemed more appropriate given the aim of the study. A limitation of the Minimax x3 itself was that it was found to be inconsistent in creating bad data or malfunctioning and recording no data at all at several points during testing. This could lead to many practical issues for use in the field by competitive athletes and must be taken into account by any user of this technology.

Finally, there are far more possible techniques that may be used within MMA than the handful used here. For example, whilst only two basic types of takedown were assessed, there are tens of different permutations of each type as well as many other different categories of takedown. As such, future research could consider examining the workloads of the hundreds of different movements, sweeps and submissions that MMA competitors perform on the ground whilst grappling. This study has used a small handful of movements in order to demonstrate how the Minimax x3 can be applied and now that this has been done, further research can continue to explore MMA techniques and skills in this fashion.

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APPENDICES

Appendix A

CONSENT FORM

The Workload Demands of Mixed Martial Arts

Chris Kirk
[redacted]

Please initial box

I confirm that I have read and understand the information sheet, dated ………….. for the above study and have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐

I understand that my participation is voluntary and that I am free to withdraw at any time, without giving reason. ☐

I agree to take part in the above study. ☐

I agree that my data gathered in this study may be stored (after it has been anonymised) in a specialist data centre and may be used for future research and I understand that if I decide to take part I am still free to stop the testing at any point but I will not be able to withdraw my data at any time - this will only be possible up until final data analysis has been undertaken. ☐

I understand that my participation will be anonymous and any details that might identify me will not be included in reports, presentations or publications produced from the study ☐

Please tick box

	Yes	No
I agree to the physiological testing being audio recorded	☐	☐
I agree to the physiological testing being video recorded	☐	☐

Name of Participant	Date	Signature
Name of Researcher	Date	Signature

Appendix B

UCLan Sports Science Labs: Health Screen Questionnaire

Name__________________________ Age_________ Gender M F

Address____

____

Phone___________________

Height______________ Weight_______________ Date of test __________

Profession____

Stage 1 - Known Diseases (Medical Conditions)

1. List the medications you take on a regular basis.

2. Do you have diabetes? No Yes
   a) if yes, please indicate if it is insulin-dependent diabetes mellitus (IDDM) or non-insulin-dependent diabetes mellitus (NIDDM).
   IDDM NIDDM
   b) if IDDM, for how many years have you had IDDM?
   _________ years

3. Have you had a stroke? No Yes

4. Has your doctor ever said you have heart trouble? No Yes

5. Do you take asthma medication? No Yes

6. Are you or do you have reason to believe you may be pregnant? No Yes

7. Is there any other physical reason that prevents you from participating in an exercise program (e.g. cancer; osteoporosis; severe arthritis; mental illness; thyroid, kidney or liver disease)? No Yes

Stage 2 - Signs and Symptoms

8. Do you often have pains in your heart, chest, or surrounding areas, especially during exercise? No
   Yes

9. Do you often feel faint or have spells of severe dizziness during exercise? No
   Yes

10. Do you experience unusual fatigue or shortness of breath at rest or with mild exertion? No
    Yes

11. Have you had an attack of shortness of breath that came on after you stopped exercising? No
    Yes

12. Have you been awakened at night by an attack of shortness of breath? No
    Yes

13. Do you experience swelling or accumulation of fluid in or around your ankles? No
    Yes

14. Do you often get the feeling that your heart is beating faster, racing, or skipping beats, either at rest or during exercise? No
    Yes

15. Do you regularly get pains in your calves and lower legs during exercise which are not due to soreness or stiffness? No
    Yes

16. Has your doctor ever told you that you have a heart murmur? No
    Yes

Stage 3 - Cardiac Risk Factors

17. Do you smoke cigarettes daily, or have you quit smoking within the past two years? No
    Yes

    If yes, how many cigarettes per day do you smoke (or did you smoke in the past two years)?
    ________ per day

18. Has your doctor ever told you that you have high blood pressure? No
    Yes

19. Has your father, mother, brother, or sister had a heart attack or

suffered from cardiovascular disease before the age of 65? No
Yes

If yes,

a) Was the relative male or female?

____

b) At what age did he or she have the stroke or heart attack?

____

c) Did this person die suddenly as a result of the stroke or heart attack? No
Yes

20. Have you experienced menopause before the age of 45? No
Yes

If yes, do you take hormone replacement medication? No
Yes

If known, enter blood pressure and blood lipid values:

21. What is your systolic blood pressure?
_________mmHg

22. What is your diastolic blood pressure?
_________mmHg

23. What is your serum cholesterol level?
______mmol/L or mg/dL

24. What is your serum HDL level?
______mmol/L or mg/dL

25. What is your serum triglyceride level?
______mmol/L or mg/dL

Stage 4 - Exercise Intentions

26. Does your job involve sitting for a large part of the day?
No Yes

27. What are your current activity patterns?

a) Frequency: ______exercise sessions per week

b) Intensity: Sedentary Moderate Vigorous

c) History: <3 months 3-12 months >12 months

d) Duration: ______minutes per session

28. What types of exercises do you do?

29. Do you want to exercise at a moderate intensity (e.g. brisk

walking) or at a vigorous intensity (e.g. jogging)? Moderate
Vigorous

I acknowledge that the above information is correct to the best of my knowledge.

Sign: ________________________________ Date: ___________________

Appendix C

Results of Shapiro-Wilk test of Normality for PL and PL_{ACC} of Isolated Techniques

Technique	**PL *p*=**	**PL_{ACC} *p*=**
Jab	.629	.964
Cross	.733	.680
Left Hook	.167	.521
Right Hook	.167	.259
Left Leg Kick	.184	.795
Right Leg Kick	.782	.753
Left Body Kick	.113	.777
Right Body Kick	.168	.505
Left High Kick	.442	.266
Right High Kick	.973	.295
Left Punch	.973	.292
Right Punch	.057	.155
Left Elbow	.265	.861
Right Elbow	.567	.915
Left Knee	.918	.964
Right Knee	.630	.981
TD Double Leg Off	.539	.151
TD Double Leg Def	.814	.205
TD Single Leg Off	.465	.970
TD Single Leg Def	.070	.236

Appendix D

Results of Shapiro-Wilk test of Normality for PL, PL_{ACC}, $PL_{ACC.}min^{-1}$, Lactate and TMA Technique Totals of Sparring Bouts

Variable	***p=***	**Variable**	***p=***
Lactate Round One	.803	Left Punch PL	.923
Lactate Round Two	.084	TD Double Leg Off PL	.119
Lactate Round Three	.880	TD Double Leg Def PL	.286
PL_{ACC} Round One	.998	Punch Winners	.417
PL_{ACC} Round Two	.602	Kick Winners	.417
PL_{ACC} Round Three	.667	Ground Punch Winners	.688
$PL_{ACC.}min^{-1}$ Round One	.775	Clinch Strike Winners	.736
$PL_{ACC.}min^{-1}$ Round Two	.598	TD Attempted Winner	1.000
$PL_{ACC.}min^{-1}$ Round Three	.664	TD Successful Winners	1.000
Jab PL	.836	Punch Loser	.463
Cross PL	.623	Kick Losers	.559
Left Hook PL	.109	Clinch Strike Losers	.463
Right Hook PL	.483	TD Attempted Losers	1.000
Left Leg Kick PL	.715	Standing Knees Losers	.637
Right Leg Kick PL	.089		
Left Body Kick PL	.757		
Right Body Kick PL	.788		
Left High Kick PL	.146		
Right High Kick PL	.852		

Appendix E - Risk Assessment

Venue: [redacted]

Assessed by: Chris Kirk Date: 22/1/2013

Activity	Hazards/Risks	How they may arise	Who may be harmed	Risk Rating (Low/Medium/ High)	Current Control Measures	What further action is necessary
Warm up	Slip, trip, pulled muscle	Contraindicated movements, not fully warming up joints and muscles	Participants	L	Tester to lead full warm up under supervision of facility owner First aid box kept on site	
Isolation Strike Testing	Slip, trip, pulled muscle, twisted joints	Incorrect techniques, not fully warming up joints and muscles	Participants	L	Tester to lead full warm up under supervision of facility owner First aid box kept on site Participants to use full hand wraps and be experienced trained competitors to limit incorrect technique use	
Isolation Takedown Testing	Slip, trip, pulled muscle, twisted joints	Incorrect techniques, not fully warming up joints and muscles, performing drills at too high an intensity	Participants	L	Tester to lead full warm up under supervision of facility owner First aid box kept on site Participants to use full hand wraps and be experienced trained competitors to limit incorrect technique use	
MMA Sparring	Slip, trip, pulled muscle, twisted joints, bruising of skin, particularly	Incorrect techniques, not fully warming up joints and muscles,	Participants	H	Tester to lead full warm up under supervision of facility owner First aid box kept on site Participants to use full hand wraps	

	face, cuts to head and nose area	use of incorrect sparring equipment			and be experienced trained competitors to limit incorrect technique use. Full sparring equipment to be used. Participants to be briefed in full prior to beginning testing of the modified rules for sparring and the aim of testing.	
Taking of capillary blood samples	Spread of blood borne viruses between participants and tester. Latex allergies	Not covering sampling sites between tests, tester not wearing gloves during taking of sample. Incorrect storage/disposal of testing strips, wipes and needles.	Participants Tester	H	Tester to wear a new pair of non-latex rubber gloves for each sample, one-use needles for puncturing of capillary bed, sampling site to be cleaned prior to immediately after each sample with alcoholic wipe. Participants to wear a single finger non-latex glove over sample site with sparring glove over top to prevent cross contamination of samples. All used needles and testing strips to be immediately disposed of in sharps bin, all used wipes and testing strips to be immediately disposed of in orange waste bag.	

Appendix F

Example Catapult Sprint output showing Minimax x3 data for a single participant's sparring bout.