SPORTS ANALYSIS, TRAINING CONSIDERATIONS AND APPLIED METHODS FOR MIXED MARTIAL ARTS

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ABSTRACT

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Introduction. Mixed Martial Arts (MMA) is a combat sport and a form of martial art that combines striking and grappling skills. Due to there not being any restrictions between switching from striking to grappling, the sport requires multiple skill sets usually derived from different martial arts. This combined with the fact that MMA requires the athlete to be highly conditioned both from an endurance and strength and power standpoint, places very large challenges on how to optimally design training programs so that individual athletes get the most out of them (Schick et al. 2010, Lenetsky et al. 2012, Alm et al. 2013, Lachlan et al. 2013, Souza-Junior et al. 2015). Psychological factors also play a huge role for MMA performance and will also be briefly addressed. Research is young and limited in MMA and therefore presents multiple issues in drawing strong conclusions. No studies have been done on female MMA athletes yet so the physiological characteristics and physiological requirements all are directed towards males. This however only is a minor limitation in context to what a female MMA athlete can get out of this paper. This paper is directed towards professional MMA athletes or athletes seeking to become professional.

Biomechanics. MMA involves stand-up and ground based combat in multiple forms so biomechanics are a challenge to isolate for MMA. None the less, strong general guidelines can be found to efficient energy transfer (avoiding energy leak) by moving through kinetic chains and directing that energy in multiple biomechanical planes. Clear differences in energy transfer can be found between high level and low level martial art athletes where usually the key difference is the use of the lower body and the hip as the main source for power.

Endurance demands. With 3-5 rounds lasting five minutes with one-minute break between rounds MMA is least to say quite demanding on all three energy systems (alactic, lactic and aerobic). Due to the long round lengths MMA seems to place more demand on the aerobic energy system compared to other combat sports, although high post bout acidosis has been reported based on RPE and blood lactate values (Antmann et al 2008, Kirk et al. 2015). Evidence towards the clear need for a strong aerobic engine can be observed from V02max tests done on male MMA athletes where test results on amateurs and professionals ranged from 57 – 62 ml/kg/min (Schick et al. 2010. Alm et al. 2013), and not surprisingly, high anaerobic thresholds are advised (Alm. et al. 2013). MMA is a highly interval based sport with its bursts of activity. Therefore, MMA athletes also require substantial anaerobic development and an efficient buffering capacity.

Strength and power demands. Because a lot of efforts in MMA require a lot of power training in different areas of the force – velocity curve becomes evident. A high relative maximal strength for the lower body (~2

x own body weight deadlift/squat) and the upper body (~1.2 x body weight in bench press, with probably the same value for the opposite muscle group) are needed. This serves as a base but to see it in performance maximal strength needs to be converted toj high levels of speed and power. Around 50 – 57 cm countermovement jump results have been reported among high level male MMA athletes but unfortunately no horizontal jump tests have been done (Schick et al. 2010. Alm et al. 2013). The capability to produce horizontal force can also be measured indirectly via looking at acceleration results via sprint testing. Unfortunately, only wrestlers have been tested in such criteria and have reported 10 meter times of ~1.73 seconds (Demirkan et al. 2015).

Periodization. As mentioned before, due to the multiple demands of the sport, programming for MMA presents a lot of challenges. Because both endurance and strength training are used it is wise to first explore what currently concurrent training research says about interference effects and how to avoid them. Once this is established solutions for programming in MMA are found in periodization methodology. There is no single approach that works, therefore multiple tools are advised. In general, though, while taking into consideration the risk of short notice fights, a combination of linear (block) and undulating periodization methods are advised (Lenetsky et al. 2012).

Key words: Mixed Martial Arts, MMA physiological requirements, MMA strength and conditioning

TABLE OF CONTENTS

ABSTRACT

1. INTRODUCTION TO MMA ... 6

2. SPORT ATTRITUBTES ... 7

2.1 Strategies ... 8

2.1.1 Brawl and Sprawl ... 8

2.1.2 Ground and Pound ... 9

2.1.3 Submission Seeking ... 9

2.1.4 Score oriented fighting ... 9

2.1.5 Clinch Fighting ... 9

2.2. Physiological characteristics of an MMA bout ... 10

2.3 Physical characteristics of an MMA athlete ... 13

2.3.1 Body composition ... 13

2.3.2 Measured endurance characteristics ... 14

2.3.3 Measured strength characteristics ... 15

2.3.4. Measured Speed & Power characteristics ... 16

2.4 Cutting weight in MMA ... 18

2.5. Psychological factors in MMA ... 20

3. MMA IN FINLAND ... 23

3.1 Rule categories and weight class divisions ... 24

4. INJURY CONSIDERATIONS MMA ... 25

4.1 Concussions ... 26

4.2 Injury prevention and rehabilitation strategies ... 27

5. THE SCIENCE OF DIFFERENT TRAINING IMPLICATIONS FOR MMA ... 29

5.1 Biomechanics in MMA ... 29

5.2. Rate of force development ... 31

5.3. The SSC-cycle and important structural adaptations ... 32

5.4. Forms of strength- & power training ... 34

5.4.1 Types of contractions in strength training and in MMA ... 36

5.4.2 Neuromuscular adaptations from different forms of strength training ... 36

5.4.3 Core training in MMA ... 39

5.4.4 Time under tension – benefits and possible performance risks for MMA.................................... 41
5.4.5 Strength training and its role in improving endurance in MMA 42
5.4.6 Conclusion of strength & power training implications for MMA athletes 43
5.5 Endurance training for MMA.. 45
5.5.1 The role of low intensity conditioning training 46
5.5.2 The role of different forms of high intensity conditioning to maximize performance in MMA 49
6. PROGRAMMING CONSIDERATIONS IN MMA 53
6.1. The science and programming of concurrent training 53
6.1.1 What forms of strength and endurance training go well together in the same program? 56
6.1.2 Order effect and recommended recovery time between strength and endurance sessions 57
6.2 The goal and challenges of periodization within MMA.. 59
6.2.1 Important periodization concepts.. 60
6.3 Proposed solutions and examples for periodization within MMA 63
6.3.1 The linear periodization approach 65
6.3.2 The Undulating & Conjugative periodization approach 65
6.3.3 Required training frequency of specific stimulus for optimal results 68
6.3.4 Microcycle periodization examples of concurrent training... 69
7. PERIODIZATION EXAMPLE OF A PROFESSIONAL MMA ATHLETE 72
7.1. Introduction to the chosen athlete 72
7.2 Macrocycle and mesocycle structure used by Anton Kuivanen.. 73
8. DISCUSSION 77
9. REFERENCES.. 82

1. INTRODUCTION TO MMA

Mixed Martial arts is a combat sport and a form of Martial art that combines striking and grappling skills. Due to there not being any restrictions between switching from striking to grappling, the sport requires multiple skill sets usually derived from different martial arts. Based on the opponent's skill sets, the fighter can choose different methods of how to use their body as a weapon to attack and defend. Mixed martial art first started with different disciplines fighting against each other, such as a Kick-boxer versus a Jiu-Jitsu athlete. This concept evolved so that MMA athletes realized the value of specializing in different martial arts. Therefore, MMA has become a unique fusion of different martial art disciplines based on what is needed to deal with the skill set of the opponent (Schick et al. 2010, Lenetsky et al. 2012, Alm et al. 2013, Lachlan et al. 2013, Souza-Junior et al. 2015).

The history of Mixed Martial Arts style fighting is long, going back all the way to the Classic Greek era in form of an ancient Olympic combat sport called Pankration that mixed striking and grappling skills. In Western countries, modern MMA made its breakthrough in 1993 when a Mixed Martial arts tournament was held by the UFC organization (Ultimate Fighting Championship) in Denver. The event summoned eight representatives of the various martial arts that fought against each other in an octagonal cage. To the astonishment to the audience was that the winner of the tournament became the Brazilian Royce Gracie who was the lightest of all the contestants. Royce's performance showed what an important role it is to have a high skill set in grappling or in MMA terms; “ground game”, and at the same time revealed the weaknesses of the traditional martial arts (Suomen vapaaotteluliitto).

In modern MMA the fight usually takes place in an octagon formed “Cage”, where fighters commence in battle for a predetermined amount of rounds with specific breaks. If the fighters do not manage to achieve a knockout/technical knockout or perform a successful submission on their opponent (leading to a “tap-out” victory) before the last round ends the winner will be determined by points. Other options for winning are if the opponent gets disqualified, injured, or the opponents corner team can also literally “throw in the towel”, which is a signal from the corner team in making the decision for their athlete to give up. Different organizations exist in the MMA realm, but in modern MMA the rules and the fighting environment itself only vary to a small extent. One example would be elbow strikes; the most popular and highest ranked MMA organization UFC allows elbow strikes, whereas DREAM, a more Asian based MMA organization, prohibits them.

Although MMA is considered more from a critics stand point violent (White C, 2007), it is extremely physically and psychologically demanding. Due to the nature of the combat rules being freer, the fighter must devote an extreme amount of time learning different combat methods while encompassing an impressive strength and stamina base. The sport is also very psychological; MMA requires a lot of bravery, discipline and persistence.

MMA seems to be a vastly growing sport right now. According to a study published in 2010 on physiological characteristics of MMA fighters (Schick et al. 2010), UFC broadcasts have drawn in before 2010 an average of 1.5 million viewers while generating more revenue than any other pay-per-view events. According to some surveys on UFC viewer ratings, mixed martial arts is also considered currently as potentially being one of the fastest growing sports in the world (Philpott. 2010).

Even though the popularity of MMA is steadily growing, knowledge of the physiological characters on the sport are relatively few compared with other similar martial art sports such as like Judo, Taekwondo or Wrestling (Lenestky et al. 2012). Although this is true, there seems to be a growing interest within the sport science community to research physiological elements within MMA.

Although in Finland there are officially 4 rule classes in MMA (A-, B-, C-, and D – class), which two are used for amateur fighters (C & D – class), this MMA sport analysis will more focus on the highest class (A-class), where the physical requirements are the largest.

The purpose of this seminar work is to build a strong scientific base for MMA and hopefully help to connect the science into practice for MMA athletes & coaches. When more studies are published they can be easily added to the structure or this paper can help other fellow scientists build an even stronger case in the future. It is important to note that due to the lack of studies on women in MMA, this sport analysis is more scientifically directed towards men, but should be in no way disregarded by women and provides valuable information to both genders.

2. SPORT ATTRITUBTES

There are multiple factors that contribute to a MMA fighter’s success. As with most sports it will inevitably come down to a balance between technique & strategy, athleticism and psychological factors. Like most combat sports it is fascinating from the perspective that it requires substantial focus from all the above mentioned categories. Therefore, the training is incredibly time consuming at a professional level and changes more or less depending on your opponent’s attributes more than any other combat sport. An MMA fighter does not have to concern themselves with fighting equipment because the only thing they are wearing in a professional fight is a protective cup, shorts, mouth guard and gloves, which are usually standardized. If the fight is in an octagon type “cage”, which an internationally accepted format for most professional MMA leagues, the change in environmental factors between fighting surfaces are usually considered insignificant.

2.1 Strategies

The techniques utilized in MMA generally fall into three categories: striking techniques, clinching techniques, or grappling techniques (Lenetsky et al. 2012).

The bout begins in a standing striking combat form with both opponents approaching each other from their corners. This type of combat is composed of punches, kicks, knees, and elbow strikes. The athletes can stay in a specific range however long they want, and many bouts stay completely in the standing striking combat form. If the MMA athlete thinks it's strategically viable, he can transition from striking range into clinch range by grabbing the opponent.

The clinch is basically grabbing the opponent in a grappling range of combat where the fighter is trying to gain body control of the opposing athlete and engaging with short range of motion strikes, such as punches, elbows and knees. The athlete may also attempt to get in a position for a trip, throw or a takedown to take the fight to the ground and therefore transitioning into grappling techniques.

Once the athletes are on the ground they will try to gain a dominant position either by getting in a striking position, submission position, or to be able to get back up. Athletes are still allowed to punch and elbow each other to the head and body as well as knee and kick but only to the body according to MMA's Unified Rules (UFC. Rules and regulations)

Most athletes in MMA usually have their specific strengths depending on their martial arts background. Although a wide skill set has been considered important in the past, due to the aggressive growth of the sport, the demand for modern MMA athletes to master many techniques possibly outside their comfort zone has grown. To make strategy simpler, tactical skill sets have been sometimes divided into the following five categories: Brawl and Sprawl, Ground and Pound, Submission Seeking, score orienteered fighting and Clinch Fighting (Snowden et al. 2010. p. 14).

2.1.1 Brawl and Sprawl

The Brawl and Sprawl tactic is usually used by fighters who consider their strengths to be in their striking techniques, hence the word "Brawl". The word "Sprawl" word is equally as important to a strong striker because if they want to keep the fight standing up and not on the ground, they will have to master a strong takedown defence. This takedown defence is usually called "sprawling", hence the expression "Brawl and Sprawl". These striking techniques can be seen in the Olympic sports such as boxing and taekwondo and non-Olympic (but still popular) combat sports such as Thai-boxing (where elbow techniques are derived from) and kickboxing (Snowden et al. 2010. p. 75).

2.1.2 Ground and Pound

Ground and pound strategy is when your goal is to take the other fighter down to the ground by either a takedown trip, or a throw. After that the goal is to get yourself in dominant grappling position so you can strike your opponent with your fists, knees (to the body), elbows or even kicks (to the body) until the opponent either submits or is knocked out. This strategy of fighting also is used often together with the submission seeking strategy, which is explained in the next section. These added striking aspects allow grappling in MMA to vary widely from grappling in its related component combat sports. Despite the evolution from the original combat sports, MMA grappling still draws heavily from the Olympic sports of freestyle and Greco-Roman wrestling and to a lesser extent current Olympic judo (Souza-Junior et al. 2015).

2.1.3 Submission Seeking

Similar to the ground and pound strategy, a submission seeker must also first take the fight to the ground by either a takedown or a throw. After this the goal is to apply a submission hold, which will force the opponent to submit or “taping out” (two taps with your hand on any surface signals that you are giving up). As mentioned earlier it is normal to combine this method with ground and pound strategy. Submission seeking is popular among fighters who have backgrounds such as Brazilian Jiu-Jitsu, Catch Wrestling, Judo, Sambo etc.

2.1.4 Score oriented fighting

Because takedowns or throws are valued also in terms of points in MMA, fighters that are superior with takedowns (usually fighters with a wrestling background), in some situations they will just perform a takedown on the other fighter for points but then come back up again. This strategy is used often when a wrestler who is comfortable with his brawl and sprawl skills and who is facing an opponent with strong submission background, such as a Brazilian Jiu – Jitsu specialist.

2.1.5 Clinch Fighting

The word clinching basically means grappling in a standing position while trying to get into a good position to elbow or knee each other, or even in some cases a submission attempt. Clinching experts in terms of striking in a clinched position are usually from a Muay Thai background, which is a striking combat sport that allows clinching with elbow and knee strikes. Boxing style techniques are used in a clinching position as well, commonly termed ‘‘dirty boxing’’. Trips, throws, and takedowns used in the MMA clinch come primarily from the Olympic combat sports of judo and freestyle and Greco-Roman wrestling. The MMA clinch does have its own evolution also due to the fact that component combat sports for MMA such as Judo and Brazilian Jiu-Jitsu have Gi uniforms in competition, where as in MMA there is not. Clinching is usually performed in MMA while leaning into the Cage. Because MMA fights are usually fought in a octagon formed cage with 7 feet metal wire walls, there is a certain skill set in using the cage wall as a leverage point. People with good clinching skills take advantage of this. As mentioned earlier, submission fighters also use a clinch position to sometimes set up their submission attempts. Fighters with a Judo background are usually good with this, but this can vary.

2.2. Physiological characteristics of an MMA bout

Although there are different strategies used by different types of athletes in MMA, in general a MMA athlete needs to be able to produce repeated explosive efforts through the entire bout, preferably at or close to a maximal effort level. With round lengths extending to 5 minutes, this intense structure requires multiple attributes from both sides of the strength & conditioning spectrum and therefore MMA becomes a fascinating multidimensional sport to train and adapt to.

It is well known that all 3 energy system pathways contribute to the energy demand in MMA (Table 1) (Bounty et al 2011). These energy systems are the two anaerobic energy systems (Alactic and Lactic) and the Aerobic energy system (in its different forms). The alactic system (Phosphocreatine system, PCr) is the most powerful energy pathway in the body. With its capability to release nearly direct energy within the muscle cell(s) it is the ideal energy system pathway for such events as knockout attempts and explosive takedowns (Table 1). It is unfortunately limited in how much it can be used due to its low storage capabilities; only around 6-10 seconds with relatively long recovery periods (McMahon & Jenkins. 2002). Literature is unclear whether the storage amount can be increased in a significant amount or not, but there has been some research indicating that with appropriate training stimulus recovery kinetics of the phosphocreatine within the muscle cell can be increased (Forbes et al. 2008), which could be essential for an MMA athlete. More about this will be discussed later in the high intensity conditioning training section.

The anaerobic system is based on the anaerobic glycolysis pathway that derives its energy from glucose molecules but instead of sending pyruvate into the aerobic pathways it ends up reduced into a lactate molecule and one free hydrogen ion. This system is clearly faster than the aerobic pathways to produce ATP but unfortunately is not sustainable once the production of hydrogen ions exceeds the removal rate of the hydrogen ions (Robergs et al. 2004). Due to the constant explosive actions in MMA, anaerobic glycolysis will be aggressively used (Table 1) and therefore acidosis will inevitably arrive (Alm et al. 2013). It is important to note in this points that lactate is often wrongly associated with lactic acid (Robergs et al. 2004). Lactate in fact works as a buffer to remove hydrogen ions from the muscle cell and then enters the bloodstream and travels to the liver where it is converted back to glucose through the gluconeogenesis pathway. It also can be used directly as energy in aerobic muscle cell environments. It is important to note that although lactate is not the enemy; its production coincides with cellular acidosis and remains a good indirect marker for cell metabolic conditions that induce metabolic acidosis (Robergs et al. 2004).

In Martial Art sports such as Boxing, Wrestling, Kick Boxing and Muay Thai the round length usually varies between 2-3 minutes with a 1-2-minute break. The amount of rounds varies from 3-12 (Mikeska, 2014). In MMA round length extends to 5 minutes and with only 1-minute recovery before the next round. Round amount can vary from 3-5 (A-class rules), therefore it is considered that there is an increasing demand from the aerobic system within MMA compared to some martial arts (Alm et al. 2013). As we can see from table 1, the aerobic system is essential for recovery kinetics and therefore performance. Alm et al. (2013) mentioned the issues of not giving the aerobic system enough attention: "because the rest period between two consecutive rounds in MMA is only 1 minute, a primary utilization of the lactate energy system indicates no chance of lactate recovery between rounds, thus fatigue early and loss of competition. Therefore, even though anaerobic capacity is very important in MMA, high aerobic capacity guarantees to

Table 1: Energy demands of the 3 energy systems related to the requirements of a Mixed Martial Arts athlete (Bounty et al. 2011)

Pathway	Brief description	Duration	Application
Phosphagen system (anaerobic)	The most immediate source of energy (i.e., ATP utilization/ production)	Approximately, the first 3–6 seconds of intense exercise	Explosive takedown attempt; rapid combination of strikes
Glycolysis (anaerobic)	Provides ATP at a fast duration but cannot be sustained. This stage also produces lactic acid	Approximately, 6–30 seconds of intense exercise	Grappling for maintaining or controlling position (i.e., tie-ups, positional changes); longer duration striking
Oxidative phosphorylation (aerobic)	Provides ATP at a relatively slower rate, but it can be sustained for a much longer duration	Typically, it refers to exercise of longer duration (i.e., 2 minutes to several hours)	Used in recovery between anaerobic burst; circling an opponent; latter stages of a round

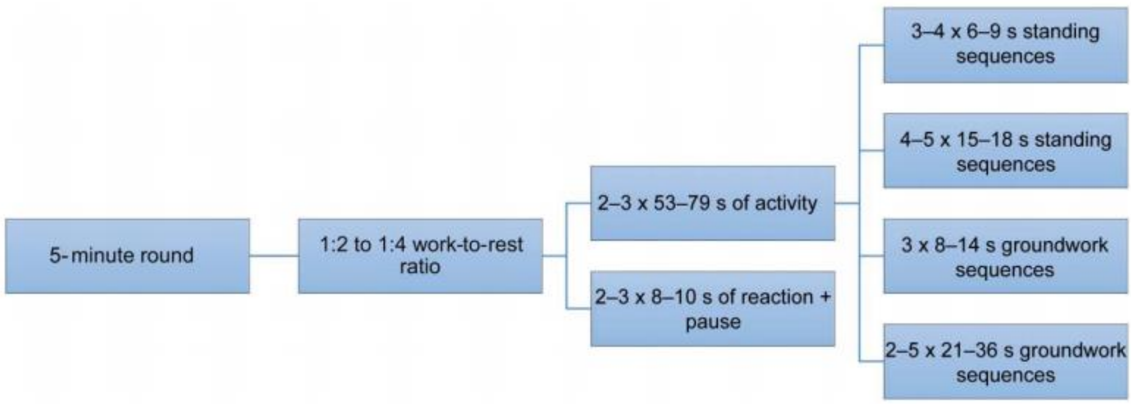
sustain an intensive competition". Alm et al. 2013 concluded that the higher the MMA athlete's aerobic conditioning, the faster the athlete can return to an aerobic environment after "visiting" the anaerobic environment through sharp bursts of activity. Unfortunately, no energy system distributions are presented between the anaerobic and aerobic pathways in MMA research, but a strong guess would be that they are close to equal with a slight lean in either direction. This is only speculation though at this point.

In Amtmann et al. (2008) study 4 MMA athletes were tested for lactate and RPE (Rate of Perceived Exhaustion) both after training and competition in a national-level MMA bout so that both environments could be compared. It is important to note some national-level events in MMA allow entry of amateur level athletes and even first-time competitors. The majority of the athletes tested in Amtmann et al. (2008) study were first-time fighters, therefore results should not be assumed to represent the highest level of MMA performance. The results showed that lactate and RPE produced post training (8.1–9.7 mmol and 15–19 RPE) were similar to those found post competition (10.2–20.7 mmol and 13–19 RPE). It is important to remember that variation seen in the post bout blood lactate and RPE testing can be partially explained by the variation in bout stoppage times. Some bouts went all rounds and some ended quickly in the opening rounds.

A recent study from Kirk et al. (2015) tested post bout blood lactate values in 6 experienced MMA athletes that were most likely more conditioned than the athletes tested in Amtmann et al. (2008) study, but via a simulated 3x5 minute bout. The results were 9.25 ± 2.96 mmol of blood lactate 5 minutes post bout with a work:rest ratio of 1:1.01, which is higher than work:rest ratios reported from real bouts: 1;2 - 1:4 (Lachlan et al. 2013), but can be partially explained by the bouts being simulated. Post blood lactate information after simulated bouts also has to take into consideration how lactate might slightly be higher in real bouts due to psychological factors. None the less, based on Amtmann et al. (2008) study and Kirk et al. (2015) study we can for now conclude (with limitations) that around 10 mmol of blood lactate is a realistic post-bout lactate value found in MMA, especially when there is no early stoppage. It is interesting to compare blood lactate data from similar combat sports and to use sports that represent grappling and striking. In elite level boxing, Smith (2006) reported post-bout blood lactate values of ~13.5 mmol in England's international senior amateur boxers (4x2 minute rounds). In elite level wrestling (Greco-Roman), Nilsson et al. (2002) reported no post bout blood lactate values but reported mean blood lactate values of 14.8 ± 2.7 mmol of the final bouts in 1998 Greco-Roman wrestling world championships (1x5 minute round). Wrestlers in Nilsson et al. (2002) study also reported the highest fatigue in the arms. Although blood lactate accumulation values have their setbacks for strong conclusions, lower reported average values of blood lactate in MMA vs. wrestling and boxing correlates with what was mentioned earlier about the increased contribution of the aerobic energy system in MMA due to the longer rounds. Although lower blood lactate values were reported in MMA compared to other combat sports, 10 mmol values are still high and therefore MMA athletes still need to work on the anaerobic system and acidosis buffering capacity for both the upper and lower body.

More specific work:rest ratios have also been studied in MMA (Table 2). Although there is a significant variation in the bursts of work (standing vs. ground game), the structure in Table 2 helps paint a picture of the interval nature of the sport. We can observe that 1:2 to 1:4 work:rest ratio is quite normal, but as mentioned earlier the lengths of activity vary considerably based on what methods are being used. For example in wrestling work:rest ratios have been reported to be 3:1 where as in striking sports such as Muay Thai 1:6 (Lachlan et al. 2013). In terms of how long an athlete needs to be able to produce an all-out interval effort when it really matters, one study report after analysing 52 professional Brazilian MMA athlete's bouts that 77% of them were decided during high-intensity sequences lasting 8–14 seconds. Many of these bouts ended in the third round and on the ground (Del Vecchio et al. 2011). This information combined with the information provided in Table 2 an MMA athlete has to clearly be able to produce at least 10-15 second burst(s) of activity when in a fatigued state both striking and on the ground.

Table 2. Average Work to Rest ratios and their specific strategy distributions within a 5 minute Mixed Martial arts bout (Lachlan et al. 2013)



2.3 Physical characteristics of an MMA athlete

As mentioned earlier, there have not been many studies published on the physiological characteristics of MMA athletes. Therefore, in this situation, there was a demand to take more data by comparing other combat sports that are normally seen as background sports for MMA. Boxing and wrestling were chosen so that there would be a combat sport that represents physiology characteristics from both sides of the striking – grappling spectrum. Middle weight athletes from wrestling and boxing were chosen because the two MMA characteristics studies that were found compare men in a similar weight division.

2.3.1 Body composition

As we can see from table 3, the data that was chosen to give a picture of an MMA athlete's body composition was taken from body fat and BMI (Body mass index results). Even though body fat varies slightly from weight class to weight class especially comparing light weight and heavy weight athletes (Guidetti et al. 2012), we can still see that in the combat sports presented in Table 3 chosen for comparison that variation between participants is low concerning body fat % (Alm et al. 2013, Demirkan et al. 2015, Guidetti et al. 2012, Schick et al. 2010). Elite wrestlers in Demirkan et al. (2015) study have in average lower body fat % compared to the other combat sports. What was also interesting is that professional MMA athletes seemed to have higher fat % than Amateur MMA athletes. This is not obviously ideal but is partially explained by different points in season (post competition vs. pre competition etc.) where body fat % variations can be seen (Alm et al. 2013).

Comparing the body fat % to the BMI score we can get an indirect picture of how much muscle mass there potentially is. Generally, if a BMI score is in the normal zone (21-25) or above (25 +) and the fat percentage is low, we can assume that there might be more muscle mass than average. Keeping this in mind and looking at table 3, we can see that Wrestlers and MMA athletes potentially have in average lower fat % and/or more muscle mass than the boxers. This is a generalization however, but one could argue that athletes in MMA get more muscle mass growth stimulus from wrestling, potentially because of its anaerobic training environment (Demirkan et al. 2015). How this information is used in training however, is completely different.

Table 3: Body composition

Tests:	11 Amateur MMA fighters (Schick et al. 2010)	5 Professional MMA fighters (Alm et al. 2013)	8 middle weight Professional Boxing (Guidetti et al. 2012	12 Elite middle weight wrestlers (Demirkan et al. 2015)
Body fat %	11.7 ± 4.0	12.25 ± 0.54	14.5 ± 1.5	7.4 ± 1.2
BMI (Body mass index)	25.3 (Counted indirectly via reported height and weight average)	24.8 (Counted indirectly via reported height and weight average)	24.7 (Counted indirectly via reported height and weight average)	22.7 ± 1.1

2.3.2 Measured endurance characteristics

Unfortunately, there was either a lack of multidimensional testing or incomparable testing methods in the studies. Even though these issues were present there were some similarities in testing so that some comparison was possible. Whether all studies had them or not, the tests that were chosen to give a strong picture of endurance characteristics were VO_{2max} values, threshold % (based on max heart rate) and 30 second Wingate (anaerobic capacity & power) test information (Table 4). These tests were considered to give a strong picture in both aerobic and anaerobic characteristics. Unfortunately, only one test was comparable between all studies, and that was the VO_{2max} treadmill test values. Based on Table 4 values, we can see that professional MMA athletes seem to have the highest VO_{2max} scores and then boxing -, amateur MMA and wrestling athletes have very similar scores not far below professional MMA athletes. Although there was a low subject amount in the professional MMA study, these findings could potentially be explained by the nature of professional MMA bouts. Due to the longer rounds in professional MMA compared to boxing and wrestling, there probably is a higher demand for aerobic capacity (VO_{2max}) (Alm et al. 2013).

Only Alm et al. (2013) presented ventilatory threshold values (aerobic/anaerobic thresholds) based on % of maximal heart rate. These findings will be interesting to compare once more studies are published with similar information. In theory, a high anaerobic threshold will help the athlete stay out of the fatiguing anaerobic zone as much as possible, and a high aerobic threshold supports recovery between rounds (Alm et al. 2013). Alm. et al. (2013) concluded that the professional MMA athlete's seemed to have above average higher anaerobic thresholds compared to similar sports.

Only Demirkan et al. (2015) study tested anaerobic power and capacity via the Wingate test on elite wrestlers. Again the information will be interesting to compare once more studies are published on MMA athletes where the same test is used. We can conclude that although aerobic capacity is very important in MMA, so is anaerobic (Schick et al. 2010, Alm et al. 2013), and the Wingate test is internationally used to test anaerobic power and capacity.

Table 4: Measured endurance characteristics

Tests:	11 Amateur MMA fighters (Schick et al. 2010)	5 Professional MMA fighters (Alm et al. 2013)	8 middle weight Professional Boxing (Guidetti et al. 2012	12 Elite middle weight wrestlers (Demirkan et al. 2015)
VO_{2max} **teadmill (ml/kg/min)**	55.5 ± 7.3	62.75 ± 4.86	57.5 ± 4.7	57.6 ± 2.0
VT 1: Aerobic threshold Wasserman (% mHR)		63.19 ± 7.7		
VT 2: Anaerobic threshold Wasserman (% mHR)		82.22 ± 7.22		
30-second Wingate test - leg peak power (relative)				15.3 ± 1.2 W/kg
30-second Wingate test - leg average power (relative)				7.7 ± 0.3 W/kg

2.3.3 Measured strength characteristics

The tests that were chosen to portray strength characteristics were compound lifts such as the squat, deadlift, bench press and even hang clean (Table 5). Although hang clean is considered more of a power movement, due to maximal weights were tested instead of maximal power output weight, it could be taken into the strength spectrum. All lifts are relative to the athlete's body weight, which is extremely important when giving strength advice. As we can see there is an issue again concerning lack of comparable data. Only Shick et al. (2010) and Alm et al. (2013) looked at compound strength characteristics and both used different lifts. Although this being the case, we can get a slight picture of the strength levels required in MMA. As one would assume, we can see that leg strength is more important than push strength based on the scores between squat and bench press in Schick et al. (2010) study. Alm et al. (2013) looked at leg strength via the deadlift. Looking at the scores there we can conclude that they are high; the athletes lifted in average 2.2 times their own body weight. Only the Schick et al. (2010) specified some technical details in the leg lift such as "squat to parallel". It is generally known that one can deadlift in multiple ways; therefore, these kinds of tests should always be taken with a grain of salt. The hang clean portrays in some manner total body strength and we can see from the score 1.09 in the Alm et al. (2013) study that professional MMA athletes hang clean more than their own body weight. Again technique criteria are not well specified so one should not take this too literally.

Table 5: Measured strength characteristics

Tests:	11 Amateur MMA fighters (Schick et al. 2010)	5 Professional MMA fighters (Alm et al. 2013)	8 middle weight Professional Boxing (Guidetti et al. 2012	12 Elite middle weight wrestlers (Demirkan et al. 2015)
1 RM Relative Bench Press (kg/kg)	1.2 ± 0.1			
1 RM Relative Parallel Squat (kg/kg)	1.4 ± 0.1			
Hang Clean (kg/kg)		1.09 ± 0.07		
Deadlift (kg/kg)		2.2 ± 0.19		
kg/kg: max kg weight related to athlete's body weight				

2.3.4. Measured Speed & Power characteristics

There is an endless amount of explosive based actions in MMA. The strikes resultant force and impulse at contact are often critical for the final result of competition. Maximizing the capability to produce forces faster (Rate of Force Development: RFD) is especially important in MMA (Alm et al. 2013). RFD is also a variable that is strongly associated with jumping or sprint acceleration performance (Knudson DV. 2009). Unfortunately, equipment to measure RFD or mechanical power is not always cheap and accessible to all MMA athletes. However, jump performance (vertical CMJ or horizontal broad jumps) measured by height and/or distance have shown strong correlations to at least late RFD (McLellan et al. 2012) and more importantly to athletic performance, such as in high level 60 m sprinting -5000 m running (Hudgins et al. 2013), high level Judo and Taekwando athletes (Markovic et al. 2005, Franchini et al. 2012b) and acceleration performance in elite level contact sports (Young et al. 2011). Jumping distance or height is also much more practical to measure because it does not require expensive equipment. Preferably a horizontally directed jump test would have been welcome to represent horizontal power (and is advised outside of this paper), but so far only the vertical jump test (CMJ) has been used to represent lower body power in physiological characteristics research papers that met the criteria to be shown in this paper (Table 6). Only Schick et al. (2010) and Alm et al. (2013) studies looked at vertical jump performance, both using a countermovement with arm swing protocol (CMJ) to take advantage of the stretch – reflex attributes of the body via the Stretch – Shortening - Cycle, or SSC (SSC will be explained in detail later on in this paper). Although both studies had average results over 50 cm, what is interesting is significantly higher scores for the amateur MMA athletes compared to the professional MMA athletes. This is particularly interesting also from the stand point that the Alm et al. (2013) studies participants seemed to have high lower body strength scores compared to the Amateur MMA athletes. Although squat and deadlift cannot be directly compared, it is still fascinating and brings forward the point that strength scores do not always correlate strongly with indirect/direct maximal mechanical power values. The potential explanation for this is again multidimensional and could come down to such things as RFD, technique, time of season and even genetics and will not be taken to further detail in this paper.

Unfortunately, we only have results of 10 and 30-meter sprint times from the Demirkan et al. (2015) elite wrestlers study. From this we can see though that wrestlers can be quite explosive with 10 meter times around 1.73 seconds and 30 meter times around 4.08 seconds. Although sprint acceleration involves a lot of technique, this gives a good picture of the explosive nature of the wrestling and the potential benefit of improving such times for a carry-over effect into similar sports such as MMA.

Table 6: Measured power & speed characteristics

Tests:	11 Amatuer MMA fighters (Schick et al. 2010)	5 Professional MMA fighters (Alm et al. 2013)	8 middle weight Professional Boxing (Guidetti et al. 2012	12 Elite middle weight wrestlers (Demirkan et al. 2015)
Countermovement Jump (CMJ) with arm swing (cm)	57.6 ± 7.3 (Vertec)	50.18 ± 5.63 (MuscleLab Infrared mat)		
10 meter time				1.73 ± 0.11
30 meter time				4.08 ± 0.14

In conclusion of physiological characteristics of MMA athletes (All values are based on an average of the 4 studies presented):

- Body composition:
  - Body fat ~11% or under
  - BMI ~24,3
- Endurance characteristics:
  - V02max: ~58 ml/kg/min
  - Aerobic threshold 63% + (Only one study)
  - Anaerobic threshold 82%+ (Only one study)
  - Anaerobic power (Wingate): 15.3 w/kg + (Only one study)
  - Anaerobic capacity (Wingate): 7.7 w/kg (Only one study)
- Optimal strength values
  - Lower body strength:1.8 x body weight or higher (Both squat and deadlift with good form). Hang clean 1.10 x body weight or higher (With good form).
  - Upper body (Only one study): 1.4 x body weight or higher (Only bench press measured but probably can be advised for Bent over row/Bench pull too (Antagonist muscle group)).
- Optimal & speed power values
  - Lower body power (indirectly measured via CMJ): ~53,9 cm or higher. There is a need for a horizontal power test such as double leg hop.
  - Speed performance (measured via 10/30m sprint): 10m: 1,73 s and 30 m:4.08 (Only one study). There is possibly no need for 30 m time and value could be possibly added by testing 5 m time.
  - Agility tests & upperbody power would be an interesting test to add.
- Possible flexibility tests but no clear research has been done

2.4 Cutting weight in MMA

Weight class divisions exist so the matches are more equitable in terms of body size, strength and agility. However, many athletes in different combat sports acutely reduce body mass in an attempt to get an advantage by competing against lighter, smaller and weaker opponents (Franchini et al. 2012a). In modern MMA, cutting weight for many athletes has seemingly become more of a strongly advised requirement than an advantage. This is due to that in modern MMA most athletes cut weight to get into a lower weight class, especially when the athletes neutral weight lays right between two weight divisions or just slightly above one. There are also other factors such as the potential energy loss from cutting weight that can directly affect performance. Therefore, in most cases the advantage of weight cutting becomes less prevalent and balances itself out. Although there are successful cases of athletes gaining weight to get into a higher weight class this section of the paper will more focus on the methods used in weight cutting and the potential benefits and harms of them.

In professional MMA weigh-in (where the athlete's weights are taken to make sure they are within their weight category) happens around 24 hours before the fight itself (Franchini et al. 2012a, Jetton et al. 2013, Coswig et al. 2015). This potentially changes the degree of how much an athlete can cut weight before the fight compared to an amateur combat sport event that can have the weigh – in on the same day of the event.

Weight cutting strategies have been in literature usually divided into two categories; Neutral/Gradual Weight Loss (NWL or GWL) and Rapid Weight Loss (RWL) (Franchini et al. 2012a, Coswig et al. 2015). RWL has been characterized by reductions of 5 to 10%+ of body weight in less than a 3-7 days (Franchini et al. 2012a, Coswig et al. 2015).

Many methods have been utilized by athletes during a weight cut week including; reduced liquid/energy (Carbohydrates & fat) ingestion, saunas, heat suits/bag or fasting (Franchini et al. 2012a, Coswig et al. 2015). Aggressive methods like specific diuretics, laxatives and vomiting have also been reported but are rare. It is important to note that diuretics are forbidden by the World Antidoping Agency (Franchini et al. 2012a).

The scientific community seems to lean more towards that RWL methods are very likely to cause some form of negative implications on physical performance (Franchini et al. 2012a, Jetton et al. 2013, Coswig et al. 2015). The negative effects that have been demonstrated in studies include: decreased short-term memory, concentration, lower lactate levels (less efficient anaerobic system), decreased testosterone/cortisol ratio, specific muscle damage markers and dehydration (Franchini et al. 2012a, Jetton et al. 2013, Coswig et al. 2015). One study on 40 MMA athletes looked at the effects of RWL on hydration markers 22 hours after weigh-in and 2 hours before the bout. At this point the MMA athletes had gained approx. 4.4% of their body mass back (around 2 - 2.5 kg). Urine specific gravity markers (used to measure dehydration) significantly reduced in 39% of participants indicating serious dehydration just before the bout (Jetton et al. 2013). It is important to note that unfortunately this study did not report the average amount of weight dropped during the RWL process, so strong conclusions are hard to draw. Another study on MMA athletes showed that using RWL methods to drop around 10% of mass increased the risk of muscle damage markers and catabolic expression pre- and post-bout (Coswig et al. 2015). Unfortunately, no clear information was given on how much weight was gained back after weigh-in.

However, there is plenty of contradictory evidence to the negative effects of RWL. In fact, it has been speculated that experienced "weight cyclers" seem to cause no significant effect on performance (Artioli et al. 2010a, Franchini et al. 2012b, Mendes et al. 2013). One study on 7 experienced Judo athletes showed no effect on anaerobic performance markers (Wingate test) after a 5% reduction in weight within 5-7 days using own selected RWL methods. The even more intriguing fact was that weigh in was only 4 hours before performance tests. It was also reported that the test group consumed large amount of carbohydrates and food after weigh – in (Artioli et al. 2010). Another study with nearly the exact same set up (5 % reduction, 4-hour recovery window) with 18 combat sport athletes showed no effect on high intensity performance with own selected RWL methods. This study also found no difference between experienced and unexperienced athletes (Mendes et al. 2013).

In regard to the magnitude of weight loss, Franchini et al. (2012b) reported that in Judo and Wrestling a considerable amount of athletes (40%) reduce 5-10% of body weight and many athletes reported more than 10% weight cuts. There seems to be adequate evidence on positive recovery markers with athletes dropping 5% of their mass using RWL methods (Artioli et al. 2010, Mendes et al. 2013), but no studies yet to my knowledge have looked at how a 10% weight cut effects performance markers. Plenty of studies are needed in this area to confirm details, but it seems that many of the negative effects of RWL can be avoided with appropriate guidelines.

Franchini et al. (2010a) advised the following guidelines:

1) If possible use gradual weight loss (easier to imply if the athlete has to reduce under 5%).

2) Athletes should aim to maximize body fat loss and minimize muscle wasting and dehydration when adjusting weight.

3) An athlete who needs to cut weight then the body fat should not be reduced under 5% for men and 12% for women.

4) During the weight loss period, strength training and BCAA supplementation (basically getting enough quality protein) will help preserve muscle mass

5) During the recovery period after weigh-in, athletes are encouraged to consume high amounts of carbohydrates, fluids and electrolytes. Creatine monohydrate supplementation may also be of use if the athlete will recover for a long period after weighing-in.

A coach should always take into consideration each athlete separately in how they react to cutting weight.

2.5. Psychological factors in MMA

Although this paper mostly focuses on the physical, mental preparation is paramount to combat sport performance (Bounty et al. 2011, Boostani et al. 2013). When training for a fight the physical is usually more important than the mental, but once you step into the ring, the mental becomes far more superior to the physical, some even claim a ratio of 90% mental 10% physical (Boostani et al. 2013). Whether this is accurate or close to accurate, one can assume that combat sports it’s not necessarily just about who the best athlete is on paper, but who fights the best when the bell rings.

This paper will only scratch the surface of some important concepts that are considered to be important within sports psychology to develop a strong mind. Mental toughness, self-belief, different forms of motivation and the coaches' role in them and pain tolerance will be discussed.

The phrase "mental toughness" is well used in sports psychology as an essential quality to success. Although it is one of the most used terms, its specific definition is quiet contradictorily the least understood (Hanton et al. 2002). According to in depth interviews with 10 successful international athletes, researchers found that mental toughness can be broadly explained to include qualities of

1. Self-belief (confidence, self-efficasy)
2. Motivation (different forms of it i.e. inner/outside motivation)
3. Dealing with competition-related stressors (outside factors i.e. opponent, critics) and anxiety (internal issues i.e. nervous behaviour)
4. Dealing with physical and emotional pain (i.e. training pain and mental pain from losing a fight or personal issues) (Hanton et al. 2002).

It might be safe to say that if an athlete harbours all these qualities, they will possibly not have to work on many other mental qualities.

Self-belief is considered to be the most important building block of a mentally tough athlete (Hanton et al. 2002). Successful international athletes believe in general that self-belief is close to unshakeable when you truly believe that you have something that your opponents do not have and if you want something (i.e. being the best in the world), you have to be strong enough to believe you are capable of it (Hanton et al. 2002). Muhammad Ali's quote "I don't think it's bragging to say I'm something special" is used as a prime example for an ideal attitude when emphasising the right direction towards harnessing a strong self-belief. Great things are usually not achieved by people who have low self-esteem and that think it's always wrong to self-praise (Landrum. 2006. p.157.).

When it comes to motivation and the different forms of it is again interesting to take a look at how highly successful athletes use the term for its contribution to mental toughness. It seems that if an athlete wants to experience and overpowering desire for success, the motivation has to come from deep within (Hanton et al. 2002). This type of motivation is in fact called intrinsic motivation and is a self-determined form of motivation, which refers to an athlete that performs their sport for the pleasure and satisfaction they personally experience from simply participating. The motivation that comes from outside factors is called extrinsic motivation, and could be explained by the example of participating in an event to win an award or avoid punishment (Gillet et al. 2010). There are though forms of extrinsic motivation that are considered apart of self-determined forms of motivation, such as "identified regulation". This form of motivation represents such a situation where the athlete willingly participates in something they don't find very attractive, such as high intensity conditioning, because they know and believe that the training will lead to significant benefits for their performance (Gillet et al. 2010). These two forms of self-determined motivation (intrinsic motivation and identified regulation), are considered to be one of the most important forms of motivation for an athlete (Gillet et al. 2010).

There have been interesting studies done on what kind of coaching style best supports an athlete's self-determined motivation to participate and succeed in their sport. Autonomy-supportive- vs. controlling style coaching have been compared and correlated to the athlete's performance outcomes. Autonomy supportive coaching means acknowledging each individual athlete's feelings and opinions and allowing them to be a part of the decision making process in some form, whereas the controlling style is a highly directive style of interaction (Gillet et al. 2010). What has been found is that the more the athletes perceived their coach to be autonomy-supportive, the more their motivation for practicing in their sport activity was self-determined (contextual motivation). This self-determined motivation for their sport led to a higher likelihood of "situational motivation" i.e. your motivation just before a competition. The higher the situational motivation was, the better the performance (Gillet et al. 2010). It was generally agreed that the coaches' behaviour is one of the most important in affecting an athlete's motivation (Gillet et al. 2010). All coaches should every now and then examine critically their motivational approach to each individual athlete and see if there is room for improvement.

It is generally supported that higher pain tolerance and increased performance go hand in hand. (Addison et al. 2012). It has been found that contact sports' athletes are able to in general tolerate significantly more pain than either those in non-contact sports or non-athletes (Addison et al. 2012). But do athletes also have a higher pain threshold? One study that made the participants put their hand in ice cold water showed that endurance athletes can have higher pain tolerance, but don't necessarily have a higher pain threshold than non- athletes. This means that both groups felt the pain at the same point, but once in pain, the athletes could tolerate the pain for a longer time (Fruend et al. 2013). Criticism has been placed to this from a couple of fronts. Once criticism is that emerging your hand into cold water is not exactly sport specific, and therefore can show pain tolerance but cannot really show clear results in terms of higher pain threshold (i.e. increased pain threshold could be associated with physiological alterations from endurance training such as a higher anaerobic threshold). The other criticism is that it is unclear whether successful athletes have naturally a higher pain tolerance (and therefore search themselves to such sports), or if the athlete has actually developed the pain tolerance (Addison et al. 2012).
One study tried to shed light on one of these criticisms by measuring pain tolerance in a group of non-athletes, and then "turning" them into "athletes" by training them for 6 weeks 3 times per week aerobically (Jones et al. 2014). The results were positive for the development of pain tolerance side of the debate; non athletes managed to increase their pain tolerance by 20% (Jones et al. 2014)!. Although there is most likely natural differences in pain tolerance between individuals, it is comforting to know for many athletes that pain tolerance can be taught. This could bring some interesting approaches to training. For example, could forms of high intensity conditioning training (all – out intervals, hill sprints etc.), where the training stimulus is

physiologically much more demanding than the actual MMA bout, increase pain tolerance and pain threshold in the actual bout? The pain threshold is more physiological due to it most likely can be correlated with levels of lactate in the blood stream, but pain tolerance is much more psychological and both can be most likely trained at the same time through high intensity conditioning training if programmed correctly (Mackenzie. 2015). There are many other approaches to dealing with pain tolerance. One example would be Mindfulness, which is a specific form of meditation and has been shown to increase pain tolerance (Kingston et al. 2007). Another would be self-selected motivational self-talk, which studies have shown to increase power output and V02 response while maintaining the same RPE (Rate of Perceived Exhaustion) (Barwood et al. 2015).

Further reading for athletes and coaches on applied sports psychology is most definitely advised and also most importantly valuing the importance of outside help, such as investing in a licensed sport psychologist if one is serious about their sport.

3. MMA IN FINLAND

In Finland MMA has been organized since 1997. Due to its international development, MMA has evolved significantly also in Finland. Even though Finland has a lot of potential to develop its MMA training standards and culture, the domestic professionals are in modern times considered elite athletes whose skill levels are a sum of several years of heavy training results. Finnish pioneers within MMA are considered to be the following people: Jari Ilkka, Jarmo Haimakainen, Ykä Leino, Jan Tilles, Marcus Peltonen, Mikko Rupponen, Michael Ekberg, Juha Saurama, Marko Leisten and Mika Petra (Suomen vapaaotteluliitto).

Finlands Mixed Martial Arts Federation (FMMAF) was founded 31.12.2004, which allows the development of the sport in Finland. Currently there are 70 registered FMMAF member clubs – or MMA gyms – in Finland (Suomen Vapaaotteluliitto). Unfortunately, no information was found on how many registered athletes are found in Finland. As a comparison, according to Schick et al. (2010) in 2006 there were 900 registered MMA gyms in North America.

FMMAF is also responsible for creating a strong amateur MMA culture in Finland, which in 2014 and 2015 has led to 3 gold medals (2 males, 1 female) in the two first organized MMA amateur world Championships in Las Vegas by IMMAF (International Mixed Martial Arts Federation). IMMAF's website shows 47 countries are currently registered as members in from all around the world.

Professional Finnish MMA athletes have had some international success with historically 5 MMA athletes getting a fight contract into the UFC. Due to the tough conditions of both the contract and the athletic/skill level in the UFC, Finland has currently only two active UFC fighters, Makwan Amirkhani and Teemu Packalen (Updated at the end of 2015). If compared to a country with a similar population size; Finland's neighbour country Sweden has sent historically 11 fighters into the UFC, from which 7 are more or less active (MMAVIKING. 2013) This partially reflects the current level of MMA in Finland but shouldn't undermine the constant efforts to improve the level of competition. Below in table 7 is the current (4/4 - 2015) official Finnish MMA fighter ranking list.

Table 7: Finnish MMA ranking list at the end of 2015 (FightSport-työryhmä. 2015)

Category	**Athletes** (Numbers next to name represents where the athlete was placed in the previous ranking)
Pound for Pound	1. Makwan Amirkhani (1.) 2. Janne Elonen-Kulmala (–) 3. Toni Tauru (2.)
Bantaweight and below	1. Janne Elonen-Kulmala (2.) 2. Toni Tauru (1.) 3. Timo-Juhani Hirvikangas (3.)
Featherweight	1. Makwan Amirkhani (1.) 2. Joni Salovaara (2.) 3. Rasul Khatev (3.)
Lightweight	1. Anton Kuivanen (1.) 2. Teemu Packalen (2.) 3. Jani Salmi (3)
Welterweight	1. Glenn Sparv (1.) 2. Juho Valamaa (2.) 3. Johan Vänttinen (3.)
Middleweight	No active names
Heavy weight and light heavy weight	1. Marcus Vänttinen (1.) 2. Saku Heikkola (2.)
Women – all weight classes	1. Eeva Siiskonen (2.) 2. Vuokko Katainen (3.) 3. Suvi Salmimies (–)

3.1 Rule categories and weight class divisions

From a perspective of sustainable development within the sport, Finnish MMA has been divided into amateur and professional categories. 4 categories were established; A-, B-, C- and D class. C&D-class are amateur categories and are clearly stricter than professional rules & regulations (Suomen Vapaaotteluliitto). Finnish professional MMA rules follow the FMMAF rules protocol, which to a large extent are the same rules as in the largest MMA organization UFC (Unified Rules of Mixed Martial Arts). According to FMMAF rules & regulations, the following weight classes are used for men (women follow the same structure and have even lower categories under straw weight):

Table 8: Weight classes (FMMAF)

1.	Strawweight: under 52.0 kg
2.	Flyweight: 52.0 - 56.0 kg
3.	Bantamweight: 56.0 – 60.0 kg
4.	Featherweight: 60.0 – 65.0 kg
5.	Lightweight: 65.0 – 70.0 kg
6.	Welterweight: 70.0 – 77.0 kg
7.	Middleweight: 77.0 – 84.0 kg
8.	Light Heavyweight: 84.0 – 93.0 kg
9.	Heavyweight: over 93.0 kg

More detailed rules can be found on http://www.vapaaottelu.fi/vapaaottelu/ottelusaannot/

4. INJURY CONSIDERATIONS MMA

There seems to be a slight issue within searching formal data on common injuries in MMA. The reason to the lack of data is that temporally injured athletes within MMA do not want future opponents to be aware of a potential weakness that they can abuse (Burns JL. 2015). Jason L Burns. (2015) wrote in his case report on injuries in MMA "these motives have created a culture of secrecy when it comes to injuries, making it difficult to track exactly how many Mixed Martial Arts athletes are injured each year, and what types of injuries they experience." Burns continues proving his point with his informal search on injuries within professional MMA "of the 101 injuries documented in professional Mixed Marital Arts in 2013, 66 of them were reported as "undisclosed injuries". This means that 65% of the injuries that took place over the course of the year were not identified". Nonetheless 35% were and they seemed to be common injuries found in such martial arts as wrestling and boxing etc. (Burns JL. 2015). In this list of the 35 injuries there seemed to be equally as much injuries in training as in competition. Common places for injuries were neck (no information) shoulder (only reported dislocations), elbow (bicep tear, subluxation) back (no information) and lower limb (quad and hamstring tear, meniscus tear and ACL tear) (Burns JL. 2015). Lower limb injuries seem to be at the top of the list as far as sheer numbers of incidents go (Burns JL. 2015), but in no way should other body parts be ignored.

4.1 Concussions

Concussions are categorized as mild Traumatic Brain Injuries (TBIs) which are brought on by biomechanical insults to the brain (Burns JL. 2015). In terms of greatest potential for severe long term damage concussions are the foremost concerning to combat sport athletes and medical personnel (Hutchison et al. 2014, Burns JP. 2015). The concern also derives from the fact there is clear evidence on a "culture of resistance" in many contact sports, where athletes do not always report concussions or coaches & parents are not aware or are in denial of the high degree of potential risk on long-term cognitive, psychiatric, and neurobehavioral problems associated with concussions (Murray et al. 2015). Due to this cultural issue this report will contribute its own section to concussions.

Recent data shows that approx. 12.7% of UFC MMA fights end in knockouts (KO) (which are always undoubtedly concussions), and therefore places professional MMA quite dramatically in the top list of all sports in risk of concussion (Hutchison et al. 2014). Technical knockouts (TKO) cannot be fully disclosed to always cause a concussion, but 90% of the time TKO's are achieved by repetitive strikes (Hutchison et al. 2014) and only 10% of reported concussions are in fact by knockout (Burns JP. 2015). If the total amount of KO's and TKO's are calculated together then the incidence rate goes up to 31.9% (Hutchison et al. 2014). Although Dana White (President of the UFC organization) states that if you get a concussion or any injury you are out for a minimum of 90 days (Guillen A Jr. 2013), there are high risks of relapses if the athlete does not take their concussion recovery seriously (Burns et al. 2015, Murray et al. 2015)

Statistics show in sports that 75% of repeat concussions happen within seven days of the first concussion, and 92% of repeat concussions happen within 10 days of the first concussion (Burns JP, 2015). Additionally, athletes with 2 previous concussions are 2.8 times more likely to get a third (Burns JP. 2015). A trained medical professional is paramount in the diagnosis of suspected concussions as there are reports of 33% of team sport players with concussions who were permitted to return to play on the same day were allowed to continue because of a delay in the onset of their symptoms as long as three hours' post-incident. Cases have also been recorded where athletes who initially appeared symptom free for the first 15 minutes' post-injury, still faced memory deficits as long as 36 hours later (Burns JP. 2015). This situation is an example of the type of dangerous situation that could potentially lead to the development of Second Concussion Syndrome (SCS). This occurs when the athlete receives a second concussion before the symptoms of the first concussion have subsided, and can have major implications in terms of injury severity in the long term (Burns JP. 2015).

For athletes to Return-to-Play, evidence suggests that they be symptom free for 24 to 48 hours and perform at levels consistent with baseline testing. Each individual will respond differently to recovery, but the typical athlete is withheld from sport for approximately one week based on a medical professional's opinion, but athletes experiencing concussion-like symptoms should never return the same day (Burns JP. 2015). Athletes whose symptoms last longer than the 7 to 10-day period are considered to have Post-Concussion Syndrome (PCS); these individuals can expect a longer recovery process with an extended Return-to-Play protocol that takes into account their decline in physical conditioning (Burns JP. 2015)

4.2 Injury prevention and rehabilitation strategies

Due to the nature of the sport, it is probably hard to prevent certain injuries to a large degree, such as concussions. After looking at peer reviewed data there was no evidence in training interventions that have directly or indirectly reduced the risk of concussions or neck injuries. Ideas have been proposed that efficient neck training could potentially reduce forces on the brain by reducing rapid acceleration turns of the head in impact (Turner AN. 2009). Although an interesting theory and makes scientifically sense on a quick glance, this is just a basic non-validated theory and should be taken with a grain of salt as to whether one needs to directly isolate (emphasizing the word "isolate") the neck in strength training in a systematic manner. One could propose that if training technical grappling and clinching and using some compound upper back lifts in the gym is in fact enough to strengthen the neck – at least indirectly - if not a clear strength deficit is noticed in the athlete. Neck isolation training has also been proposed to potentially reduce cervical injuries (Lenetsky et al. 2011), but unfortunately no intervention data exists on this either.

What are the most effective training methods to reduce the chance of injury? Luaersen et al. (2013) systematic review and meta-analysis study looked at the effects of strength training, proprioception training and stretching on injury prevention (26 610 participants, 3464 injuries). What they found was that multiple exposure programmes such as programmes with strength training and proprioception training showed highest effect. Strength training had the largest impact with reducing injuries with 1/3 and overuse injuries with 50%! There was no direct injury prevention result from stretching (Lauersen et al. 2013). It is important to note that although stretching is not directly correlated with injury prevention outcomes in the above mentioned study, it might help indirectly in multiple exposure programmes. There are many forms of stretching (which are rarely separated in studies) and other uses of it, such as increasing a martial art athlete's flexibility. The bigger question is what specific kind of strength- and proprioception training lowers most effectively an MMA athlete's injury risk, which will only be answered partially in this paper.

One important injury prevention role of strength training is to remove unbalances in the body. All joints in the body have agonist and antagonist muscle groups, which switch roles for a given movement. Total 1:1 balance ratios are extremely hard to achieve between some agonist and antagonist muscles due their size differences, such as the plantar flexors vs. the dorsiflexors, that have a proposed ratio of 3:1 (Table X). If these ratios are ignored and antagonist muscles are neglected, performance will be inevitably impaired due both to neural inhibition of the agonists and injury (Bompa & Buzzichelli. 2015. p. 200). Coaches involved in MMA should be aware of common agonist – antagonist ratios and compare them to common unbalances within MMA (i.e. shoulder, spine & knee unbalances). Table 9 provides some information on these ratios for low, isokinetic speeds. This information should definitely only be used as a guideline for maintaining ratios (Bompa & Buzzichelli. 2015. p. 200), and will most likely be updated in the future.

Table 9: Agonist - to Antagonist ratios for slow concentric isokinetic movements (Bompa & Buzzichelli. 2015. p 199)

Joint	Strength training	Ratio
Ankle	Plantar flexion (gastrocnemius, soleus) to dorsiflexion (tibialis anterior)	3:1
Ankle	Inversion (tibialis anterior) to eversion (peroneus)	1:1
Knee	Extension (quadriceps) to flexion (hamstrings)	3:2
Hip	Extension (spinal erectors, gluteus maximus, hamstrings) to flexion (iliopsoas, rectus femoris, tensor fascia latae, sartorius)	1:1
Shoulder	Flexion (anterior deltoids) to extension (trapezius, posterior deltoids)	2:3
Shoulder	Internal rotation (subscapularis, latissimus dorsi, pectoralis major, teres major) to external rotation (supraspinatus, infraspinatus, teres minor)	3:2
Elbow	Flexion (biceps) to extension (triceps)	1:1
Lumbar spine	Flexion (abdominals) to extension (spinal erectors)	1:1

Proprioception is explained as being our sensory receptor system (mainly in our muscles and joints) that gives us information on our current position and movements of our joints in dynamic conditions (Zamani et al. 2015). Balance training seems to be in some literature considered the same thing as proprioception training (Laurersen et al. 2013). Outside rehabilitation and looking more at injury prevention strategies, the more interesting question is that can we train our proprioception or balance effectively by other means than directly isolating it? Plyometrics has been usually used to increase explosive performance markers (Markovic et al. 2010), but it can also reduce injury risk significantly due to higher control in quick movement (Markovic et al. 2010, Zamani et al. 2015). There is evidence that if plyometrics are used consistently in a program with high technical quality, it directly improves proprioceptive markers and therefore reduces injury risk (Zamani et al. 2015). Looking at the busy schedule of a professional MMA athlete, one has to prioritize time use very efficiently. If plyometrics in fact increase explosiveness and proprioceptive markers, one could question if injury prevention strategies (not rehabilitation) for MMA athletes need to include such things as isolated balance training.

As mentioned before this paper will not go into depth on injury prevention, but it is worth mentioning the role of sleep in reducing injury risk. Milewski et al. (2014) research obtained and analysed 112 youth athletes sleep data for 21 months. The data showed that athletes that slept in average less than 8 hours per night were 1.7 times more likely to injure themselves compared to athletes that slept in average over 8 hours per night.

5. THE SCIENCE OF DIFFERENT TRAINING IMPLICATIONS FOR MMA

In this section we take a step forward from the physical requirements set for MMA athletes and start investigating what current sport science says how to get there. Unfortunately, there is only space to scratch the surface of the relatively complex sports science that is important within MMA. This section will provide some direct advice, but will more lean towards the abstract, so that the coaches or athletes can decide for themselves what to do with the information presented. Certain beliefs within combat sports strength & conditioning training will be more or less challenged, which one could say to be the fundamental goal of science; never settle. The first section is focused on biomechanics in MMA, forms of strength & power training and the structural adaptations they can potentially bring along. The second section focuses on forms of endurance training, and what forms of it could bring the most important physiological adaptations. All of this is obviously devoted to shed light in how to become an elite MMA athlete.

5.1 Biomechanics in MMA

When an MMA athlete creates large amounts of energy to shift into their opponent, there is considerable amount of biomechanical science involved. This is not purely a biomechanical paper so it will only take into consideration some of the most important concepts. One of these important concepts is the kinetic chain, which tries to present scientifically the most efficient route to transfer energy to the opponent. This kinetic energy is derived with help from gravity from the ground and shifted up through the lower body via the spine to the upper body in form of a strong “chain”, hence the phrase “kinetic chain” (Turner AN. 2009). To further develop the optimal synchronization pattern of the kinetic chain, movements that utilize “triple extension” from the ankle, knee and hip (i.e. squats, Olympic lifts, plyometrics); in other words, these three joints are working together and extending more or less simultaneously, are advised for “carry-over training” (Turner AN. 2009). To demonstrate evidence that certain kinetic chain patterns are more efficient than others we can look at studies that compare force transfer patterns between high and low level athletes. Filimonov et al. (1985) research looked at a straight punch in 120 boxers, ranging from elite to junior rankings (Table 10). The research demonstrated that the highest level boxers could utilize their lower body over two times more than the lowest level boxers. Also, the lower body’s capability to generate force was the most important followed directly by the trunk and then only ¼ by the arm.

Table 10: Level of athleticism and contribution of punching force by different components of the kinetic chain (Filimonov et al. 1985)

Category	Arm extension (%)	Trunk rotation (%)	Push off with extension of back leg (%)	Total (%)
Masters of sport and candidates for masters of sport	24.12	37.42	38.46	100
Class I	25.94	41.84	32.22	100
Class II, III	37.99	45.50	16.51	100

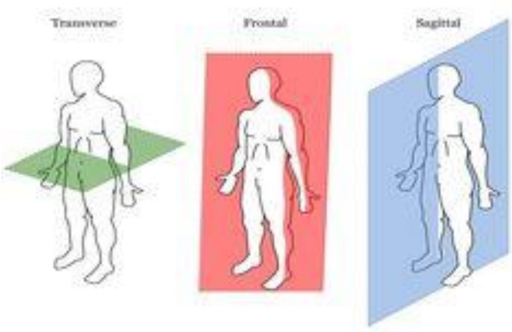


Figure 1 Biomechanical planes

Another study on Shot Putters showed similar finding, where differences between high level and lower level athletes was the capability to generate more force from the legs and then the arms in that respective order (Verkhoshansky & Siff. 2009). To specify even more what is meant with lower body force production in martial arts, it seems that a high level athlete utilizes the hip muscles more in a strike (Cheragbi et al. 2014) and transfers energy from the sagittal plane (Vertical/horizontal force) into other planes such as the frontal plane (lateral force) and transverse plane (rotational force) depending on the type of strike (Figure 1). For example, both a punch and a roundhouse kick are initiated in the sagittal plane (Kim et al. 2011, Cheragbi et al. 2014) and then different planes are used depending on the type of strike. After the sagittal plane the roundhouse kick transfers into the frontal and transverse plane when rotation is initiated (Kim et al. 2011). So it becomes evident that an MMA athlete has to be good at transferring force in all directions. It is worth mentioning that all of the above mentioned examples are from a standing position and do not necessarily represent biomechanical principles of ground game/grappling. None the less physiological studies on elite level wrestlers have shown a similar relationship between the upper and lower body with a bit more value for upper bodies use (Demirkan et al. 2015).

At this point a very important term called "energy leak" comes into play. Energy leak means simply that the energy is not moving efficiently in the wanted direction because joints are forced into suboptimal positions due to lack of stability. Prof. Stuart McGill, a world renowned spine specialist, explains that an athletes hip is the centre of power production, but this power cannot be transferred when there is unwanted movement, for example from the spine if the core is functionally weak: "when jumping or changing running direction, the spine bending when the hip muscles rapidly contract forms a loss of propulsion. The analogy ''you can push a stone but you cannot push a rope'' exemplifies this principle" (McGill. 2010). Therefore, to avoid energy leak in any joints, when energy is shifted through the kinetic chain the athlete has to have a very efficient technique (Machado et al. 2010) and a very strong structure to be able to stabilize joints and transfer forces from the hip in the ideal direction (McGill. 2010). In conclusion:

- Optimize lower body to trunk to upper body contribution ratios in creating kinetic energy
- Training stimulus should be brought to all biomechanical zones i.e. training horizontal, vertical, lateral and rotational force production.
- Use movements that improve the athletes triple extension.
- Build a strong functional foundation around all joint segments so energy leak is avoided.
- Make the athlete aware of what it means to transfer energy efficiently through the hip and the entire body.

5.2. Rate of force development

We have so far established in the MMA athlete's physiological characteristics section that it is important to have high relative maximal strength and be able to produce high levels of strength as quickly as possible through high levels of rate of force development (RFD). RFD is measured usually isometrically on a force plate and is estimated based of the force produced within the first 250 ms of action. This can be later divided into early RFD (0-50 ms) and late RFD (150 – 250 ms) (Moir. 2015. p. 200). The need for high levels of RFD comes simply from looking at the biomechanics of technical maneuverers in MMA, specifically the limited time to complete certain explosive techniques such as punching and kicking. For example, punches involve completion times of 50–300 ms depending on how it's measured (Turner AN. 2009, Cheragbi et al. 2014). A vast majority of MMA movements ideally occur within 50–300 ms (Turner AN. 2009). In average it takes a person around 600 – 800 ms to develop peak force (Edman KAP. 2002) so it is not possible to reach peak force in any of these techniques, except for potentially a takedown. But what we can do is significantly improve our capability to create force between 0 - 300 ms. What is very interesting is that there seems to be a double impulse of rate of force development in a well-executed striking techniques (Mcgill et al. 2010). Mcgill et al. (2010) found in high level MMA athletes (including Georges St. Pierre) that when initiating for example a punch or a kick they cause a spike in muscle activity, then directly after there is a follow through process where certain muscles relax and just before contact they contract again. This in turn creates a contract – relax – contract impulse pattern within a very short time frame, but slightly different in terms of time depending on the technique used (Mcgill et al. 2010). These results show that it is important to be able to produce force fast so there is more time to relax between initiating a strike and hitting the target (therefore conserving some energy in the long run) and more importantly being able to produce two high impulses of rate of force development in a span around 300 ms. The second impulse is slightly more isometric of nature, therefore might be best promoted with the capability to be able to stabilize rapidly. For example, when the punch hits the target, what role of isometric RFD do the scapula stabilizing muscles have (and in what position should they be to avoid energy leak)? There is unfortunately no research yet that answers this question. Also, the importance of the capability to relax while performing explosive movements seems essential. Because RFD is a function of enhancing neuromuscular activation (i.e. inter-& intramuscular coordination – Table 11) and certain structural properties in your body (i.e. MTU stiffness, fiber length – Table 12), we should use appropriately both strength training and power training to develop long term RFD and improve capability to relax whenever appropriate in powerful movement for an MMA athlete (Turner AN. 2009, Bounty et al. 2011, Souza-Junior 2015). More information about strength and power training will be provided later on.

In conclusion:

- Although maximal strength is important, how fast you can use certain thresholds of strength is significantly more important in sports with bursts of speed such as MMA. Therefore, rate of force development is a crucial detail to improve in MMA.
- Due to most strikes have a double impulse and a relaxing phase in between, emphasis should be devoted to teaching the athlete either directly or indirectly (depending on the coaching methods) to produce a spike of power when initiating and finishing strikes. This approach should also be taken into the S&C realm, for example trying to accelerate the bar as fast as possible right from the start and learning to stabilize the body while energy is being transferred.
- Also, it is very important for the athlete to avoid tensing up, or in other words, being able to relax as much as possible to maximise RFD and energy conservation.

5.3. The SSC-cycle and important structural adaptations

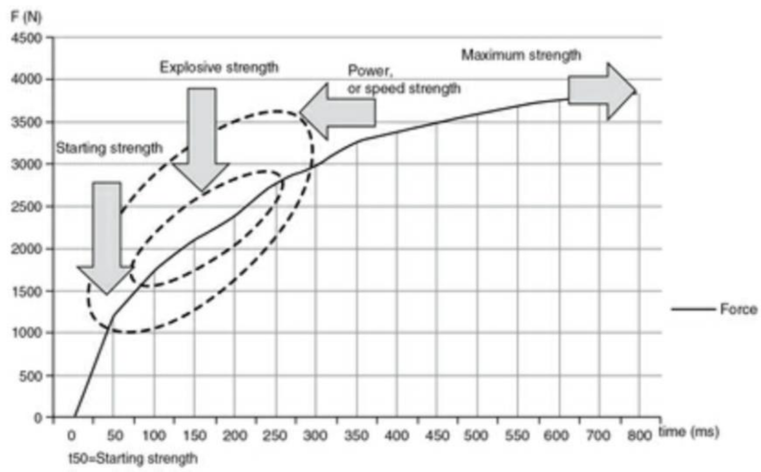


Figure 2 Force - time curve. Circle represents manipulations of traditional force curves when power training is used (Bompa & . Buzzichell. 2015. p. 36)

While delivering a punch or a kick, an athlete’s goal is to show minimal "loading" of the strike so that the opponent will not be able to anticipate it. Creating a powerful punch with no loading by a pure concentric phase might be very hard to achieve and will probably lack a lot of power. In this context "loading" to create power means utilizing the elastic properties of the body or the stretch-shortening cycle (SSC), commonly used to explain sprinting & jumping biomechanics (Markovic & Mikulic. 2010).

The SSC-cycle occurs when specific muscles eccentrically stretch just before the concentric action (Komi & Nicol. 2011). Any muscle that is stretched prior to a concentric contraction will always contract with more speed and force (Markovic & Mikulic. 2010). The reason for this can be explained at least in a neuromuscular and structural manner. Simplified, the neuromuscular system and its mechanoreceptors within the muscle react to small stretches leading to a stretch – reflex signal. This is an afferent signal that inevitably leads to increased contraction force during the concentric phase. Also the eccentric stretch phase gives the neuromuscular system some valuable time (although preferably minimal) to create force before the concentric phase (Schenau et al. 1997). Structurally the muscle is built of elastic properties (i.e. design of muscle fiber cross-bridges), but the most important tissue to store and utilize elastic energy seems to be the tendon, which together with the muscle forms a muscle tendon unit (MTU) (Cormie et al. 2010c). Longer fiber lengths in muscles combined with increased MTU-stiffness have been associated strongly with higher levels of speed performance due to higher absolute fiber shortening velocity (Kumagai et al. 2000, Macdougall & Sale. 2014. p. 305), just like a longer and thicker rubber band. Therefore, the SSC-cycle enhances the ability to use the neural and the elastic elements of the MTU complex to improve RFD, creating a strong bridge between maximal strength and speed (Markovic & Mikulic. 2010) (Fig. 2)

An efficient and powerful MMA athlete uses the SSC-cycle constantly. While an MMA athlete is in their fighting stance there is usually some form of constant movement by bouncing on their toes or shifting their weight from leg to leg and therefore flexing/extending constantly the ankle, knee, hip, shoulder and elbow joints to a very small extent. These very small joint movements are constantly causing small stretches of muscles and tendons and creating opportunities in utilizing the SSC - cycle, and if used well increasing the chance of the opponent not seeing the initiation of a powerful strike.

Before we look at what kind of training might help with the largest significance to improve the SSC-cycle, let's look at a couple of adaptations we are looking for. Firstly, we want to increase the stiffness of most MTU's involved in explosive movement (Aagaard. 2010) and secondly we want to increase neuromuscular performance from many different standpoints (Table 11) to the muscle (Schenau et al. 1997). A stiffer MTU will react to a stretch reflex potentially faster and be able to create more power in a shorter range of motion. The third way is potentially increasing muscle fiber length but research still needs to confirm this. Relative maximal force in the muscles is important because tendons cannot create power but can only transfer power by releasing the energy provided from external sources such as the musculature. MTU stiffness and muscle maximal force seem to be best developed efficiently under heavy to moderate strength training loads (Kongsaard et al. 2007), muscle neuromuscular performance through both power and heavy strength training (Bompa & Buzzichelli. 2015. p. 60) and fiber length can be potentially best improved with power training with strong eccentric movements (Alegre et al. 2006). For more details, see Table 12.

In conclusion:

- The SSC - cycle is an important neuromechanical part of the puzzle in increasing RFD that takes advantage of the elastic components of the body. The SSC-cycle should be taken full advantage of in MMA performance to increase the amount of powerful strikes that can be delivered during a MMA bout.
- Strength & Conditioning training for MMA athletes should aim to stiffen the MTU complex and improve neuromuscular performance via appropriate heavy /moderate strength & power training so that more power can be delivered in smaller ranges of motion (the opponent cannot potentially see small loading movements).

5.4. Forms of strength- & power training

Conventional strength training can be traditionally divided into heavy (neural), moderate (hypertrophic/work capacity /power) and light (work capacity/power) loads and the % and repetition ranges vary slightly between researchers. These loads do not say anything about repetition ranges and therefore do not yet lock in a specific stimulus. For example, moderate loads can be used to train either primarily hypertrophic, work capacity ("strength endurance") or power properties depending on the repetition range and speed of movement. Schoenfeld (2010) proposed the following ranges: 1 – 5 repetitions being low, 6 – 12 repetitions being moderate, and 15+ repetitions being light. These repetition ranges likely correspond to percentage of 1 repetition maximum (RM) as follows: 80 – 100% of 1RM being heavy, 60 – 80% of 1RM being moderate, and <60% of 1RM being light. To simplify things usually heavy & moderate strength training (65 - 100% of 1 RM) are pushed into one category; maximal strength training. This is because both heavy and moderate strength training can contribute to maximal strength by increasing different aspects of it; both neuromuscular and structural. Both forms can slightly blend into each other and one might affect performance more than the other, but in general heavy strength training increases neuromuscular performance, and moderate strength training increases performance via adding muscle size (hypertrophy). The goals of maximal strength training are quite simple: to build a strong athletic foundation. Different sports of course vary with how big this foundation has to be, but in general if a long injury free career is the goal, there needs to be some long term focus on this area in any power endurance sport. What is interesting is that if an athlete has a low strength base, they will most likely not benefit from power training nearly as well as an athlete who has a strong strength base (Cormie et al. 2010a, Bazyler et al. 2015). Also, a relatively weak athlete will improve power variables just by doing high quality strength training (Cormie et al. 2010b). There are a lot of misconceptions about strength training in martial arts (potentially less in MMA), that are good to clear up this paper to some extent.

Simply put the goal of power training is to use the maximal strength foundation and maximize its potential for performance. Power training can be completed with varying loads from 0 – 80%of 1 RM. Power training is therefore a very abstract term, including variations of methods such as plyometrics, sprinting and agility (body weight exercises in this case with 0 load), ballistic training (i.e. loaded jump squats, MD-ball throws), Olympic lifts (i.e. power clean, jerk) and non-ballistic power training (i.e. strength training explosively with lighter loads but without jumping/throwing). Although sprinting and agility can be separate to speed exercises, for simplicities sake, they are all kept under the "power training" term in most of this paper, and separate when appropriate. In terms of convenience and practically for an MMA athlete, plyometrics, sprinting and agility are very easy to implement and can even be taken into the program as a neuromuscular warm-up before MMA training. Weighted power exercises are certainly more than advised (as mentioned in the biomechanics section), but should not be practiced without first learning a high standard of technique, starting with learning a high level of technique for strength training movements.

In general, although hypertrophic specific strength training (moderate loading) can be important for some athletes in the beginning of the season, weight class sports such as MMA should prioritize focusing on increasing maximal strength & power related to their body mass. This is done by focusing more on neuromuscular adaptations from maximal strength training and power training (Bompa & Buzzichelli. 2015. p. 198). Some structural growth should not be viewed as negative though. We need muscle mass to protect joints and we need our passive tissues (tendons, ligaments) to stiffen and therefore grow to tolerate higher strains. But as mentioned earlier, the lean of focus is more towards the neuromuscular. It should also be noted again that moderate strength training loads also stimulate neuromuscular adaptations if done correctly (Table 11) and do not imply always that there will be excessive muscle growth. Theoretically, as long strength training does not take away too much time from the sport itself, slow you down, does not increase too much mass, and is always considered in a relative sense, there is no such thing as a "too strong athlete". It is important to remember that ultimately, due to the substantially large endurance element in MMA, an MMA athlete will most likely never reach their true potential of maximal power production (i.e. if they were a shot putter). This however, in no way means that power values can be improved throughout most parts of an MMA athlete's career. More about programming maximal strength and power training will be presented in the periodization section.

In conclusion:

- The maximal strength training zone includes both heavy and moderate strength training, therefore when used as a term one should be aware that it does not yet specify which form should be used for a specific stimulus.
- Although neuromuscular adaptations from maximal strength and power training should be prioritized in MMA, some structural tissue growth (both active and passive tissue) is needed for both performance and injury prevention.
- Power training is a very abstract term with loads ranging from 0-80% of 1 RM. All these ranges are important to stimulate for an MMA athlete, because there is such a large variation of force application in MMA.

- In this paper speed & agility training are included in power training.

5.4.1 Types of contractions in strength training and in MMA

Strength training can also be divided into concentric, eccentric, and isometric contractions (Bompa & Buzzichelli. 2015. p. 40). All of these contraction types are used in MMA and should be given appropriate attention. For example, in the “stand-up” game, isometric contractions come from such aspects as maintaining posture and therefore a strong structure, and eccentric and concentric contractions come from loading and delivering strikes. In wrestling isometric strength becomes even more evident when holding specific positions before transferring into the next (Bounty et al. 2011).

5.4.2 Neuromuscular adaptations from different forms of strength training

An MMA athlete should want to improve their intramuscular and intermuscular coordination while removing inhibitory mechanisms, but what does this all mean? Intramuscular coordination refers to the neuromuscular adaptations that happen to one specific muscle after certain forms of strength training, such as improving simultaneous recruitment of motor units (that include slow- and fast twitch muscle fibers). To get a better idea of what strength training zones give the optimal intramuscular stimulus we can observe from Table 11 that we want to stay in the heavy strength training zones 80 – 100% of 1 RM. For an MMA athlete this intramuscular improvement might mean being able to withstand a takedown attempt due to more motor units being recruited in the right muscles, especially in a fatigued state.

Table 11: Neural adaptations according to strength training zones (Bompa & Buzzichelli. 2015. p. 60)

Adaptations	INTENSITY ZONES (% OF 1RM)					
	6	5	4	3	2	1
	40–60	60–70	70–80	80–85	85–90	90–100
Intramuscular coordination:						
• Synchronization	****	****	****	****	****	****
• Recruitment	**	***	****	****	****	****
• Rate coding	****	***	***	***	****	****
Intermuscular coordination	****	****	***	***	**	*
Disinhibition of inhibitory mechanisms	*	***	***	***	****	****
Specific hypertrophy	**	****	****	***	**	**

Adaptation stimulus: **** = very high; *** = high; ** = medium; * = low
All loads are supposed to be moved with the most explosive (and technically correct) concentric action that the load allows.

But the effect of intramuscular coordination is dependent on intermuscular coordination. Intermuscular coordination refers to the neuromuscular adaptations that happen to the muscles in the kinetic chain, and their optimal cooperation between each other (Bompa & Buzzichelli. 2015. p. 59). In other words the body’s capability to coordinate force in athletic motion is improved. Although this also happens in maximal strength training (Table 11), intermuscular coordination seems quite logically to be further enhanced in power training in training loads ranging from 0 – 80% of 1 RM, where "0" is body weight exercises such as plyometrics, agility and sprinting. In terms of MMA, this might mean exactly what was mentioned in the in biomechanics section: the capability to use powerful well-coordinated triple extension from the lower body in strikes and takedowns.

Inhibitory mechanisms are fascinating and refer to reducing involvement of injury protector mechanisms such as the GTO (Golgi tendon organ) and renshaw cells (Bompa & Buzzichelli. 2015. p 59). Eccentric strength can be up to 40% higher (!) than our maximal isometric strength (Bompa & Buzzichelli. 2015. p. 40) and this strength portion is largely inhibited in an unconditioned athlete due to the above mentioned inhibitory mechanisms. It seems that these inhibitory effects are best removed with heavy strength training (Table 11), but with long term training can be possibly removed with the help of plyometric training (Kyrolainen et al. 1991).

Due to explosive strength training effects intermuscular coordination possibly the most, teaching weak form/technique will most likely impact negatively muscle firing patterns that directly affect performance outcome. For example, due to high level strikers use mostly their hip as an source for power with the help of the SSC-cycle, initiation of a powerful strike is much like initiating a very small (in terms of angles) jump (although not leaving the ground). It has been shown that the optimal intermuscular coordination in a jump is that the energy shifts from the hip to the knee and for controlling the direction of force the hamstrings should fire first, then the gluteus and then the quadriceps (Moir. 2015 p. 226). Therefore, successful execution in explosive tasks is not just about generating large forces, but also coordinating the correct muscles in the correct sequence to maximize results. It is important to note that firing patterns do not confirm which muscles are used the most in a movement, but help paint a picture of efficient movement in performance. This is why it is most likely essential for long term sustainable development that an athlete avoids substantial levels of strengthening via just thinking about how much weight they lift and instead consider even when lifting heavy (where intramuscular coordination is the goal) how they weight is effecting intermuscular coordination (i.e. load the muscles in a functional movement pattern). While strengthening and even in sport specific tasks, it seems appropriate to make an athlete (ideally already in young age) aware of using/feeling their hamstring and gluteus in movement, and therefore promoting functional "hip dominance" (Patel. 2010), and correct intermuscular coordination. In Fig 3 we can see an example of teaching an athlete hip dominant vs a knee dominant jumping pattern.

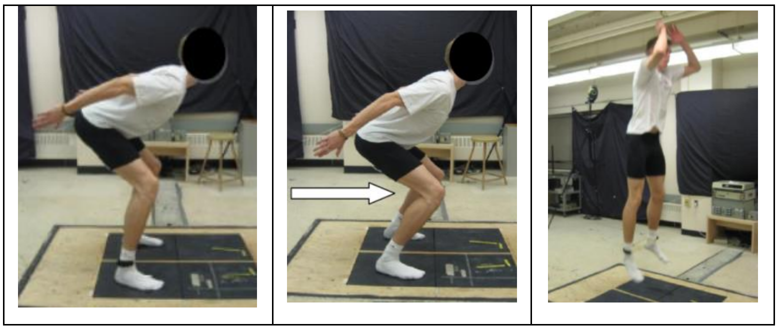


Figure 3: Hip dominant vs. knee dominant movement pattern in a vertical jump (Patel. 2010)

In conclusion:

- Neuromuscular training can further be divided into intramuscular and intermuscular coordination adaptations. Both are essential for increasing performance and different methods of training should be used from the maximal strength & power training spectrum
- Inhibitory mechanisms should be removed as much as possible and seem to best react to heavy strength training.
- Intermuscular coordination is something that should be taken into consideration in all movements done in strength & conditioning because it effects how we coordinate muscles in different sequences. If we want to learn to transfer energy without energy leak via the hip into the kinetic chain, training that can in any way stimulate an adapt intermuscular coordination to a new level should be thought through very thoroughly if the movement pattern/technique used is the most optimal one to effect the athlete's performance.

5.4.3 Core training in MMA

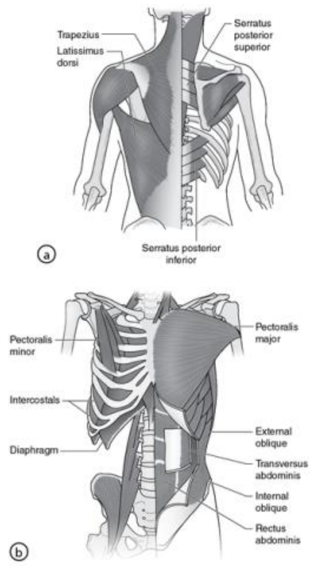


Figure 4: Anterior (a) and Posterior (b) core (Not all muscles are presented here) (Willardson. 2013. p.13)

The development of core stability has also become a focus of many strength and conditioning programs, especially for martial art athletes (McGill et al. 2010, Bounty et al. 2011. Willardon. 2013. p.185. Lee & McGill. 2015). implementing effective strategies to condition the core for sport performance has been the subject of debate (Young. 2006. McGill. 2010). Putting the benefits of core training for rehabilitation aside, what is interesting is that many authors argue that there is no significant benefit to training the core with isolated core endurance exercises, if the end goal is power and strength in performance (Nesser et al. 2008. Behm. et al. 2009. Nesser, & Lee, 2009). Although this sounds both interesting and provocative, we have to remember that isolated core endurance exercises are just a little part of the puzzle. To understand the reason for the lack of results for performance, we must first get an image of the complexity of the core according to modern research.

The core can be defined as the entire trunk region that runs from the pelvic girdle through the vertebral column and the rib cage to the shoulder girdle. Between all this are multiple layers of fascia, ligaments and muscles that create a uniquely complex anatomical network around the spine (Willardson. 2013. p.13) (Fig.X). In sport performance, core stability has been described as the ability of the trunk to support transfer of energy from the lower extremities to the upper extremities (McGill. 2010. Willardson. 2013. p. 12), therefore creating an anatomical bridge between the lower body and the upper body. Not long ago, the core was considered to include the diaphragm muscles at the top, the paraspinals and the gluteals as the back, and the abdominals as the front, forming a sort of anatomical "box" (Kibler et al. 2006). What is fascinating is that over the years the muscles that are considered a part of the core have been constantly updated, adding such muscles as the latissimus dorsi (that is said to connect the shoulder to the hip), pectoralis major, hamstrings and the psoas as "upper and lower extremity core-limb transfer muscles", reaching at least a minimum total of 22 muscles (Willardson. 2013. p. 25).

Focusing on a single muscles of the core generally does not enhance stability but quite interestingly can create patterns that when quantified result in less stability, such as isolating the transverse abdominis and multifidus (Koumantakis et al. 2005). Also again quite controversially, according to Dr. Stuart McGill (2013), a world renowned spine specialist who has worked with martial art athletes, isolated core training should be used but it should not be dynamic where the spine is moved each repetition from hyperextension to flexion/lateral flexion (i.e. forms of crunches). This puts unnecessary load on the spine and might affect intermuscular coordination in a negative manner when the goal in most athletic movements is for the spine to stay still (i.e. going into excessive spine flexion while initiating an explosive movement = energy leak) (McGill 2010. Lee & McGill. 2015). Therefore, the problem of core training might derive from the fact that many practitioners are simplifying core training too much, when we now know that there are so many more muscles involved, which are actively cooperating with each other for efficient core stiffness so that energy is transferred efficiently from the lower extremities to the upper extremities.

Keeping these facts in mind, while knowing that core strength is an essential part of martial art performance (Filimonov et al. 1985. Bounty et al. 2011, Lee & McGill. 2015), what kind of core exercises should a MMA athlete spend most of his time doing? What seems to be preferred are movements that significantly activate multiple local and global muscles isometrically at the same time while specific upper and lower extremity "core-limb transfer muscles" are working dynamically and/or isometrically to help shift efficiently energy from the trunk to the extremities (Lee & McGill et al. 2015). Just like in the biomechanical section, movements in different planes are advised. From Lee & McGills (2015) perspective just a few examples would be movements such as "stir the pot" and "bird dog", which isolate and train the core isometrically while adding dynamic movement from the extremities to challenge stability more. Also, in the case of maximal strength for the core, more dynamic movements such as the squat and the deadlift can be used in a well-rounded program to further increase results (Hamylin et al. 2007). Hamylin et al (2007) found 50 – 60 % higher muscle activity in erector spinae muscles and no difference in external oblique and lower abdominals in heavy squats and deadlifts (80% of 1 RM) when comparing to traditional core exercises such as side plank and "Swiss ball Superman". However, it is very important to note that the study is very limited due to only observing a few heavy strength training movements and more importantly, only a few of the core muscles (i.e erector spinae, external oblique, lower abdominals), and there was no talk about what technique was used in such movements as the squat, even though research shows that different squat techniques (i.e. narrow, neutral, wide, front, back, was the spine kept neutral?) active certain muscle groups differently (Clark et al. 2012). We also know that movements such as the deadlift (again, multiple forms can be used) activate specific local and global core muscles while having high activity from important "core-limb transfer muscles" such as the hamstrings and latissimus dorsi (Beggs. 2011).

Also, to build "abdominal armour" for an MMA athlete (McGill. 2013), hypertrophy is advised and therefore increased time under tension (TUT) under moderate loads should be used (Bompa & Buzzichelli. 2015. p. 44). In beginner athletes "moderate" loads might mean specific isolated bodyweight core movements that can be possibly enough to cause hypertrophy in specific core muscles. To conclude and to promote objectivity, although more dynamic movements such as specific forms of squats and deadlifts might train specific core muscles more efficiently in performance terms, as stated earlier this does not disregard the value of more isolating isometric core movements outside of the heavy strength training spectrum. For now, the strongest advice that can be given points to that exercises with excessive movement of the spine (especially flexion) do not promote results in terms of performance or injury prevention (Lee & McGill. 2015).

In conclusion:

- The complexity of the core training is underestimated, and often trained in manners that most likely promote unfunctional neuromuscular adaptations.
- Being able to isometrically stabilize the spine with the help of local and global core muscles while using core-limb transfer muscles seems to be a good starting point to learn efficient energy transfer
- The core should also be trained via forms of heavy strength training by using high quality hip dominant compound lifts that promote a neutral spine and put positive pressure on the core.
- To avoid unnecessary long-term negative loading on the spine, movements that promote a high degree of dynamic flexion of the spine, especially at the same time as rotation, should be avoided.
- Much more research needs to be done to strongly conclude anything and further reading is advised for this controversial subject.

5.4.4 Time under tension – benefits and possible performance risks for MMA

In heavy load- and moderate load strength training the contraction speeds are slowed down for at least 3 reasons: 1. To maintain technique. 2. Due to the force – velocity relationship; a human cannot push high force with high velocity (at least without the help of elastic elements). 3. Deliberately to increase timer under tension (TUT). For certain adaptations to take place increasing TUT is a beneficial method because it increases the effect of different structural (architectural and morphological), metabolic-, and endocrinal adaptations (Bompa & Buzzichelli. 2015. p. 44).

When doing longer sets, to avoid any speed deficits while creating other adaptations, it seems that an athlete should create the increased TUT via slowing down the eccentric phase and possibly via isometric holds at certain angles, and not by slowing down the concentric phase. When the technique is of sufficient quality (to avoid injury), there seems to be nearly no valid reason for slowing down concentric phase (Bompa & Buzzichelli. 2015. p. 44). In fact, moderate to significantly better results in maximal strength and power have been reported in strength programs where the bar is moved with maximum intended velocity in the concentric phase compared to a pacing strategy (weight is not moved at full speed) (Padulo et al. 2012, Gonzalez-Badillo et al. 2014). Also, it is worth mentioning how to avoid certain negative effect on structural properties of non-pacing vs. pacing strategy, such as on fiber length. Although forms of power training seem to be the most appropriate training method to improve fiber length, if the concentric phase is done with maximal intended speed in heavy and moderate strength training, fiber length decreases can possibly be avoided (Alegre et al. 2006), and more importantly, any negative effects on intermuscular coordination (i.e. reduction in strike speed). Also, heavy strength training with maximal intended speed in the concentric phase has been shown to improve speed of contraction and therefore a longer relaxation time before the next contraction in elite athletes (Rønnestad et al. 2015), leading most likely to conserved energy and improved performance, more about this in the endurance section.

In conclusion:

- In specific times during the early season, increasing TUT is important for further adaptations
- When increasing time under tension, manipulate eccentric and isometric variables more than concentric
- In heavy and hypertrophic strength training move weight with maximal intended speed in concentric phase

5.4.5 Strength training and its role in improving endurance in MMA

Studies on endurance athletes and how concurrent strength training has affected their performance outcome can be of extreme value to an MMA athlete; not only from a performance perspective but from a programming one. Strength training has been shown to improve endurance performance in elite level endurance athletes in multiple studies (Bazyler et al. 2015, Rønnestad et al. 2015), while maintaining body mass, relative V02max and capillarization (Rønnestad & Mujika. 2014). In terms of what loads should be used for endurance athletes, it might be argued that moderate and light strength zones are good to have in the program for metabolic purposes such as increasing glycogen content in muscles via inducing fiber hypertrophy (Tesch PA. 1988). While it is very important to increase storage size for the two most important energy sources in MMA glycogen and PCr (Phosphocreatine), interestingly enough this has been shown to happen via maximal strength training (6-8 RM zone) in young untrained subjects already before the onset of fiber hypertrophy adaptations (Goreham et al. 1999). While these results should not be generalized within MMA, it does show that hypertrophy is not always necessary for such adaptations. Studies have shown on higher level endurance athletes in a big variety of distances that increase their maximal strength via heavy load strength training (< 6 RM) can significantly improve endurance performance. This is achieved not with affecting such elements as V02max but more by enhancing neuromuscular function such as improving intramuscular coordination (Table 11) in all movement and therefore being more economical in movement (Aagaard. 2010. Rønnestad & Mujika. 2014. Bazyler et al. 2015. Rønnestad et al. 2015). This is an interesting finding and questions the need of loads in strength training that produce repetitions past the hypertrophy zone (>12 -15+ rep).

Forms of power training were also mentioned as a great tool to enhance endurance performance (Bazyler et al. 2015). The reasons for this are obviously multifactorial and complex, but one very fascinating way to explain the improvements from power training to endurance performance is through a fascinating study done on elite cyclists. Rønnestad et al. (2015) showed that explosive heavy strength training (meaning heavy strength loads done with maximum intended velocity) reduced the time to reach peak force during the pedal stroke and improved cycling endurance performance. This in term created a very interesting theory that improvements in RFD for the pedal stroke led to a longer relaxation time before the next pedal stroke, therefore increasing the time of blood flow (more oxygen) before the next contraction (Rønnestad et al.

2015). Although it is a completely different sport, it gives a good image on how the body's neuromuscular system adapts to support endurance performance. As mentioned earlier in the RFD section, a strike produces a contract – relax – contract impulse pattern (McGill. et al. 2010). Just like the cyclists, what if we can increase in the relaxation time between these impulses by improving early RFD, how will it affect energy use? In MMA this might mean the difference between having the energy to perform a couple of more significant strikes before the last round is over.

In conclusion:

- To maximize endurance performance, use heavy strength- and/or forms of power training on a weekly bases.
- These forms of training will improve exercise economy, power/velocity at lactate threshold, improved anaerobic capacity and repeated sprint ability (RSA).
- Avoid too much hypertrophy stimulus, so no unnecessary mass will be gained, therefore no compromised relative V02max and capillarization

5.4.6 Conclusion of strength & power training implications for MMA athletes

Table 12: Structural and neural adaptations from different forms of strength & power training

Structural and neural changes that should interest an MMA athlete:

- Increase of muscle fiber size (CSA) to a certain extent
- Increase tendon & muscle stiffness: MTU stiffness
- Improved intra & intermuscular coordination and removal of inhibition mechanisms
- Increased fiber length
- Although it would make sense that MMA is a fairly fast twitch glycolytic sport where there is a priority of IIA fibers and fiber switches towards it, if possible a sacrifice of slow type I fibers rather than type IIB fast twitch fibers to IIA fibers would be preferred.

There is not one specific form of training that best promotes or even inhibits these adaptations, hence both strength & power training are advised. Underneath is a list of possible positive and negative adaptations for performance caused by either strength or power training:

Maximal strength training (Heavy & Moderate - loads between 65 – 100%):

Are known to have positive effects on:

1. Increased CSA of muscle fibers (Type I, IIB, IIA) (Shepstone et al. 2005)
2. Increased CSA of tendons and improved tendon stiffness (Kongsaard et al. 2007)
3. Increased intracellular coordination and decreased inhibition mechanisms (Bompa & Buzzichelli. 2015. p. 60)

Notes: First two seem to be effected more by high force and longer TUT (Bohm et al. 2015, Bompa & Buzzichelli. 2015. p. 65). MTU stiffness can also be enhanced by certain forms of intense isometric- (Burgress et al. 2007) and eccentric contractions (Morrissey et al. 2011).

Could cause negative effects on:

1. Shifts from type IIB fiber to type IIA fiber (Andersen et al 2010).
2. In certain cases (i.e. excessive hypertrophy– not enough power training), might cause reduction in fiber length but indirect proof only exists at this point (Kumagai et al. 2000)
3. Might cause negative intermuscular coordination due to weak form/technique in strength training (Patel. 2010. Moir. 2015 p. 226)

Notes: Shifts from Type IIB -> IIA fiber can be reduced (Hedayatpour & Falla. 2015) and fiber length can even be possibly increased (Aagaard. 2010) by certain forms of intense eccentric strength training. At the very latest these possible negative effects can be likely reduced by maintaining explosive training in the program.

Explosive strength training (ie. Olympic lifting, ballistic training, plyometrics, sprinting, agility) - loads between ~0 – 80%

Is known to have positive effects on:

1. Shifts from type I fiber to type IIA or maintenance of IIB fibers (Liu et al. 2003)
2. Increase in fiber length (Alegre et al. 2006)
3. Increased tendon stiffness (Burgress et al. 2007)
4. Increase in intermuscular coordination (Table X) (Bompa & Buzzichelli. 2015. p. 60)
5. With long term training decreases inhibition mechanisms (Kyrolainen et al. 1991)

Could cause negative effects on:

1. Not optimal intermuscular coordination due to weak form/technique in explosive training (Patel. 2010. Moir. 2015 p. 226). Due to high ground reaction forces, bad form will also increase injury risk significantly.

Notes: Shifts from type I fibers to Type IIA fibers seem to happen most optimally under fast eccentric training conditions (Paddon – Jones et al. 2001). Also it is worth mentioning that increases in fiber length are quite interestingly not effectively caused by stretching. It seems that stretching more effects increases in stretch tolerance, or in other words: increased pain tolerance without affecting the architecture (Weppler et al. 2010), but more research is needed to confirm this.

CSA = Cross sectional area	Type IIB fiber: Fast twitch glycolyctic
Type I fiber: Slow twitch oxidative	
TUT = Time Under Tension	Typer IIA fiber: Fast twitch oxidative glycolytic

5.5 Endurance training for MMA

For clarities sake, it is worth repeating in this section what was already established in the endurance characteristics of an MMA bout and an MMA athlete; a relatively high V02max (~58 ml/kg/min) and anaerobic conditioning in both the upper and lower body (correlated to high blood lactate post boutt) seems to be essential for an MMA athlete's conditioning. There are at least a couple of interesting questions that need to be answered in this section. To start with, what kind of aerobic base should be promoted to an MMA athlete? Are long slow runs (training under/around aerobic threshold) essential for an MMA athlete's aerobic base at some point of their program? And moving on to aspects that more directly portray combat performance, what kind of high intensity conditioning training should be used to improve an MMA athletes V02max and anaerobic conditioning? New research is constantly produced towards understanding the optimal training stimulus for improved endurance performance, and this papers goal is try to portray the most up to date answer to these questions so coaches can further adapt it to practice.

Using figure 5 below, it is easier to explain later on where certain training stimulus is optimally performed. As we can see, our conditioning can be divided into 3 zones; below aerobic threshold, between aerobic and anaerobic threshold and above anaerobic threshold.

As established before with 5 minute rounds, MMA has considerably higher round lengths compared to other combat sports such as Muay Thai, Boxing & Wrestling (around 3 minute rounds). This quite obviously increases the role of aerobic endurance properties. The general idea is, the longer the round the more aerobic it becomes, therefore an MMA athlete has to be much more aerobically prepared than most combat sports (Jamieson. 2009. p.31, Alm et al. 2013).

Figure 5: Three intensity zones defined by defined by aerobic threshold (VT/LT 1) and anaerobic threshold (VT/LT 2). MLSS = Maximum lactate steady state (Seiler & Tønnessen. 2009)

5.5.1 The role of low intensity conditioning training

For optimal performance in training sessions and in the actual bout, the capability to recover is key. This is where the debate comes in concerning a strong "aerobic base" and how it should be achieved within MMA.

To understand this section of the paper better, a brief summary will be presented on what the ventilator threshold is and what the lactate threshold is.

Ventilatory/Lactate threshold 1 (VT/LT 1): Point during training at which pulmonary ventilation becomes disproportionately high with respect to oxygen consumption (V_{02}); believed to reflect the mild initiation of anaerobiosis (energy produced without oxygen) and therefore slight lactate accumulation (Stedman's. 2011). Training under or at this threshold is considered zone 1 training according to Figure 5.

Ventilatory/Lactate threshold 2 (VT/LT 2): The point during exercise of increasing intensity, when an aggressive nonlinear increase in blood lactate level occurs (see blue line in figure 5). At this point certain molecular products that can decrease performance are being produced faster than they can be removed/used within the body. This is in conjunction with an exponential increase in respiratory frequency. (Stedman's. 2011). Training at or above this threshold is considered zone 3 training according to Figure 5.

If we observe highly successful Olympic endurance athletes (runners, swimmers, cyclists, cross-country skiers) yearly program structures from different countries around the world we can conclude some very interesting information concerning which heart rate zones most training is spent in. These athletes in average trained 10 – 12 times per week (Seiler & Kjerland. 2006. Seiler & Tønnessen. 2009),which is a very similar volume to a professional MMA athlete (Lovell et al. 2013). For long-term success there seemed to be a shift from a "lactate threshold training model" to a "polarized training model" approach (Figure 6).

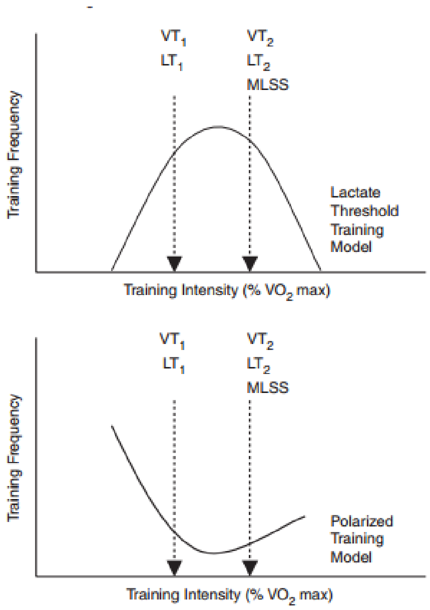


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Figure 6: The lactate threshold training model and the polarized training model (Seiler & Kjerland. 2006)

In the new polarized approach, there is a very low emphasis on zone 2 and most training is done in zone 1, and when more intense sessions are done athletes train at the zone 3 threshold or above, with an ~80:20 training ratio between zone 1 and 3, respectively (Seiler & Kjerland. 2006. Seiler & Tønnessen. 2009). Seiler & Kjerland (2006) reported based on high level Norwegian cross-country skiers that in reality these ratios ended up being ~75% in zone 1, ~8% in zone 2 and ~17% in zone 3 (if counted according to session-goal method). It is obviously not possible to completely isolate zone 3 in training because an athlete has to move through zone 2 in many situations, such as when recovering from intervals. The point is more that zone 1 is by far the most important zone for elite level endurance athletes to stay in followed by zone 3 and then zone 2, which is given by far the least attention (if any direct attention). This translated to an average of 1-3 high intensity conditioning sessions and 9-11 lower conditioning sessions (varying in length) per week depending on the time of season. According to Seiler & Tønnessen (2009) this information is of very high value because there has been a misconception created by the popular media, where specific research results have been abused to create simplistic notion that high intensity conditioning training can replace the benefits of low intensity conditioning training. The value of shifting the workload from zone 2 and making zone 1 dominant for elite athletes has been explained in multiple ways. One of the most important reasons seems to be quite simply being able to increase the athlete's weekly training volume without overtraining them in the long run (Seiler & Tønnessen. 2009).

In terms of exercise physiology, low intensity training is essential for improving components of cardiac output, such as increasing stroke volume of the heart (Figure 7). It has been observed that there are two clear ways of growing the size of the heart; through eccentric or concentric hypertrophy (Jamieson. 2009. p. 36). Concentric hypertrophy happens via aggressive contractions of the heart via high intensity training, which helps to increase the actual size of the heart walls. Eccentric hypertrophy training on the other hand seems to be more achieved (but not limited to) through stretching (hence the word eccentric) the ventricle bags by filling them with as much blood as possible before the next beat, chronically adapting the heart to have more space to pump more blood per beat. Quite logically, this cannot be achieved if the heart rate is too high, because there will be not enough time for a maximal stretch. Therefore, long (45 – 90 + min) and low intensity conditioning training (HR: 120 -150) is advised for such adaptations (Jamieson. 2009. p. 36).

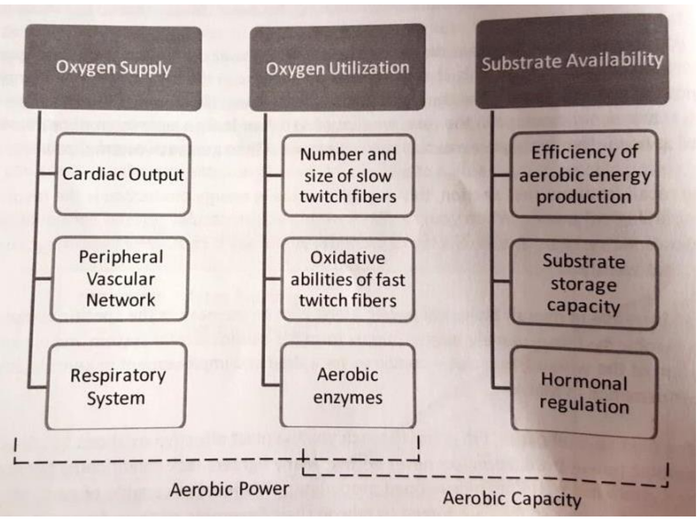


Figure 7: Components of aerobic energy production (Jamieson. 2009. p. 33)

One could argue if this eccentric hypertrophy can be achieved sport specifically by just doing light technical sessions instead. There is no doubt that some form of positive stimulus could be achieved in this format, but it is still very hard to achieve high quality results this way due too it being much harder to control the heart rate under such circumstances. We also have to remember that low intensity jogging/cycling can be combined as a longer warm up to a technical session, which is actually quite common practice in Thailand for Muay Thai athletes.

The issue also is not always the lack of awareness but instead the lack of quality. Successful endurance athletes are good at training light when they are supposed to train light and can train hard enough when the goal is to train hard (Seiler & Tønnessen. 2009). This might sound simple but it is highly understated. For example, when the goal is to train light, using low intensity training in forms of jogging/cycling is nothing new for many coaches. The issue is most likely more in the direction if the athlete is training light enough and not constantly jumping into zone 2. This is why it can be important to establish individual athlete's aerobic and anaerobic thresholds through such tests as V02max, so that the athlete can follow what zones they are mostly moving in every now and then. In striking sessions, it is quite easy to wear a heart rate monitor but in wrestling sessions it is still unfortunately a challenge (hopefully technology will catch up someday).

In conclusion:

- To maximize cardiac output and avoid overtraining in the long run, most of the yearly training volume should be low intensity in nature by staying in or around zone 1 (Figure 5).
- Low intensity training can be done sport specifically (with a slight lack in quality from a physiological standpoint) with sessions that only focus on light technical drills. If done separately from MMA training, duration of 45 – 90+ minutes (depending on the level of the athlete) with an average HR of 120 -150, or HR under or at the first ventilatory threshold (Zone 1) is advised (1-3 x week). Coaches should experiment to find ways to improve the quality of training in light sessions, so that the heartrate stays appropriately low.
- Completing a direct V02max test where the ventilatory thresholds become present is one smart way to find out if the athlete is lacking in aerobic conditioning and is relaying too much on the anaerobic metabolism, therefore possibly needing a different conditioning approach.

5.5.2 The role of different forms of high intensity conditioning to maximize performance in MMA

High intensity conditioning involves performing multiple series/sets of exercise above the anaerobic threshold. Forms of interval or circuit training are nothing new within sports that include any form of speed bursts; however, there is plenty of debate of what the most optimal forms of high intensity conditioning training are for a specific stimulus. High intensity conditioning training in general is divided into HIIT and SIT. High Intensity Interval Training (HIIT) is considered efforts at or around V02max speed, and Sprint Interval Training (SIT) is considered to be shorter "all – out" interval efforts. It is very important to note that both formats can be used for circuit training (even sport specifically) but SIT might be more practical for such manipulations due to (among other things) it's "all – out" bursts of activity. If we simplify things, MMA is actually an interval based sport by itself (i.e. attack, recover, attack), so at first glance it does not seem very complicated to create similar interval protocols that simulate a tough bout. MMA athlete wants to be able to reproduce fast bursts of power (i.e. strikes & takedowns) or maximal isometric efforts (i.e. wrestling efforts) from both their lower and upper body (i.e. speed/power endurance) within 3 x 5 minute rounds with 1-minute break. These bursts of maximal energy production are mixed with submaximal techniques (i.e. moving around in the ring, changing pace) through all the rounds. Ideally if the conditioning has worked well, the MMA athlete is recovering to some extent during these submaximal efforts and not just relaying on being able to stay a long time in a maximal effort zone.

HIIT and SIT are nothing new in elite level periodization, if we recall the "80:20" principle from the low intensity training section, for elite level endurance athletes a large part of that 20 % is trained at desired race pace or “supramaximal” efforts of the sport itself (Seiler & Tønnessen. 2009). One fundamental goal of interval training is training a speed that an athlete cannot yet hold constant or repeat for longer periods of time. It is important to note that conditioning via intense interval training is not a simple black and white practice; it’s not just about manipulating speed but also manipulating such things as sport specific work:rest ratio stimulus, therefore creating a higher “biological ceiling” (Hawley. 2008). Increasing the biological ceiling is nothing different from using the popular martial art catch phrase “Train hard, fight easy”. The goal is just to put more quality in it. If we look at an MMA bout, the most challenging situations are when multiple all-out efforts have to be repeated in a short time span. Even though normal work:rest ratios in MMA are considered to be around 1:2 – 1:4 (Table 2), a lot of that work is not all-out due to the very challenging round lengths, incomplete conditioning and also on purpose in form of fight tactics. But when a clear opportunity rises, you would assume that an MMA athlete would always want to have the conditioning to move at full speed whenever they want. The principle of specificity states that sports training should be relevant and highly specific to the sport for which the athlete is training (McCafferty & Horvath. 1977). Although this principle can easily promote all too simplistic solutions, the idea has some merits. For example, in terms of becoming more efficient at a specific speed, there are endurance research results that support the idea of specificity by showing that if you dominantly train at a certain speed, you will be become more efficient (economical) at utilizing energy around that speed (González-Mohíno et al. 2015). In terms of MMA, this information could be taken into for example striking & takedowns; when the goal is to improve the capability to move more often at full speed during a bout, an MMA athlete should consider training dominantly at full speed in high intensity conditioning training, and then one will become economical at delivering knockout power when fatigued. This approach supports the idea that even though an MMA athlete might not always want to move at full speed during a bout, they can if they want to. This approach obviously promotes the SIT format over HIIT, but it is good to remind the reader that improving speed/power endurance is just one piece of the cake (although a substantial one).

Simply put, we want to functionally improve an MMA’s capacity to use their alactic, lactic and aerobic system. Because the cardiovascular system is not aware of what sport you are doing, it is actually easier to approach the problem from a less sport specific and more physiological standpoint. As stated in the physiological characteristics of an MMA bout section all 3 energy systems are important for an MMA athlete with a slight lean towards the aerobic compared to other combat sports. Therefore, the next step would be summoning research which tries to explain what type of high intensity conditioning training effect the anaerobic (alactic, lactic) and the aerobic system, or possibly more than one!

For a long time, at least among sport science researchers, it was considered that longer intervals only affect significantly aerobic performance and shorter intervals anaerobic performance. For example, intervals with a length of 4-8 minutes with intensity around $V0_{2max}$ or slightly under were considered ideal for improving aerobic performance tests such as the 40 km time trial among cyclists. Septo et al. (1999) was not the first study to contradict this simplification, but the results surprised even the authors. The study compared 5 different interval protocols, and did it by replacing a portion of trained cyclist's weekly endurance programs with 2 interval sessions for 3 weeks. Then the cyclists were randomly assigned to the following interval protocols: 12x30 s at 175% PP (PP = Peak aerobic power), 12x60 s at 100% PP, 12x2 min at 90% PP, 8x4 min at 85% PP, or 4x8 min at 80% PP. The 4 minute intervals were carried out at a pace similar to that of the time trial, so they were expected to give the best results according to the principle of specificity. But what was surprising is that both the 30 second sprint intervals and 4 minute intervals were successful at improving the 40 km time trial performance (Septo et al. 1999). A good explanation to this paradox can be found in many studies, including one that was made the following year. In this study, subjects completed 14 days of daily SIT consisting of two 15-s all-out bouts separated by 45 s of rest, followed by two bouts of 30 s all-out sprints separated by 12 min of rest. Every two training sessions, an extra work bout was added. The last 3 sessions consisted of seven bouts of 15 s and seven bouts of 30 s. The study was not solid; with only 5 subjects and a questionable post-test time structure with the anaerobic Wingate test done directly the next day after 14 days of training (V02 max test done 5 days' post training), but still provided some fascinating results with muscle biopsies and V02max tests. V02max increased quite significantly from 57 ± 3 to 64 ± 3 ml/kg/min (ideal area for an MMA athlete), and there were also significant increases in activity of aerobic enzymes citrate synthase and 3-hydroxyacyl-CoA dehydrogenase. These changes in aerobic enzyme activity may increase the efficiency of aerobic glycolysis and also fat oxidation leading to smaller drops in muscle pH (acidosis) during high intensity performance (Rodas et al. 2000). These results from Rodas et al. (2000) are in line with conclusions with relatively new systematic reviews on SIT training; if done correctly SIT improves athletic performance by taxing both the anaerobic and aerobic energy systems to a significant extent, with the rate of anaerobic glycolysis progressively decreasing and the aerobic energy production increasing as more all-out intervals are added (Iaia FM & Bangsbo J. 2010).

The importance of an all-out intensity via SIT protocols and more importantly; repeating the interval multiple times may be very evident in changing the performance of the alactic system. Due to the presence of "power endurance" in MMA, the alactic system is one of the most important energy systems for MMA athletes, therefore looking at research that clarifies alactic system recovery kinetics- in other words PCr (Phosphocreatine) recovery – is important. Quite interestingly, the speed of PCr recovery seems to be highly effected by the state of aerobic conditioning of the athlete. In other words; if aerobic conditioning is improved it will most likely lead to improved rates of PCr recovery (Forbes et al. 2008). A simple explanation for this is that PCr recovery happens via the enzyme Creatine Kinase (CK) in the mitochondria. Mitochondrial biogenesis (the multiplying of mitochondria in the muscle fiber) happens after training that stimulates improvements in aerobic power/capacity, therefore quite interestingly creates the perspective that adding mitochondria is adding "PCr recovery factories". There have been studies that directly look at mitochondrial biogenesis after HIIT and SIT training interventions. It seems that it is quite obvious to researchers that HIIT protocols would stimulate mitochondrial biogenesis due to its strong focus on the aerobic, but it was interesting to see more directly that so do SIT protocols (Ma et al. 2013). Ma et al. (2013) SIT protocol was very similar to the work structure of a typical 4 minute HIIT interval; with a 20 second "all-out" bike sprint followed by a 10 second recovery repeated 8 times (also called a "Tabata" protocol), which created a total work of 4 minutes. It is important to note that long - term submaximal endurance training will also improve PCr recovery kinetics due to its stimulus on the aerobic system, but additional SIT protocols has the potential to enhance PCr recovery kinetics even more (Forbes et al. 2008). This extra "peak" can be simplified by looking at both the rate and net utilization of PCr during SIT protocols. One can assume that compared to HIIT training, SIT has a significantly more aggressive rate of use for PCr in the muscle, due to the higher energy demand when initiating "all-out" intervals. Repeating "all – out" intervals multiple times per session, causes a high net utilization of PCr per session, which when done for weeks will most likely send an aggressive signal to the aerobic system that the capability to create both more energy in a shorter time frame - and increased capability to buffer pH dropping elements (i.e. Hydrogen ions) - are needed. This though only takes place if optimal recovery is allowed so that the athlete does not completely fatigue in the first intervals.

As in terms of hill sprints done as SIT protocols, it seems that currently there are no studies that measure the chronic adaptations of all-out hill sprint training on athletes. Often hill sprints are used later in the general preparation/pre competition phase to help peak anaerobic capacity/power, but quite interestingly legendary distance runner coach Renato Canova also uses hill sprints in the beginning of the season with a different goal in mind. His reason for hill sprints in the early preparation phase is to improve leg extension power without increasing the risk of injury. This is done in combination with a low intensity run then finished off with 6-8 very short 8-10 second all-out hill sprints with "full" recovery (2 min +) (Runnersworld. 2012). If an MMA athlete is already using maximal strength-and especially forms of power training these types of hill sprints might not be necessary to emphasize but might be worth putting in the training tool box for certain situations. One study used endurance athletes for a hill sprint interval group vs. flat ground sprint interval group for 6 weeks. Unfortunately, the hill sprints were paced and relatively short in duration compared to their intensity (30 seconds x 10 -12). Even though both groups significantly improved time to exhaustion performance based on how long they can hold their V02max speed, flat ground group improved it more (Ferley D et al. 2013). It is though unfortunate that the study did not add a 3rd group for all-out hill sprint intervals. One can only hypothesize that a very aggressive drop in muscle pH would be achieved, potentially higher than a similar all – out sprint on flat ground (also, potentially with lower injury risk). There might be value for both in specific times of the season but the implications on performance are still unclear and no strong conclusions can yet be made.

Unfortunately, this paper does not have time to go into more detail, but the goal was more to open coaches eyes in the versatile world of high intensity conditioning training. It is important to note that there is no ultimate conditioning protocol to improve all elements of aerobic and anaerobic power & capacity, therefore different protocols are advised through the season to hit specific physiological targets harder via both submaximal aerobic training, HIIT and SIT protocols (i.e. Alactic vs Lactic vs. Aerobic). But keeping the speed principle in mind that was mentioned earlier (becoming more economical at utilizing full speed efforts) combined by the fact that SIT seems to significantly stimulate both the anaerobic & aerobic system (Iaia FM & Bangsbo J. 2010, Ma et al. 2013), the main argument of this text is that SIT protocols should definitely be taken into consideration as a valid – if not potentially favourable - option in peaking speed/power endurance in a more functional manner for MMA.

In conclusion:

- SIT protocols are a great tool for speed burst sports such as MMA to stimulate both functional aerobic and anaerobic capacity/power adaptations
- In terms of speed and the principle of specificity, certain forms of SIT training support the maintenance of maximal speed while improving endurance. For MMA athletes, pacing protocols (HIIT) to improve aerobic capacity can be used but consideration should be taken into account if they should be a dominant form of conditioning, due to that SIT protocols also affect aerobic capacity kinetics (more research is needed).
- Holding pads for an athlete is a normal form of conditioning in MMA. Work:rest ratios taken from high intensity conditioning protocols could be wise in certain cases to use in pad holding to cause certain physiological adaptations (i.e. 10-30 second bursts, 10-30 recovery), and not just thinking about what the round length/round break in a MMA bout. To boost certain physiological adaptations even more, non-sport-specific conditioning is also advised.
- SIT training can be used in a circuit training format (Sport specific elements can be added in, such as bag work combined with line sprints)
- Further reading is advised on appropriate work:rest ratios in SIT and HIIT protocols for stimulating more the anaerobic and/or aerobic energy system

6. PROGRAMMING CONSIDERATIONS IN MMA

In this section we explore the science of concurrent training (strength & endurance), different common issues found in programming for MMA, look at different periodization models and finally build up practical periodization solutions on yearly (annual), monthly, weekly and daily level.

6.1. The science and programming of concurrent training

Programming of specific forms of strength training and endurance training within the same microcycle/mesocycle is also called concurrent training and its possible interference effects are a highly debated field of research and far from clarified. Simplified, there are a few substantial anabolic signalling responses in the body that are good to know if there is any interest towards understanding performance biology. A basic knowledge of these provides an opportunity to understand new research slightly more and also provides a platform for critical thinking when new information is presented from any source.

In terms of understanding the basics of molecules that regulate endurance adaptations, the enzymes AMPK and SIRT1 are the most important. In terms of cell growth, the protein mTORC1 is the most important. AMPK, SIRT1 and mTORC1 are constantly mentioned in key concurrent training research; therefore it is good to understand their task.

Both enzymes AMPK and SIRT1 among others are activated by endurance training in skeletal muscle and are in involved in multiple processes. In this paper their most relevant task is when they converge/unite with other proteins in the muscle cell to coordinate mitochondrial biogenesis (multiplication of mitochondria) so that oxidative capacity can be improved. mTORC1 is mostly activated from moderate/hypertrophic strength training and is generally accepted as a mediator for muscle hypertrophy by activating protein synthesis. Of particular relevance to the concurrent training interference effect is that various signalling responses activated by endurance training appear to interfere with those that regulate muscle hypertrophy. There is a substantial amount of evidence that suggests AMPK activation has a significant inhibitory effect on mTORC1 and its downstream signalling that leads to protein synthesis, thereby negatively regulating hypertrophy (Figure 8. Observe flat lines vs. arrows). Slightly less evidence has been yet published on other enzymes such as SIRT1 but they point to the same direction as AMPK (Baar. 2014. Fyfe et al. 2014)

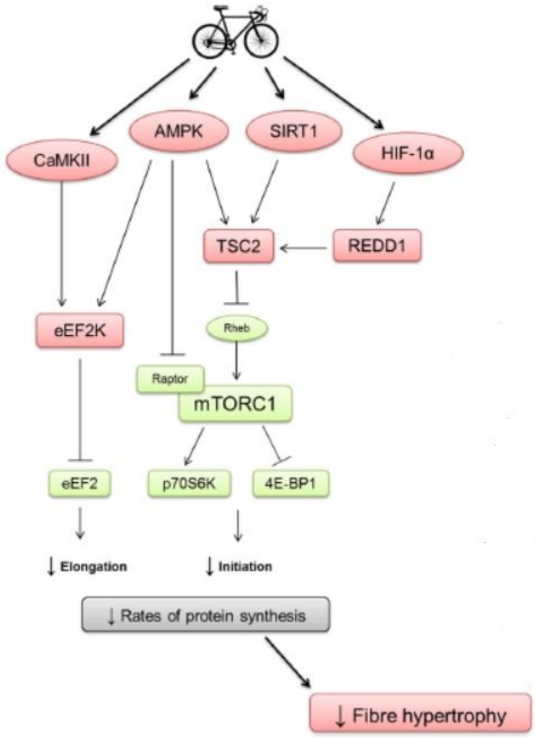


Figure 8: Important signalling pathways that may cause an interference effect for fiber hypertrophy (Fyfe. et al. 2014)

New research is constantly published, but what we know so far is that: 1) inference effects are both evident & multifactorial 2) there is a certain volume- (frequency & length of session), intensity- and timing (how close to a strength session) response relationship between endurance training and its potential negative effects on strength training (Fyfe et al. 2014).

We already know that certain forms of strength training increase significantly endurance performance (Bazyler et al. 2015). But how should we optimally implement strength training on a weekly base into an endurance dominant sport? The first question is what level is the athlete? Research from the 80's already showed that low level of "athletes" (low strength & endurance base) can do submaximal endurance (40 min) and strength training (40 min) even directly after each other (15 – 30 min break) 5 times per week most likely without any interference effect within the first 6 – 7 weeks (Hickson. 1980). After 6-7 weeks though interference signs start to become present if no further programming skills are devoted to the cause (Hickson. 1980). We are obviously past this point with higher level MMA athletes, therefore the goal of the next section is to give a stronger image of what type of endurance and strength training can be programmed together, possible order effects and optimal recovery time between sessions.

6.1.1 What forms of strength and endurance training go well together in the same program?

According to most research, the form of strength training that tends to be able to "jump into an inference zone" when more intense/higher volumes of endurance training are used is hypertrophy strength training, or in other words according to figure 9 "peripheral adaptation focused resistance training".

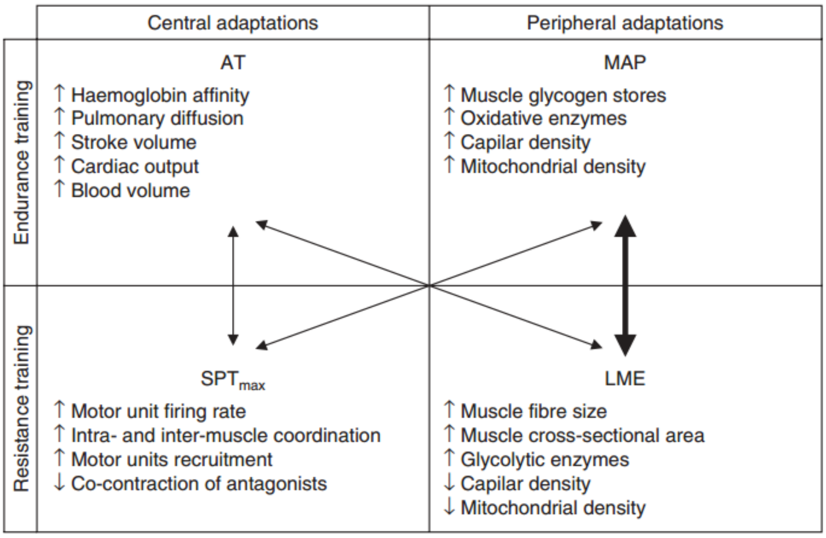


Fig. 4. Optimal combination between resistance and endurance training intensities. **AT** = anaerobic threshold or lower endurance training intensities; **LME** = local muscle endurance training; **MAP** = maximal aerobic power; **SPT$_{max}$** = maximum strength and power training; ↑ indicates increase; ↓ indicates decrease.

Figure 9: Possible interference effect(s) when combining specific forms of resistance and endurance training

This according to Garcia-Pallarés & Izquierdo (2011) is due to that both high intensity aerobic training (In figure 9 as MAP) and hypertrophy based resistance training (In figure 9 as LME) both stimulate peripheral (within the muscle) adaptations, but with some opposite effect. For example, high intensity aerobic training increases mitochondrial and capillary density, while hypertrophy based training can decrease it (at least relative to muscle size). At this point It should be clarified that hypertrophy/peripheral focused strength training can also be put into the "lactic training" category according to up to date periodization standards (Bompa & Buzzichelli. 2015. p. 191). This is due to that longer and moderate resistance strength training sets stimulate larger lactate spikes much more than heavy strength training, therefore possibly improving the speed of anaerobic glycolysis, i.e. the lactic energy system. Heavy strength training or power training are primarily focused on central/neural- and not peripheral adaptations (except for the alactic system), therefore they seem not to significantly disturb either high or low intensity aerobic endurance training (Garcı´a-Pallarés & Izquierdo. 2011). This of course is in its own limitations, but in general this seems to be a strong guideline.

In conclusion:

- In terms of avoiding interference effects, it seems that heavy strength training and power training can be successfully trained in periods of both high and low intensity endurance training.
- In terms of causing a possible interference effect, hypertrophy based strength training, or forms of strength training that dominantly stimulate peripheral adaptations, seem to clash with peripheral adaptations caused with high intensity conditioning training.
- If hypertrophy is the goal, or even other forms of peripheral endurance adaptations via strength training (i.e. changes in fiber types, increased power of glycolysis), such training should be implanted in the early general preparation (see periodization section), where low volumes of intense endurance training are employed.

6.1.2 Order effect and recommended recovery time between strength and endurance sessions

Talk about glycogen levels is much more of a familiar concept for coaches than AMPK, therefore it might bring much more clarity to the interference issue by approaching the problem also from the glycogen standpoint. It appears that high levels of glycogen inactivate AMPK and lowered levels of glycogen activate it. It is quite agreed upon that if glycogen depletion is present, highly glycolytic muscle fibers such as the fast twitch fibers (IIA, IIB) will not sufficiently activate, therefore not only causing decreases in protein synthesis (through higher levels of AMPK) but acute performance issues in the strength/power training session (Baar. 2014, Fyfe et al. 2014).

What is quite interesting is that AMPK activity seems to be more dependent on the intensity of the endurance session. Although the length of the endurance session has to also be taken into consideration, research has provided some evidence that completing a 45-minute submaximal endurance session did not cause an interference effect on mTORC1 when resistance training was done in the second session 6 hours later (Lundberg et al. 2012). Interestingly, activation of the mTORC1 following a strength session was completely lost if the subjects had performed a high intensity conditioning session 15 min before strength training (Coffey et al. 2009). Based on all this information the next step would be to look at recovery of AMPK and mTORC1. Assuming the athlete has done a high intensity conditioning session or an intense strength training session, if glycogen and protein repletion is started directly after endurance exercise, how long does it take for AMPK and mTORC1 to return to baseline? According to limited research AMPK (and SIRT1) return to baseline around 3 hours after slightly more intense endurance exercise (Baar. 2014), compared to mTORC1 that takes around 18-24 hours to return to baseline (Baar. 2014, Fyfe et al. 2014). Even though there needs to be much more clarification on the matter, there seems to be more flexibility from the AMPK recovery standpoint. If hypertrophy is the goal, it might be wiser to program higher intensity conditioning sessions (sport specific also) in the morning, while doing hypertrophy later in the evening (Baar. 2014), but again hypertrophy is not an important training mode a large part of the season.

Now returning back to the glycogen standpoint, we already know that glycogen replenishment is connected to lowering AMPK levels and increasing force production to all fibers but more significantly to fast twitch fibers (Baar. 2014, Fyfe et al. 2014). When glycogen stores are strongly depleted (which is relatively easy to achieve), it takes about 24 hours for them to fully recover with an appropriate diet (MacDougall et al. 1977). An MMA athlete has in average 10-12 session a week, meaning if every session would aggressively deplete glycogen either via long sessions or high intensity sessions, the weekly load would be detrimental to recovery long term. This is probably one strong reason why very well-conditioned athletes do not easily over train; because they have the capability to also utilize fat oxidation by keeping their heart rate down in most sessions. Obviously bad programming even for the well-conditioned would cause constant dominant use of glycogen, so the point is that there is a need for a clear divide between easy and hard days, and even moderate days. In fact, training over periods of 3-8 weeks with frequent high-intensity session (3-4 sessions per week) is an effective means of temporarily compromising performance and inducing overreaching and possibly overtraining symptoms in athletes (Halson & Jeukendrup, 2004). In Bompa & Buzzichelli (2015. p. 40) periodization book, this issue is avoided by dividing every session into either alactic, lactic or aerobic days. It is good to clarify that sometimes just using the term "aerobic" can be a bit confusing because the term encompasses multiple physilogical qualities, but by Bompa & Buzzichellis (2015) definition it is most likely training that is around the aerobic threshold or under, so light sessions. Obviously some days hit more than one system, but what they advise is that in average at least, every second day is not aggressive on the glycogen depletion or in other words; the "lactic system".

In conclusion:

- To increase the likelihood in avoiding interference effects (AMPK, SIRT1) time for proper glycogen replenishment is crucial.
- Highly glycolytic (lactic) training sessions (i.e. Interval training, heavy MMA sessions) should have at least 3-6 hours of recovery between them and frequency should be restricted during the week. As a reminder, hypertrophy strength training can also be labelled as lactic training.
- During the week clear space should be given for full recovery of glycogen via lighter days with lighter (aerobic) sessions.
- As mentioned earlier, if muscle growth is the goal, it should be placed in the early "off season" where there is less high intensity training. If there is a lactic dominant MMA session planned to the same day, it might be wiser to program the hypertrophy session to the evening, due to that mTORC1 recovery rates that effect protein synthesis far exceed AMPK or SIRT1 recovery rates.
- If maximum strength or power is the goal, mTORC1 becomes slightly less important and the recovery focus more leans to glycogen recovery for the muscle fibers and the nervous system. Such sessions can be done in the morning or in the evening, but around 6 hours is still advised as an appropriate minimum break between sessions.

- The weekly volume should also be taken into the account and not just how intense specific sessions are. More than 3-4 intense sessions per week should be avoided for longer periods, even in highly conditioned athletes.
- Complete depletion of glycogen can also be achieved through longer (1.5 hours +) moderately paced sessions, and also reduce the opportunity for recovery time. Strength training should not far exceed 1 hour.
- It is slightly harder to put time restraints on MMA sessions, but on lighter days' caution should be practiced with exceeding frequently 1.5 hours, especially if there are short comings in the athletes conditioning.

6.2 The goal and challenges of periodization within MMA

The overall goal of periodization is to optimize scheduling/programming of specific stimulations so that training adaptations can be maximized and overtraining can be avoided. In average, a professional MMA athlete competes every 6 – 12 weeks with approximately 3-5 fights a year (Bounty et al. 2011). This almost traditional set up within MMA creates its own challenges to optimize strength & conditioning and MMA session periodization. There are plenty of ways to design an MMA athlete's program, and usually different forms of periodization are used due to lack of research. The most important aspect of periodization should be making the program as individual as possible, which has been a common issue at least within the strength & conditioning world. Relatively recently John Keily, a lecturer in elite performance at the university of central Lancashire in England, published quite an interesting paper titled "periodization paradigms in the 21st century: evidence-led of tradition-driven?" In this paper Kiely (2012) criticized certain aspects of periodization contradict modern science and instead are tradition driven, too simplistic and are used as "one size fits all" for athlete populations. Nonetheless, periodization has its strong merits if used in accordance to updated research in determining programming guidelines. The much more important "the art of coaching" comes in by seeing what is needed when for a specific athlete, which is something that is probably best learned via reflective and open minded long-term coaching experience.

When approaching programming for MMA, it might be wise to look at some common challenges found in MMA to optimize periodization and then propose logical solutions according to new research and guidelines from experienced & successful coaches in the field.

Designing a well-structured program for MMA can be challenging for the following reasons:

- A rational way of planning a well-structured periodized program is by programming "backwards" from a known upcoming event. Unfortunately, this cannot always take place, because in some cases MMA athletes have to commit to a competitive fight short notice (i.e. 1-4 weeks' notice) (Bounty et al. 2011).

- MMA training is quite hard to quantify to endurance intensity zones, due to that HR monitors are very unpractical to use in grappling sports.
- It is challenging to program concurrent training (More info in the concurrent training section)
- All of the above mentioned issues create larger chances for overtraining.
- A specific opponent can have a significant impact on periodization before a fight. For example, if more wrestling work is needed in preparation for the fight (Bounty et al. 2011), there might be much more use of the lactic energy system compared to a striking fight. This in term might change recovery patterns.
- In terms of strength & conditioning, it is a slight challenge to program it in compared to more cyclical sports because most of the MMA athletes training time should be devoted to developing skills in all aspects of fighting such as wrestling, Brazilian Jiu-Jitsu, boxing, and Muay Thai kickboxing/boxing (Bounty et al. 2011).
- Allowing time for recovery (Bounty et al. 2011).
- Taking all of these variables into consideration to create an effective periodized program (Bounty et al. 2011).

6.2.1 Important periodization concepts

Marcocycle: A macrocycle is considered in most sources an annual plan that works towards peaking for competition. There are three phases in the macrocycle (terminology changes): general preparation, specific preparation, and precompetition (Lachlan et al. 2013).

***Mesocycle**:* An entire program that focuses on improving specific qualities, usually ranging around 4-8 weeks. A macrocycle usually includes multiple mesocycles (Lachlan et al. 2013).

Microcycle: The weekly plan. Therefore, a year includes around 52 microcycles (minus holidays). Sometimes though, microcycles can be designed as 5-14 day blocks (Lachlan et al. 2013).

General preparation phase**:** This is the first phase of periodization and can start directly once the athlete has recovered from a fight. It is also from an annual plan perspective where an athlete should stay the longest if possible. This is due to that the phase is not too taxing on nervous system by focusing on basic abilities such as the lower ranges of aerobic conditioning via lighter technical sessions/low intensity training, coordination (as mentioned in the injury section, coordination training is not necessarily direct balance training) and learning new techniques or optimizing old ones. This is also a great time to improve strength. Volume is steadily increased (the amount of weekly sessions) while intensity is kept low (Figure 10). One great outcome from the general preparation phase would be that the athlete increases their capability to recover faster between sessions. It is important to note what “low intensity” means in this context. Full speed efforts can definitely be completed in this phase in many instances, such as specific technical drills & even SIT protocols (in form of maintenance) and maximal strength (which is considered from a strength training perspective as high intensity) can be used, but the total weekly volume of high intensity efforts is fairly low (Lachlan et al. 2013). As mentioned earlier, due to there being in average 3-4 fights a year, this phase can last around 5-8 weeks, or even longer if stronger adaptations are wanted for a specific athlete.

Specific preparation & precompetition phase: Intensity is increased and volume is decreased to add recovery time between intense sessions (Figure 10). This can either be done by decreasing training sessions are decreasing the length of training sessions, or a bit of both. As mentioned before, if the general preparation has gone well, the athlete has increased recovery capability. Tactical training is slowly but surely prioritized over technical training. Intensity is increased also in volume both sport specifically and non-specifically in form of tougher sparring sessions and HIIT or SIT protocols. In terms of strength training this is the phase were usually maximal strength is **converted** (term used in Figure 9) to power (Lachlan et al. 2013) and power endurance via interval training. Maximal strength can be still used as a priority longer if the athlete is already explosive of nature, or vice versa for a naturally strong but slower athlete. This phase is very taxing so it usually ends with a taper in the match phase.

***Match phase* (Includes taper and weight cut):** This phase starts with the athlete at least physiologically quite drained, so a taper designed specifically for the athlete is used. This taper can last 8-14 days according to Lachlan et al. (2013), but it is again highly individual how long is needed and might even go under 8 days. Figure 9 has the match phase set up to around 3 weeks due to that most MMA athletes use a weight cut strategy on the last week. We can also observe from figure 9 that volume is dropped clearly more than intensity, the reason for will be explained in the proposed solutions section. Cutting weight can be very taxing on the body so it would advisable to peak from the taper before starting the weight cut. In figure 9 this represents the double performance spike, where the curve down between the spikes is the weight cut. All in all with an 8-14 day taper and 5-7 day weight cut maximally we can consider 3 weeks, but many MMA athletes will only taper for around 1 week. Therefore 2-3 weeks is a more realistic structure. It would be an obvious wish to be able to taper as late as possible because it probably allows the athlete to stay slightly more confident and focused with their training close to the fight, but again each individual reacts differently.

***Transition phase* (T):** Following a long period of hard work and stressful competition(s), the athlete experiences a high degree of physiological and psychological fatigue. Although muscular fatigue/pain might disappear as fast as a couple of days, fatigue of the nervous system and even the psyche is most likely still present for a while. This phase slightly changes with its methodology, but basically the athlete comes out of the transition phase first when they are completely relaxed and regenerated both physically and psychologically so that they can continue successfully with normal training (Bompa & Buzzichelli. 2015. p.340). After a loss, especially if there is a concussion involved, this phase might take longer for some due both physical and psychological reasons. Some might be able to refocus with a quick holiday and with light non sport-specific activity. It is important though to be active as fast as possible so large drops in conditioning are not experienced once the athlete returns to the sport. Bompa & Buzzichelli (2015. p.340) advice that the athlete should stay active at least 3 times per week and that the phase should not last longer than 6 weeks (if no severe injuries happen), with at least one strength training session per week. Usually strength training is taken in as fast as possible in form of "anatomical adaptation", which is explained in the following paragraph.

Anatomical adaptation **(AA)**: "AA" is a form of strength training and is either part of the transition phase of the general preparation phase or both depending on the status of the athlete (Table X). Bompa & Buzzichelli (2015) explain that the "AA" phase starts directly when the athlete can strength train again. The goal is to get the body used to training again after competition and build back basic physiological adaptations after detraining via strength training. This could also be considered a "prehab" program, where unbalances are fixed before heavier training. This is the reason why this phase might take longer than a couple of weeks. This phase basically prepares the athlete for the upcoming strength program, which depending on the athletes goals can be anything from maximal strength to power.

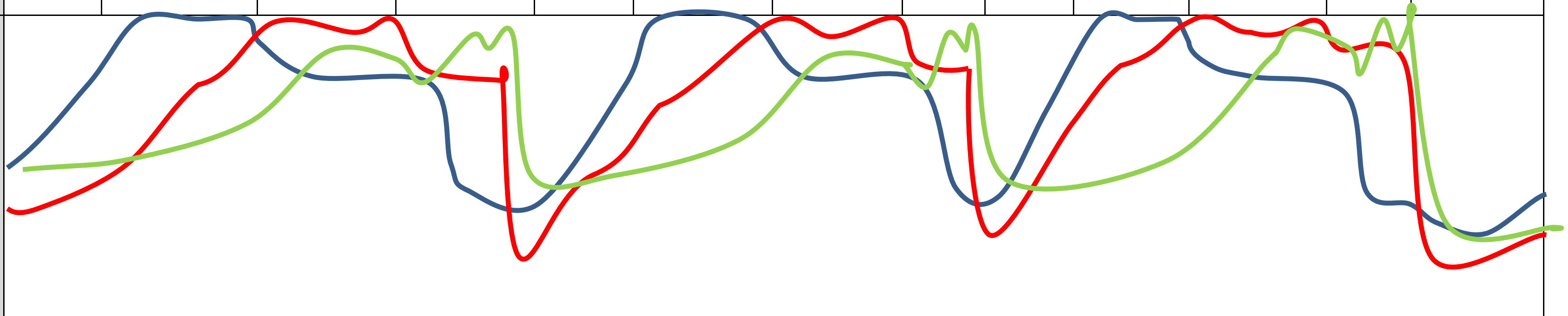
Linear periodization**:** Terminology changes but linear periodization usually includes all the above mentioned phases. Linear periodization moves in blocks and starts with general preparation, going into specific preparation and precompetition, while finishing off with a taper (one marcrocycle). It is characterized by slowly increasing intensity with high volume in the beginning and reducing volume in the end while intensity peaks. This is done by the help of multiple mesocycles that focus on specific abilities mentioned above (Bounty et al. 2011).

Undulating periodization: Generally includes large daily and/or weekly fluctuations of intensity and volume. From a strength & conditioning perspective undulating periodization was first created for intermediate/higher level athletes that no longer react well with the standard linear periodization approach where the same sets & rep zone is used every week and training load (intensity) is increased every week until the end of the mesocycle. In the periodization training for sports 3rd edition book, Bompa & Buzzichelli (2015. p. 110) wrote this on undulating vs. linear periodization from a daily/weekly standpoint: "Despite being an effective way to progress load over time for beginners, linear loading has been proven, both scientifically and empirically, to be an inferior way if applying progressive overload for intermediate and advanced athletes. In fact, it is very unlikely that the biological system progresses in a mechanical or mathematical fashion over time" and later on "a better approach is to implement a model that is cyclic, undulating and self-adjusting".

6.3 Proposed solutions and examples for periodization within MMA

Periodization formats such as traditional linear periodization via block periodization, where only a few specific attributes are isolated for entire mesocycles, are not very practical for an MMA athlete. There definitely should be some form of isolation present due to interference effects. But in general periodization formats that allow as many abilities as possible to be trained at once and more importantly; no detraining of abilities, are more optimal.

As mentioned earlier, short notice fights can happen, therefore some mild form of constant preparedness might be necessary. This though can often be minimized with smart management of fights through the year and having the capability to say no every now and then. If short-term fights are used, then the following periodization cycle should be changed to avoid overtraining. It is quite logical that in terms of long-term development and avoiding overtraining, short notice is not ideal, meaning the initial goal should be that the professional MMA athlete is given for the most part of the year a minimum of 3-4 months between fights (even outside injury) and hopefully at least 5-6 weeks' notice so that higher volumes of intense training can be in some form "periodized" through the year. Nonetheless, short notice fights do happen even at a higher level, therefore as a result, combined advice on linear and undulating periodization models might be the most advantageous approach (Bounty et al. 2011).

PERIODIZATION	Sept.	Oct.	Nov.	Dec.		Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.
	Gen Prep. 1		Specific prep and precomp phase 1	Match*	T	Gen Prep 2.	Specific prep and precomp phase 2	Match	T	Gen Prep. 3	Specific prep and precomp phase 3	Match	T
Strength & Power training	**2w:** AA	**7w:** MxS + P	**5w:** Conv. to P Maint. MxS	**3w-:** Maint: MxS + P	**4w:** AA	**4w:** MxS + P	**4w:** Conv. to P Maint. MxS	**3w:-:** Maint: MxS + P	**4w:**AA	**5w:** MxS + P	**6w:** Conv. to P Maint. MxS	**2w:** Maint: MxS + P	**4w:** AA
Energy systems		Aerobic, alactic P, lactic cap	Lactic cap/P, Aerobic cap/P, alactic P	Alactic P, aerobic	Aerobic	Aerobic, alactic P, lactic cap	Lactic cap/P, Aerobic cap/P, alactic P	Alactic P, aerobic	Aerobic , alactic P	Aerobic, alactic P, lactic cap	Lactic cap/P, Aerobic cap/P, alactic P	Alactic P, aerobic	Aerobic
Volume & Intensity **Volume** **Intensity** **Performance**													

* Match phase includes tapering and weight cut

Gen Prep: General Preperation, Precomp: Precompetiton, T: Transition, AA: Anatomical adaptation, Maint: Maintenance, Conv: Conversion, MxS: Maximal strength, P: Power, Cap: Capacity

Figure 10: Annual plan for an MMA athlete in form of 3 peaks

6.3.1 The linear periodization approach

Figure 9 is a good example of a linear approach on a macrocycle level with 3 fights in a year. It is a good reminder when viewing linear periodization from the "bigger picture" that although in general volume is first increased linearly and then later on intensity (observe the blue and red lines); this does not characterize how the volume and intensity lines move on a daily/weekly base. When undulating periodization is used in combination with linear, when zooming in, we would see that the volume and intensity lines are actually small waves that drop and increase on a daily/weekly base.

Although figure 9 only shows a model of 3 fights, we can still see a trend where when there is less time between fights, usually the preparation period is cut down before the specific preparation and precompetition phase. This is because there is no time to adapt to new abilities via the preparation phase, therefore maintaining the same performance as the previous fight will become more important. To get a better idea of what is prioritized during specific mesocycle phases in the linear approach, take a look at table 13, which is inspired (but slightly modified) by Lachlan et al. (2013) research paper on periodization for MMA.

Table 13 Example for order of priority of different abilities during a marocycle in linear periodization

MARCROCYCLE				
Order of priority	Mesocycle 1: General preparation	Mesocycle 2: Specific preparation and precompetition	Mesocycle 3: Taper + weight cut	
1.	Low intensity conditioning (non- and/or sport specific)	Technical & Tactical	Tactical (Short sessions with high intensity = works also as maintenance of high intensity conditioning)	BOUT
2.	Technical (dominantly light)	High intensity conditioning (non- and/or sport specific)	Strength training (Maintenance of maximal strength and power)	
3.	Strength training (Priority usually: Heavy- or some hypertropghy strength training)	Strength training (Priority usually: Power and heavy strength training)		
4.	Tactical			

6.3.2 The Undulating & Conjugative periodization approach

Because intensity and volume is switched also in daily MMA sessions, undulating periodization can be both seen in strength & conditioning and MMA practice on a weekly basis (Figure 10 & 11). Undulating periodization might not be necessary in all areas of the macrocycle, like the AA phase, but as mentioned before it is in general best for higher level athletes. As mentioned already a few times, undulating periodization can be done either on a daily base or a weekly base. Daily base undulating periodization is for example switching between a heavy and a medium day by dropping intensity but keeping the same reps. It can also be done by switching from hypertrophy/muscular work capacity training (6-12 rep zone - or higher time under tension) 1 day and the heavy strength training the other (1-5 reps). This though might be slightly too taxing for an MMA athlete in the long term because hypertrophy/work capacity type of training can also fatigue the neuromuscular system quite significantly. Therefore, on a daily bases a heavy and a medium day structure are proposed and on a weekly bases a mixture of linear or undulating periodization depending on the level of the athlete. If the athlete has more lifting experience, even though there are daily undulating fluctuations in intensity they might not react to weekly increases in intensity (linear periodization = blocks). In these cases, weekly undulating periodization is proposed as one practical solution where focus is shifted between heavy & moderate strength training. Moderate is a better term, because it does not imply yet if the focus is hypertrophy. It could be just improving peripheral work capacity of the muscle cell (metabolic adaptations) and coordination patterns (quality technique improvements) while the central nervous system is recovering from the previous taxing week. Weekly undulation may actually reduce the risk of hypertrophy due to shorter chronic growth stimulus but this cannot yet be backed up with any solid research. None the less, central nervous system recovery is essential and that's what weekly undulating periodization combined with daily undulating periodization might support very efficiently in higher level athletes. Table 14 shows a good example of this.

Conjugative periodization has not been properly researched to give solid scientific advice, but the theory is that also fluctuations between modes of training, such as maximal strength and power training could be trained concurrently and shifted on a daily/weekly bases. If a longer preparation phase is present with the athlete injury free (3 weeks +), there could be a clear mixture of maximal strength, sprint/agility/plyometrics/weighted power sessions as long as intensity and recovery is monitored and adapted to each individual athlete. For example, using daily conjugative periodization allows quite comfortably (if the athlete is well conditioned) on a weekly bases 2 maximal strength training sessions with 2 "track sessions" (sprint/agility/plyometrics sessions). These track sessions can be easily combined as a neuromuscular (alactic) warm up for technical sessions if time is an issue. Even if daily/weekly conjugative periodization is used; there is usually some form of focus either on maximal strength or power. There is at least one strong reason why forms of power training are kept in an MMA athlete's strength program even when it is not the focus. The risk of short notice fights is ever present and we have to remember that power training is a fairly broad concept (at least in this paper when it also includes speed & agility training) that involves a lot of coordination/technique (i.e. plyometrics, sprinting, Olympic lifting). One cannot expect an athlete to keep a high level of technique in power training methods if no maintenance is kept during maximal strength phases. Even though an MMA athlete does not need a world class Olympic lift technique or jumping form, a high level of technique will most likely promote higher levels of body awareness and therefore more significant functional results in controlling/directing power in different directions (avoiding energy leak) and avoiding injury in the long term. Also, when power is the focus, we still want to maintain maximal strength levels. This is why we keep it in the program on a minimal level. Based on this, there should always be at least a mild form of conjugative training present in strength training for an MMA athlete, so that strength & power techniques can be maintained/improved with precision throughout the year. But as mentioned earlier, more research is needed on this area.

Table 14 Example of weekly undulating periodization for maximal strength with maintenance of power abilities (2 Sessions a week)

<table>
<tr><th colspan="3">Session 1 - Maximal strength (MxS)
Intensity: High
Finish off with light power</th><th>Session 2 Maximal strength (MxS)
Intensity: Medium (same reps, lower load)
~35% of session has power focus (Maintenance)</th></tr>
<tr><td colspan="3">Squat (MxS)</td><td>Squat (MxS)</td></tr>
<tr><td colspan="3">Romanian deadlift (MxS)</td><td>Hang power clean (P)</td></tr>
<tr><td colspan="3">Barbell bent over row (MxS)</td><td>Chin ups (MxS)</td></tr>
<tr><td colspan="3">Bench Press (MxS)</td><td>Military press (MxS)</td></tr>
<tr><td colspan="3">5-10 min Medball throws (light) (P)</td><td>20 min Plyometrics/Sprint/agility drills (P)</td></tr>
<tr><th colspan="4">Mesocycle structure for combined daily & weekly undulating strength training:</th></tr>
<tr><td></td><td>Sets</td><td>Reps</td><td>Intensity</td></tr>
<tr><td>Week 1</td><td>3</td><td>3-5</td><td>Day 1: 80%, Day 2: 70%</td></tr>
<tr><td>Week 2</td><td>4</td><td>6-8 (Reps can also be kept at 4-5 but with longer TUT)</td><td>Day 1: 70%, Day 2: 60%</td></tr>
<tr><td>Week 3</td><td>4</td><td>3-5</td><td>Day 1: 85%, Day 2: 70%</td></tr>
<tr><td>Week 4</td><td>4</td><td>6-8 (Reps can also be kept at 4-5 but with longer TUT)</td><td>Day 1: 75%, Day 2: 60%</td></tr>
<tr><td>Week 5</td><td>2-3</td><td>4-5</td><td>Day 1: 70%, Day 2: 60% (Recovery week)</td></tr>
<tr><td colspan="4">MxS: Maximal strength movement P: Power movement
All concentric phases should be done with maximal intended velocity</td></tr>
</table>

Unfortunately, the first version of this paper will not show detailed examples on SIT or HIIT training and how to program them for MMA athletes. The next version will include detailed descriptions on what types can be used to cause a specific training effect, and how to potentially make them more or less sport specific depending on the situation.

6.3.3 Required training frequency of specific stimulus for optimal results

In terms of frequency required to cause a significant training adaptation from strength & conditioning, research has been relatively clear on what is required. In terms of maximal strength training, for performance increases a minimum stimulus of twice a week seems to be a valid advice for endurance athletes (Bazyler et al. 2015). Unfortunately, no clear research is presented on power training for endurance athletes (includes speed/agility training) but probably the same advice applies. In terms of high intensity conditioning sessions (and as mentioned before in the concurrent training section), SIT and HIIT methods should be used at least twice a week and no more than 3-4 times a week if used for multiple weeks in a row (Lachlan et al. 2013). More than 4 high intensity conditioning sessions in a week will most likely require some sort of aggressive block periodization taper approach (1 week heavy, 3 weeks' light) to avoid overtraining. This has been shown to work for high level cyclists (Rønnestad et al. 2014b), that used 5 HIIT sessions during 1 week, followed by 3 weeks of low intensity training with 1 HIIT maintenance session. This could be useful information in times where a short notice fight is accepted. MMA athletes training (especially outside of strength & conditioning) becomes more and more match and/or sport specific the closer the fight is (Lovell et al. 2013). It should be made clear that although forms of strength & power training are not a priority through specific parts of the season for many athletes, maintenance of maximal strength with at least 1 strength/power training session (can be combined) a week seems crucial for maintenance of performance gains (Häkkinen K. 1993. Rønnestad et al. 2011). For example, the reason for not taking away strength/power training can be avoiding neuromuscular setbacks and the maintenance of muscle mass and other anatomical adaptations. In terms of neuromuscular performance setbacks and the avoidance of them, one study showed that when professional football players trained maximal strength training (heavy) within the in-season once every week compared to another group that trained only once every second week managed to maintain their speed throughout the in-season (Rønnestad et al. 2011). Although the sports are not very related in terms of technique, in physiological terms, the body does not know what activity you are doing so the same physiological guidelines apply to any sport that has used maximal strength- and power training to enhance performance. In terms of dropping volume vs. intensity in the taper, it seems that a drop of intensity is more sensitive to performance outcomes than a drop in volume (Bompa & Buzzichelli. 2015. p.331). Intensity is important to keep present in form of short sessions (sparring, tactical sessions, low volume heavy strength training) so that the taper is successful. Due to the lower volume in the maintenance strength & conditioning sessions, they are in general clearly shorter than performance enhancing sessions so they are not hard to program in and can be even done in combination with a less taxing technical session depending on the athlete's preferences.

In conclusion:

- Different approaches can be used in strength & conditioning based on the competition schedule and the athletes conditioning levels but in general if a significant chronic adaptation is wanted, a minimum stimulus of 2 sessions a week for a minimum of 4-6 weeks is needed.

- High intensity conditioning methods seem to be more flexible, where a above mentioned format can be used (a couple of sessions a week) or a much more concentrated and intense period of training where 4+ high intensity conditioning sessions are used for 1-2 weeks followed by a clear taper phase. This method might only work for advanced athletes, but is a good tool to have when there is a short time frame between fights (under 9 weeks).

6.3.4 Microcycle periodization examples of concurrent training

In high complexity sports like MMA (technical, tactical and physical), the alternation of energy systems and strength training could follow a similar model presented below in Table 15.

Table 15 Classification of training methods according to the main energy system taxed (Bompa & Buzzichelli. 2015. p. 40)

Anaerobic alactic day	Anaerobic lactic day	Aerobic day
1. Technical skills (1-10 seconds) 2. Tactical skills (5-10 seconds) 3. Acceleration and maximum speed 4. Maximum strength and power	1. Technical skills (10-60 seconds) 2. Tactical skills (10-60 seconds) 3. Speed endurance (10-60 seconds) 4. Power endurance, muscle endurance short	1. Long-duration technical skills (>60 seconds) 2. Long- and medium-duration tactical skills (>60 seconds) 3. Aerobic endurance 4. Muscle endurance medium and long

Every day that has more than one session, it is proposed at least in theory that it taxes one energy system dominantly. It is advised that no more than three activities are planned per day. Although we can separate certain energy systems to some extent, some training methods such as SIT or HIIT type protocols can tax all three energy systems (Usually taxing dominantly the lactic and aerobic power/capacity system, but the SIT protocol most likely to some extend also the alactic system). As mentioned earlier, potentially the most important divide is between days that stimulate dominantly the lactic system and days that stimulate dominantly the lower ends of the aerobic system. Forms of power endurance are not the priority on most weeks but could/should be maintained around one session a week, but once it is a priority there should be a clear divide between easy (aerobic) and hard (lactic) days so that recovery is efficient. Depending on the athlete's goals in within the strength spectrum the programming can be done in the following way (two different athletes are presented - Figure 11 & Figure 12) so that similar energy systems are being trained the same day:

Athlete A Time of season: Pre competition phase or even late preparation phase. Improve: Power & speed (Alactic) Maintain or improve: Power endurance + Maximum strength (Alactic + Lactic) Colours: Green = light days, Red: Intense days	
Monday	Morning: Power/speed & Maximum strength (alactic) Evening: Technical/tactical skills (alactic + aerobic)
Tuesday	Morning: Speed/Power endurance (alactic + lactic) Evening: tactical skills (Lactic)
Wednesday	Morning: technical and tactical skills (aerobic) Evening: technical and tactical skills (aerobic)/low intensity endurance training (i.e. jogging under/around aerobic threshold)
Thursday	Morning: Power/speed and/or maximal training (alactic) Evening: Technical/tactical skills (alactic + aerobic)
Friday	Evening: tactical skills (Lactic)/Speed/Power endurance
Saturday	Morning: technical and tactical skills (aerobic) Evening: technical and tactical skills (aerobic)/low intensity endurance training (i.e. jogging under/around aerobic threshold)
Sunday	Day off

Figure 11 Example A of a weekly periodization model of concurrent training stimulus

As one can see only 3 days are shown but it gives an idea of the divide between light and heavy (aerobic vs lactic), and that the alactic system is not as sensitive to recovery as the lactic. Here is another example, where the athlete has slightly different goals, but is in a similar time of season.

<table>
<tr><td colspan="2">Athlete B
Time of season: Late preparation phase – pre competition phase.
Improve: Maximum strength with slight hypertrophy (Alactic + lactic)
Maintain or improve: Power endurance and maximum power (Alactic + lactic + aerobic)
Colours: Green = light days, Red: Intense days</td></tr>
<tr><td>Monday</td><td>Morning:
technical/tactical drills (lactic + alactic) or Power endurance (lactic + alactic + aerobic)

Evening:
Maximum strength (alactic + lactic)</td></tr>
<tr><td>Tuesday</td><td>Morning:
technical and tactical skills (aerobic)
Evening:
technical and tactical skills (aerobic)/Basic endurance training (i.e. jogging under around aerobic threshold)</td></tr>
<tr><td>Wednesday</td><td>Morning:
Maximum strength & Power (alactic)
Evening:
Power endurance (lactic + alactic + aerobic)</td></tr>
<tr><td>Thursday</td><td>Morning:
technical and tactical skills (aerobic)
Evening:
technical and tactical skills (aerobic)/Basic endurance training (i.e. jogging under around aerobic threshold)</td></tr>
<tr><td>Friday</td><td>Evening:
Maximum strength (alactic + lactic)</td></tr>
</table>

Saturday	Morning: technical and tactical skills (aerobic) Evening: technical and tactical skills (aerobic)/Basic endurance training (i.e. jogging under around aerobic threshold)
Sunday	Day off

Figure 12 Example B of a weekly periodization model of concurrent training stimulus

In conclusion:

- A clear divide between lactic, alactic and aerobic (light) sessions helps to increase performance and avoid overtraining
- Coaches should use physiological performance science to design MMA sessions so that they can avoid excessive use of the lactic system
- Some sessions more than one energy system (such as high intensity conditioning sessions), but there still should be adequate room for recovery during the week with days that are fully aerobic or have slight alactic elements.

7. PERIODIZATION EXAMPLE OF A PROFESSIONAL MMA ATHLETE

In this section we explore a highly successful professional MMA athlete's periodization program from a macrocycle, mesocycle and microcycle perspective. The goal of this section is to give a more concrete example of how periodization theory is applied in real life. We have to remember that although an example is given, the exact structure will not work for everyone and is always most intelligent when designed as athlete specific as possible. Also, periodization methods do change slightly between every fight. None the less, it will have common themes of linear, undulating and conjugative periodization and give a strong image of what workloads a highly experienced & conditioned MMA athlete can tolerate. It was important that the athlete chosen has years of experience and also no clear overtraining phases.

7.1. Introduction to the chosen athlete

The athlete that chose to participate is Anton Kuivanen. Anton is a 31-year-old Finnish MMA athlete that trains out of GB - Gym in Helsinki, Finland). His head coach is Sammy Hämäläinen. He has also had training camps in ATT (American Top Team) in Florida. Kuivanen competes in the lightweight division (70 kg) and currently holds a fight record of 23 wins and 9 losses (since November 21) (Table 16) that includes 3 fights fought in the most respected MMA organization; the UFC (Sherdog. 2016). Anton is one of the most accomplished MMA athletes in Finnish MMA history and is currently ranked as n.1 in the lightweight division in Finland according to Table 7 derived from fightsport.fi (FightSport-työryhmä. 2015).

Anton has had a very active childhood with high volumes of ice hockey and football and also showed strong interest towards martial arts through his childhood and early adulthood. With a cooper test result (12-minute run) of 3470 m at the age of 15, he seemed to have a strong conditioning base going into MMA. Unfortunately, no data exists for public view that shows Anton's V02max and anaerobic capacity/power. From his other testing results we can observe that his lower body strength significantly surpasses that of what is required as a base level in MMA according to Table 5 (1.4 times own body weight), but he slightly is below the speed and power levels according to Table 6 (47,5 cm CMJ vs. a reported 50 - 57 cm CMJ in 2 MMA characteristics studies). Also the 10-meter time compared to the wrestler's results presented in table 6 is slightly below the base level (1.8 sec vs 1.7).

Table 16: Anton Kuivanen stats and testing results

Athlete	Anton Kuivanen	**Testing results**	
Age	31	**V02max**	No direct tests done
Height:	175 cm	**Anaerobic test**	No direct tests done
Weight:	~78 kg (Competes in 70 kg)	**10 m sprint**	1.895 s (8.10.2015)
Years as pro	9 (Debut 2006)	**3 double leg hop (DHL)**	7.95 m (8.10.2015)
Fight record	23 - 9 (26.1.2016)	**Counter Movement Jump (CMJ)**	~47,5 cm (done with MyJump app) (8.10.2015)
		Power clean	85 kg (Estimated technical max)
		Back squat	140 kg (Estimated technical max)

7.2 Macrocycle and mesocycle structure used by Anton Kuivanen

The period of training that is shown is from 20.9 - 22.11, therefore a 9-week macrocycle (Table 17). In this macrocycle Anton is training to compete against Thibault Gouti in the CAGE 33 event after a title win against Eric Reynolds in CAGE 31. It is important to note that in table 17 all numbers are in hours, so for example in the specific preparation phase where there is an average of 21 - 21.75 hours of training a week, this is divided into about 10 - 12 sessions according table 18 (shows the periodization on a microcycle level), depending on if speed/power sessions are separated. Kuivanens periodization starts with a transition phase after the previous competition, where the body is recovered both physically and mentally. Kuivanen's transition phase took place in Portugal, where he stayed physically active by the help of surfing. 9 weeks is a quite short interval between fights, but to support a long term carrier, recovery has to be taken seriously. When there is such a short time frame to prepare, everything is slightly cut down starting with the preparation period, which we can see is only 3 weeks once Kuivanen returns from the trip. The general preparation phase started and picked up quickly with 3 weeks of higher volume training, but intensity was kept low until going into the specific preparation and precompetition period, which lasted 2 weeks. These 2 weeks were very high in volume of intensity and one could say based on the combined information from Table 18 that a similar block periodization approach is used by Kuivanen as the Rønnestad et al. (2014b) study used for the elite cyclists. This is where in a very limited time frame high intensity training is picked up to an extreme volume (4-5 high intensity conditioning sessions a week) for 1 or 2 weeks and then drastically cut down for a couple of weeks before the event. As mentioned earlier, this might be a practical approach when there is only a short time frame between fights so that recovery can be allowed in the beginning of the macrocycle.

Kuivanen also completed his power tests (expect for the power clean) in the beginning of his preparation phase after his holiday (18.10). This probably to some extent explains his lower power values due to the neuromuscular systems function being slightly passive. None the less, the appropriate focus became quite clear cut. By completing the tests in the early preparation phase, Kuivanen could adapt his training approach to support the increase of power while maintaining his maximal strength (Table 17). There was not much time to cause a significant result in such a short time frame (only 4-5 weeks before the taper), but a trend towards the right direction was definitely possible. Unfortunately, no post-tests exist. As we can see in Table 17 power training has now been cut down to explosive strength (Plyometrics, Oly. Lifting, Jump squats), Speed (Sprint acceleration) and Agility (Change of direction). This increases the quality of strength & conditioning to another level, where power and speed are more complex terms and can be increased more functionally from many different directions and more importantly, from the direction most important to the athlete. Unfortunately, this version of this paper did not have time to explain in detail the appropriate use of such methods. Also, Kuivanen preferred to use 30 second maximal hill sprints with long breaks between sets to increase lactate power. Usually there is more than 1 week of this stimulus in previous programs but it was left out for reasons unknown.

Table 17: 9-week macrocycle structure used by Anton Kuivanen in 2015

Periodization phases and applied focus		Transition phase	Preparation phase		Specific prep and precomp phase	Match Phase	
						Taper	Weight cut
		Anatomical adaptation		MxS & P	Conv. to P Maint. MxS	Maint: MxS + P	
		Aerobic	Aerobic, alactic P, lactic cap		Lactic cap/p, Aerobic cap/P, alactic P	Alactic P, aerobic	
	Training focus	**Post fight week** (20.9 - 27.9	**Week 8-7** (28.9 - 11.10)	**Week 6** (12.10 - 18.10)	**Week 5-3** (19.10 - 1.11)	**Week 2** (2 - 8.11)	**Week 1 - Fight week** (16 - 22.11
MMA	**Days per week**	1 (holidays in Portugal)	6	6	6	4-5	5
	Total hours per week	2 (+ surfing)	18	18,5	21-21,75	14	14
	Technique/drills (Lower intensity)		9	9	7,5	4,5	4 (losing weight)
	Sparring/wrestling (High intensity)		2	2	3,5-4	2,5	1
Strength & Conditioning*	**Strength** (Maintenance)			1 (75 - 85% of 1 RM)	0,5 (80 - 90% of 1 RM)	0,5 (80 - 90% of 1 RM)	0,33 (80 - 85% of 1 RM)
	Explosive strength (Plyometrics, Oly. Lifting, Jump squats)		1		1,75 (0 - 80% of 1 RM)	0,75 (0 - 80% of 1 RM)	0,33 (0 - 70% of 1 RM)
	Speed (Sprint acceleration)			0,5	1	0,5	0,33
	Agility (Change of direction)		1	1	1	0,5	0,33
	Hill sprints (Lactic Power)				1		
	Low intensity training outside of MMA		2 (+cycling 40-80'/day)	1 (+ cycling 40'/day)	1 (+cycling 40'/day)		
	Stretching(Static/Dynamic)/**Mobility**	1	3	4	3	5	8 (losing weight)
	*Strength & Conditioning sessions are usually combined (i.e. strength training 20 minutes, plyos&speed&agility 40 minutes)						

In table 18, we can see Kuivanen's microcycle structure in the last week of the preparation phase, the specific preparation & precompetition phase, and the match phase separated by a taper and a weight cut microcycle. In table 17 technique/drills are technical sessions that are on the lighter side and tactical sessions are not directly included in table 17 but represent variations of more intense sessions where sparring protocols are used for both stand up- and ground game. On the taper week, when volume is drastically cut down, we can still see that the total weekly volume of sessions still remains similar (only 2 less) while the session volume (length of session) is cut down instead. This seems to be a preferred method for most MMA athletes to stay focused while being able to recover. The intensity is cut down but still kept in form of very short maximal intensity methods (short sparring/pad work, short speed/power sessions).

Table 19: 9 Microcycle structure used by Anton Kuivanen in 2015

Last week of preparation phase							
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Morning		Speed/power session	Technical session, stretching session	power/strength session	Low intensity training (cycling)	Day off	Day off
Evening	Technical session	Technical session	Technical session	Technical session and pads	Technical session and light tactical session		
Specific preparation & precompetition phase (3 weeks)							
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Morning	Technical session, speed/power session	Technical session	Low intensity training (cycling)	Technical session, speed/power session		Hill sprints on week 1, sparring on week 2	
Evening	Tactical session	Tactical session	Technical session	Tactical session	Tactical session		
Match phase 1/2 (Taper: 1 week)							
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday

Mornin g		Short Speed/powe r session			Walk outside	Short Speed/powe r session	
Evening	Active recovery	Short tactical session	Short tactical session	Recovery strategies (massage)	Technica l session, stretchin g session	Short tactical session	
Match phase 2/2 (Weight cut: 1 week)							
	Monday	Tuesday	Wednesda y	Thursday	Friday	Saturday	Sunda y
Mornin g		short speed/power session	Outside walk	Outside walk	Weight cut		
Evening	Active recovery	Prep session	Weight cut with short tactical session	Weight cut	Weigh - in Refuelin g	Fight	

8. DISCUSSION

When first initiating this sport analysis, the course requirements listed that the paper should be around 40-60 pages. As a passionate strength & conditioning coach within MMA, slowly but surely this seemed like an impossible task to write anything of higher value in such a concentrated capsule. But once continuing further and elaborating on specific subjects I noticed that this is obviously something you could write a book about and maybe one day there will be. This paper is still far from the standards that I value but time ran out and some significant compromises had to be made. Some subjects will be opened for discussion but mostly I will list details that need to be improved in the following version of this paper.

The first issue of the paper came up when research physiological characteristics of MMA athletes. As mentioned before there was either a lack of multidimensional testing or incomparable testing methods in the studies. Comparing only 4 studies with each other with limited subjects is far from ideal. In the biomechanics section it was hard to give a high quality explanation due to that MMA is such a versatile skill sport. Biomechanics from a wrestler's standpoint would have been interesting to add in more detail but there was a lack of quality research. Also, scapular stability and its role in transferring energy through the arm when punching would be of high value to study. One question that would be interesting to answer from a research perspective is that when a punch hits contact, if the scapula of the punching arm is not too protracted will this stabilize energy delivery to the opponent more efficiently even though some reach distance is sacrificed from

76

the punch? None the less, I felt that there were some strong biomechanical guidelines that could be applied to most forms of MMA movement. Unfortunately, there was too little time to separate agility & speed training from power training, but hopefully this will still not confuse the reader too much because agility & speed training does affect power.

It would have been interesting also to write more about removal of inhibitory mechanisms via overload eccentric training but there was too little science to currently propose this idea and might be slightly confusing if not presented properly. Overload eccentric training will probably be included in the future as a great tool for higher level athlete's neuromuscular performance. Also the science for coordination and how it is affected via strength & power training (intermuscular coordination) is very young. This will be an extremely interesting topic for the future of strength & conditioning research.

Continuing in the same area, it would have been great to be able to give practical advice in how to possibly use the information from the McGill et al. (2010) double peak (impulse) study in strength & conditioning. For example, how do we improve early RFD? Working on acceleration mechanics? How do we improve the second peaks performance? Would it be just a matter of building strong scapular/core stability so there is no energy leak while the energy is being transferred to the opponent? Heavy bag work to "finalize" coordination patterns? Questions like these would have been interesting to address and give options.

It was unfortunate that there was no room for SIT and HIIT programming. The science is a bit confusing, and in terms of all-out protocols (SIT) there are very few quality studies done on high level athletes. 15-30 second all - out intervals seem to be quite normal. 10 second intervals under or lower can also be used but then the recovery has to be quite short so that (according to some research) anaerobic glycolysis can reach full speed. There is a large need for studies that directly compare SIT and HIIT protocols on high level athletes. This information might also be essential to MMA because of the higher aerobic capacity demands compared to other combat sports. One study that directly tests SIT and HIIT protocols effect on aerobic capacity & power (V02max, time at V02max, Anaerobic threshold etc.) and anaerobic performance (Wingate test) on high level athletes would be very interesting. Also, The SIT protocol should be designed so that its main purpose is to stimulate aerobic capacity/power. To give an example of a SIT protocol that might affect aerobic capacity/power would be doing 20 second all-out intervals in a circuit format (split jumps, sprints, push ups, wrestling, bag work etc.) with a 20 second break between movements. If 7 movements are done this would add up to 4 minutes and 20 seconds of activity for 1 circuit. This could be directly compared then to a typical HIIT protocol that lasts around 4 minutes, where the goal is to maximize time at V02max. It should be noted now in the discussion that even though V02max test is considered the gold standard for endurance testing sometimes there is a slightly too high emphasis on V02max markers when in fact V02max can be largely based on heritage and the highest values do not always correlate with the best performances within endurance sports. Although most athletes can probably train V02max to some extent, it seems that the anaerobic threshold is in average more trainable. More research is needed on this though.

Nutrition was not mentioned other than the importance of fuelling carbohydrates in between sessions to avoid interference affects and some advice was given on protein intake during the weight-cut. This again was due to time and that nutrition is quite complex. Looking through all the trends put in social media concerning nutrition, one can get quite far with just following common sense. Healthy sources of carbohydrates, protein and fat that are rich in minerals, fiber and vitamins. Also keeping the fluid intake in balance by drinking a lot of water is important. In training possibly adding some electrolytes into the water (i.e. salt) for better water absorption of the cells might be wise and in general planning ahead.

There should also be an open discussion about the need for isolated "muscular endurance training" for higher level athletes. This discussion is opened here because the science is so unclear and is mostly based on traditional models so it is not worth adding into the main paper. Muscular endurance training is where high volumes of body weight movements (or sometimes slightly weighted) are done at a submaximal pace as a way to increase peripheral conditioning by improving the muscles metabolic efficiency for different levels of athletes. At a higher level at the latest, we want to cut out any unnecessary time from recovery. This should quite obviously not imply that training that stimulates muscular endurance is not needed. It is very important to condition all the muscles peripherally that are used both aerobically and anaerobically in MMA. Also, it does not imply that body weight exercises are not needed, in fact they are a great tool as activation exercises (warm-up, "prehab"), rehabilitation, power exercises (plyometrics), speed/power endurance exercises (SIT protocols) and cooldown exercises (support active recovery). Just how they are used is what is slightly confusing. Also, although sport specific training such as wrestling sessions are great for peripheral conditioning, it is too unpredictable to cause even adaptations through all sides of the body and therefore balanced body weight muscular conditioning exercises are usually used. But we have to remember that quality strength training is far more successful in correcting unbalances on a neuromuscular and peripheral level than muscular endurance training, not to mention balancing out muscle mass. This only though applies if strength training is monitored, because an athlete probably will not feel an unbalance in a heavier set, but will usually see it and potentially feel it once made aware by a qualified strength & conditioning coach. Also, moderate strength training where higher reps are used (6-12) or higher TUT protocols cause quite significant intramuscular metabolic adaptations. If we look at forms of SIT protocols, specifically circuits that use bodyweight movements, here we are conditioning the muscle both anaerobically and aerobically while moving at a maximum intended velocity. What does this imply for the neuromuscular system in terms of intermuscular coordination? Would this increase agonist/antagonist/synergist coordination in much smaller windows of time while in a fatigued state? One would very much assume so, but yet we choose to replace such conditioning a lot of times with highly paced circuits where the athlete is “taught” to move at slower speeds. Now we have to remember that using SIT circuit training to train muscular endurance can be very taxing on the nervous system, but if use it correctly and in appropriate volumes (lower work:rest ratios and manipulation of sets/series) could it be a much more functional approach to increase muscular endurance, could it be enough in combination with quality maximal strength training for higher level athletes? Even if muscular endurance training is done without “SIT protocols”, should they be designed to avoid pacing? I think it’s an interesting thought that needs to be somehow clarified instead of just being a matter of opinion based on tradition.

Details of overtraining and over-reaching should of been addressed. For example, how can a MMA athlete monitor their recovery and performance? What markers indicate parasympathetic or sympathetic nervous system overtraining? What recovery methods influence potentially more one or the other? As quick advice to the reader, both subjective and objective markers have been successful in monitoring athlete’s reaction to training. Objective tests would include non-invasive tests such as morning heart rate or more invasive tests such as a double leg hop/vertical jump test. Subjective tests would be writing down from 1-10 how a specific athlete feels, or just looking at how they move in the session. Both should be used to help create long - term individual training plans.

The truth is that at least in terms of strength & conditioning we are still at a very primitive level in understanding what works best for an individual athlete. A very important point is that just because something works does not mean it can be done better. Keeping an open mind for possible changes in training approach and therefore supporting the high paced evolution of the strength & conditioning industry is key when implementing training methods of any kind. Martial arts have been practiced for thousands of years but the history of producing peer reviewed strength & conditioning articles is only in its infant stages. Scientific applications in different sports hit a significant peak around the mid-20th century in the former Soviet Union and Eastern Bloc nations. Then the study of sports migrated to the United States, and by the ’60s, many scientists were investigating the sport science phenomena. The faculty of Sport and Health Sciences in the University of Jyvaskyla in Finland (my university) is the only university-level educational research facility for sports science in Finland, and it became a faculty of its own in 1966. Based on this it looks like higher level sports science has only really been around actively for 40-50 years, at least in western culture. This is why it is important that we do not settle and stay humble for new information. Small deeds are a big help when they are all pulled together. A small deed would be updating this sport analysis of MMA on a relatively frequent level (potentially every second year). If we ever want MMA to become an Olympic level sport, or at least respected as one, there is still a lot of work to do from both the practitioner side and the sports science side.

Thank you for your attention and feel free to contact me with any new information that might add value to future MMA analysis papers. I would also like to thank Anton Kuivanen for devoting time to the cause by sending in his information.

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