Strength & conditioning for Taekwondo athletes

Anthony Turner MSc, PGCE, CSCS, ASCC

Introduction

Taekwondo, meaning literally 'the way of the foot and fist', is a Korean martial art, which first became an Olympic sport at the Sydney Olympics in 2000. A Taekwondo match is 3 rounds of 2 minutes, with a minutes rest between rounds, and takes place on a $10m^2$ mat. In competition, kicks and punches score points. (When contact is made to the torso (with kicks and punches), or head (with kicks only), and is of sufficient enough force to produce displacement of the body segment). As in most martial arts, contestants are weight matched.

In Taekwondo, and more than likely most martial arts, fitness appears to be gained through a traditional combination of running, pad work, technical drills and sparring. Most athletes are reluctant to undergo strength training due to fears of a loss in flexibility, speed and a gain in body mass. The latter point is especially important and provides for a significant barrier, as athletes will often aim to compete at their lowest possible weight in order to fight opponents of lower mass.

The aim of this article therefore, is to rationalise the use of Strength and Conditioning (S&C) within Taekwondo, and dispel any myths that prevent this form of intervention. The article further aims to describe and rationalise "gym based" methods to further enhance athletic performance and finally, present the reader with an evidence-based S&C programme.

Needs Analysis

As with any sport to which S&C interventions are to be implemented, the S&C coach must first undergo a needs analysis to identify the biomechanical and physiological requirements of the sport. Following this, the S&C coach must construct an appropriate test battery to measure the strengths and weaknesses of the athlete against these variables. In addition, it is fundamental to identify mechanisms of injury and prehabilitative strategies. Finally, through consultation with the athlete and sports coach, individual goals must be identified.

Anthony Turner is a Strength & Conditioning Coach and a Senior Lecturer and Programme Leader for the MSc in Strength & Conditioning at Middlesex University, London, England.

Biomechanical Analysis of Taekwondo

Striking

Although Taekwondo involves both punching and kicking, 98% of all the techniques used to score by the champions of the Sydney Olympic Games were kicks.[73] In addition, it has been established[126] that during competition, the round house kick is the most frequently used technique. There are two types of round house kick, the rear-leg round house kick and slide roundhouse kick. The former produces a significantly greater peak velocity at the toe (16.48 ± 1.62 vs. 13.43 ± 0.89 m/s, $p>0.05$) and knee (7.7 ± 0.66 vs. 5.38 ± 0.42 m/s, $p>0.05$), and a significantly lower movement time (0.22 ± 0.01 vs. 0.31 ± 0.03s, $p>0.05$) and may therefore provide a more effective attacking strike.[126] The round house kick was also reported to have the highest velocity by Serina and Lieu,[110] as well as the highest impact force.[98] Finally, kicking enables the athlete to strike from a greater distance due to the increase in limb length. Interestingly however, there is no significant difference between the distance of the target and athlete for either of the roundhouse kicks[126] and the choice of either therefore, is likely to be based on force and velocity parameters. Taken collectively, this analysis may justify the dominance of kicking within competition.

Figure 1 – 4. A Taekwondo athlete executing a punching technique, which enables him to strike from distance. The athletes must drive (through triple extension) from the back leg.

Despite the apparent need for athletes to place emphasis on the development of kicking techniques and despite the lack of scientific research, fist striking is still an important technique and will therefore be discussed. However, due to a lack of research into Taekwondo punches, empirically similar sports must also be considered. The need to address and develop the punch may be exampled by Pieter and Pieter[98] who found that while the reverse punch was slower than the round house kick (11.38 ± 3.68m/s vs. 15.51 ± 2.27m/s), it was faster than both the side (6.87 ± 0.43m/s) and spinning back kick (9.14 ± 1.49m/s). Similarly, while the greatest impact force was found for the spinning back kick (606.9 ± 94.6N), this was followed by the reverse punch (560.5 ± 139.2N) and then the round house kick (518.7 ± 96.3N) and side kick (461.8 ± 100.7N).[98] Moreover, Kazemi *et al*.,[73] suggests that punching skills should be trained since most athletes may not be trained sufficiently and may not have proper defensive techniques to counter.

Punching and Kicking

A Taekwondo punch, much like boxing, involves triple extension whereby the ankle, knee and hip extend to generate force from the ground. Via the additional links of the kinetic chain i.e., the trunk, shoulder and arm, they then apply this force to the opponent. The need for this synchronisation can be evidenced from studies conducted by Filimonov *et al*.,[39] and Verkohshansky.[123] Filimonov *et al*.,[39] analysed the straight punch of 120 boxers, ranging from elite to junior ranks. All boxers were instructed to perform a straight right to the head, "maximally fast and powerful". The results of this study are illustrated in table 1 where it can be noted that elite level boxers predominately generate force from the leg musculature, whereas lower ranked boxers generate the majority of force from the trunk and arms. This finding is corroborated by data acquired by Verkohshansky[123] who showed that with mastery in the shot put, (which may be considered biomechanically similar to a straight punch), the emphasis gradually shifts from the shoulder to the leg musculature. This investigation revealed that for beginners, the correlation between athletic achievements and strength of the arm muscles is 0.83 and with leg strength is 0.37. For highly qualified athletes however, the correlations were 0.73 and 0.87 respectively.

As illustrated in figures 5 – 8, triple extensions movements are also required for kicking. The development of this synchronisation and use of triple extension based exercises may therefore be considered essential to the generation of force within Taekwondo. Olympic lifts and their derivatives are often hypothesised to provide an appropriate stimulus for motor skills requiring triple extension.[59,66,69,113] Moreover, the 2nd pull position (i.e., power snatch/clean from hang - Figure 9), provides a biomechanical comparison to the punching and kicking start position, therefore sport specificity can be further gained by commencing lifts from this position.

To further facilitate the development of optimal synchronisation patterns within the kinetic chain and to assist in the carryover of triple extension based exercises to Taekwondo techniques, a derivative of complex training (referred to as carryover training) is recommended. (See the following references for a review of complex training: Docherty *et al*.,[31]; Ebben[33]). In this context however, the objective is not the potentiation of force (although this may be an outcome), but rather the carryover of neuromuscular stimulus/firing sequence (i.e., generating force predominately from the legs as described by Filimonov *et al*.,[39] and Verkoshansky[123]). For example, an athlete may perform a set of power snatches (often from the 2nd pull/hang), followed by performing punches to the bag during the rest period. The athlete is encouraged to visualise the carryover and draw comparisons with the two forms of triple extension and in effect, regarding the punch as synonymous with the power snatch. It is important to only perform a few punches (usually 2-3 per arm) and ensure the emphasis lies with power generation with enough rest between reps to minimise fatigue.

Table 1. Level of mastery and the contribution to punching force by key components of the kinetic chain.[39]

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%

Figures 5-8: Rear-leg roundhouse kick. Note that in order for the athlete to generate power, he uses the stretch-shortening cycle mechanism at the front leg, whereby he performs a countermovement (figure 6) prior to the explosive triple extension (figure 7), thus incorporating elastic energy. This is then followed by 'punching' the knee forward on the striking foot (figure 7) thereby reducing inertia. These observations will be discussed in the stretch-shortening cycle section.

The need to use carryover training for these athletes may be exampled from Pieter and Pieter,[98] who found that Taekwondo athletes do not use their body mass effectively during the performance of various kicks and the reverse punch. The investigators reported that the athlete's body mass and lean body mass was not always selected as force predictors (via non-significant correlations). This form of carryover training is currently being tested within our laboratory in order to provide an objective assessment of its validity.

Reactive Strength

Reactive strength, which describes the stretch-shortening cycle (SSC) capabilities of an athlete, may also be considered fundamental to force generation within Taekwondo. It is well documented that efficient SSC mechanics result in enhanced propulsive forces[16,19,20] and conservation of energy[17,122,124] and this therefore suggests that within martial arts, this may translate into enhanced power and power-endurance of striking. As an example, double kick techniques require that following each strike, the leg is quickly driven back down into the ground and then quickly driven back up toward the opponent.

Optimisation of SSC mechanics dictate that these movements, which, (in the opinion of the author), may be considered biomechanically similar to sprint running (whereby the knee is 'punched' forward (figure 7) and then the leg is quickly driven back down into the ground), requires that ground contact be made via a forefoot landing only,[58,82] thus minimising ground contact time,[4,62,84] increasing energy return (and thus striking force)[58,82] and rate of force development[18] and reducing the duration and metabolic cost of movement.[16,17,30,122,124]

Moreover, and as can be noted in figures 5-8, in order for Taekwondo athletes to generate power during a single kick or the first kick in a sequence of successive kicks, they first utilise the SSC mechanism at the front leg (figure 6), whereby they perform a countermovement (and thus incorporate elastic energy) prior to the explosive triple extension. Finally, because Taekwondo athletes attack their opponent from distance (i.e., they stay out of range), the first steps towards their opponent are often short, rapid shuffles and therefore require efficient SSC mechanics.

This SSC efficiency however, is a learned ability gained through the generation of muscle stiffness, thereby optimally utilising the elastic recoil properties of the tendon.[4,30,60,62,83,86] Muscle stiffness however, is under the subconscious control of the nervous system, whereby the Golgi Tendon Organ (GTO) inhibits the generation of high forces (and muscle stiffness) as a protective mechanism against the risk of injury.[108] Through observations made by this author, most martial artists do not train SSC mechanics (enabling GTO disinhibition) beyond that gained from their sports practice. This is illustrated by the fact that the majority of athletes make heel contact, which is suggestive of a prolonged amortization phase and muscle compliance consequent to GTO inhibition.[40] It appears evident therefore that sports practices do not provide sufficient stimulus for this adaptation and that purposeful exercises such as plyometrics must be included.[85,88,91,102,105,108,111] For example, Kyrolainen *et al.*,[85] reported that 4 months of plyometric training, consisting of various jumping exercises such as drop jumps, hurdle jumps and hopping, was required for the disinhibition of the GTO and the generation of muscle stiffness (concurrent with pre-activation tensioning and antagonistic co-contraction). Moreover, as well as take-off velocity increasing by 8%, energy expenditure decreased by 24% suggesting that adaptations from this plyometrics protocol also resulted in a reduction in the metabolic cost of these movements.[85] It appears apparent therefore that chronic plyometrics training is required to not only condition the Taekwondo athlete to increase striking forces of this nature, but also to facilitate them in employing these strikes with regularity (i.e. aid the development of power-endurance). Finally, inherent to plyometric exercises is the powerful execution of triple extension (as previously described), so these exercises are also likely to have a carryover to kicking and punching mechanics and striking power.

Appropriate plyometric drills include drop lands (figure 11), whereby the body is hypothesised to adapt to high landing forces (eccentric loads) and disinhibition of the GTO is learned.[128] This drill may then be progressed to drop jumps whereby the focus shifts to reducing the amortization phase and ground contact time (GCT) and thus the loss of elastic energy.[40] It may be prudent however, to commence plyometric training with ankling/stiff leg hops (see caption 1), which enhance the stiffness of the ankle joint, as overall leg stiffness has been reported to largely depend on ankle stiffness.[4,37,38] Of course, the S&C coach must determine safe and conducive plyometric intensities (e.g., drop height). It may be appropriate therefore, to first practice landing drills by jumping up to a box (figure 10) or simply jumping forward along the ground, as the intensity of each is less than when dropping from a box.

Figure 9-12 and caption 1 (from left to right): 2nd pull position; Jump up to box; drop land; step from box (prior to drop land or drop jump) and ankling (caption 1).

Caption 1: Ankling. The knees should remain straight as the athlete hops from one foot to the other. Throughout the swing phase, the foot should be dorsiflexed. At ground contact and the instant before, the plantarflexor muscles should forcefully contract. Only the ball of the foot should make contact.

Force Generation Characteristics

Boxing movements (i.e., punches) involve contraction times of 50-250ms[1] and round house kicks have a movement time of 210 – 340ms.[126] As described earlier, GCT during double kicks should (anecdotally) resemble that of sprint running where this has been reported to be 101ms.[90] Taekwondo motor skills therefore, like the vast majority of athletic movements, occur within 250ms[113] to 300ms[127] and the opportunity to develop peak force, which may require up to 600 to 800ms,[35,80] is not a time luxury afforded to these athletes. This therefore suggests the need for these athletes to develop power.

It is hypothesised that if the time available for force development is less than 0.3s (as is the case in Taekwondo), training should focus on improving rate of force development (RFD).[94,108,128] Because RFD is a function of neuromuscular activation[106] and is representative of an individual's ability to accelerate objects,[108] many authors recommend ballistic (explosive) training to improve this quality.[13,50,52,53,125] It is generally recognized that while heavy resistance training improves the final height of the force-time (F-T) curve, ballistic training improves the slope of the initial portion of the F-T curve, specifically within the first 200ms[52] to 300ms[94] when striking is most likely to occur.

Ballistic exercises can best be described as explosive movements, (rapid acceleration against resistance), whereby the body or object is explosively subjected to full acceleration. Reviews by Flanagan and Comyns[40] and Hori *et al*.,[66] recommended the use of plyometric training and Olympic lifts respectively to train RFD, as in addition to their ability to be adapted to the specifics of the sport, they encourage full acceleration with zero velocity achieved only by the effects of gravity. In addition, Olympic lifts produce some of the highest power outputs of any exercise modality. For example, Garhammer[47] reported that the snatch and clean and-jerk exhibit much greater power outputs compared with the squat and deadlift. For example, the relatively slow velocities involved in powerlifting (i.e., back squat, deadlift and bench press) produce approximately 12 watts per kiliogram of body weight.[47] However, during the second pull phase of both the clean and snatch, an average of 52 watts per kilogram of body weight is produced.[47]

It should be noted that a high and positive correlation exists between peak power and maximum strength (r = 0.77-0.94),[6] illustrating the significance of strength training as a prerequisite to power development. With this in mind and because strength levels may only be maintained for approximately 2 weeks,[67] it is advisable to include strength sessions throughout the entirety of a periodized programme, so as to optimise and maintain high levels of power output. In further support of using a combined strength and power training approach, Cormie *et al*.,[27] Harris *et al*.,[57] and Toji *et al*.,[117] concluded that when considering the improvement of a wide variety of athletic performance variables requiring strength, power, and speed, combination training produces superior results (compared to strength training only and power training only). The premise of this approach is thought to result from the additive improvements in both maximum force (through strength training) and maximum velocity (through power training), thus leading to a greater enhancements in power output across the entire force-velocity curve.[117]

Finally, since most movements within Taekwondo are performed unilaterally, this should therefore be trained accordingly to increase the competition carryover. This suggestion is corroborated by Coyle *et al*.,[29] and Vandervoort *et al*.,[120] who reported the existence of a bilateral deficit whereby when the limbs are working together, their net force is smaller than the combined total of when each limb is working independently. The lower force generated during bilateral contractions has been attributed to interhemispheric inhibition, thus reducing neural drive.[121] Continued resistance training using simultaneous contractions (e.g. the bench press) however, can switch this deficit so that the force generated by two limbs simultaneously is greater than the sum of forces produced by either limb.[46,68,114] However, as mentioned, Taekwondo is a unilateral sport and this may therefore be seen as an undesirable adaptation. Ballistic movements therefore, such as plyometrics, should advance to incorporate unilateral movements and barbells should be progressed to dumbbells.

Reps, Sets, Intensity & Rest

Like most sports, developing an athlete's power output is considered a key component to successful sports performance (as most activities are force and time dependent). Since power production is largely a consequence of efficient neuromuscular processes, quality should be stressed at all times. Therefore, the effectiveness of a power programme may be related to the quality of each repetition. It has been hypothesised

Table 2. Energy system contribution to sports considered empirically similar to Taekwondo. Table adapted from Ratamess.[104]

Sport	Phosphagen System	Anaerobic glycolysis	Aerobic metabolism
Wrestling	High	Low	Low
Fencing	High	Moderate	-
Boxing	High	High	Moderate
Mixed martial arts	High	High	Moderate
Basketball	High	Moderate to High	-

that each repetition should achieve ≥90% of maximum power output or velocity[42] and that this, anecdotally, is best achieved with the use of 3 repetitions per set, at least 3 minutes rest between sets[9,42] and a maximum of 5 sets.[42] An additional method to ensure quality of repetitions is through the use of cluster training.[51] This form of training involves interrepetition rest intervals of between 10 and 30s (interval length depends on exercise complexity), whereby the quality of performance is enhanced through decreases in repetition induced fatigue. This method therefore can be used for both power/ballistic training and strength training.

As previously mentioned, strength is the prerequisite to power and therefore adequate strength training must be included. However, as Taekwondo is weight classed, S&C coaches should aim to increase athletic strength without concomitant increases in muscle cross-sectional area. For athlete populations, maximal strength gains are elicited at a mean training intensity of 85% 1RM, ≤6reps, 2 days training per week and with a mean training volume of 8 sets per muscle group.[95] In addition, a build-up of lactate and hydrogen ions (H+) should be avoided as these are a contributing factor to the release of anabolic hormones and subsequent muscle hypertrophy (and therefore body mass).[48,54] These metabolic by-products may be dissipated with long rest periods and/or alternation of body parts in a set for set or exercise for exercise format. For example, an athlete can alternate between upper body and lower body exercises or between agonist and antagonist exercises.

Physiological Demands of Taekwondo

Scientific data on Taekwondo is scarce and the problem is further confounded by suggestions of Kazemi *et al.*,[73] who report that due to the new World Taekwondo Federation (WTF) rules, whereby the duration of each round was reduced from 3 minutes to 2 minutes and the competition area from $12m^2$ to $10m^2$, each round is likely to be of a higher intensity than those previous to the Sydney Olympics. This may therefore reduce the validity of any existing data regarding the physiological profile and needs of Taekwondo athletes prior to the Sydney Olympic Games. It may be prudent therefore, to consider the existing data in conjunction with empirically similar sports, so as to provide an evidence-based physiological profile of both the athlete and the competition demands. In the opinions of the author, sports such as wrestling, fencing, boxing and mixed martial arts (MMA) provide for a good comparison. In addition, Cordes[26] compares boxing with basketball, and therefore this will also be considered. Table 2 illustrates the primary metabolic demands of these sports as described by Ratamess.[104]

From the information presented above and through empirical observations, Taekwondo involves predominate anaerobic energy contribution and the speed and explosive nature of the sport further suggests phosphogen system dominance. In addition, rounds are fewer than boxing (3 vs. 12) and shorter than both wrestling and mixed martial arts (2mins vs. 5mins). Therefore, aerobic energy system contribution may be minimal and be involved only in ring movement and recovery mechanisms.

These findings likely suggest that road running (and any other training modality directed at increasing aerobic capacity) may be detrimental to Taekwondo performance and unfavourably alters energy system adaptations. This is in agreement with Hoffman *et al.*,[65] who analysed basketball competitions over a 4 year period and reported that aerobic capacity had a significant negative correlation to performance. Castagna [et al.],[23] also found no correlation with VO_{2max} and the ability of basketball players to perform repeated sprints. The findings of these studies are further corroborated by authors who suggest that once an aerobic base is achieved, sport-specific team practices and games are sufficient to maintain aerobic fitness in anaerobic dominant sports.[22,63,64] Training programmes therefore need to be directed towards high intensity training such as interval and repetition training. Many athletes however, use long distance running as a means to rapid weight loss (RWL). This however, may be to the detriment of sports performance and perhaps more emphasis needs to be placed on nutritional interventions, (but those based on scientific research). RWL is briefly discussed later in this article.

Also of significance, Kezemi *et al.*,[73] reported that during the Sydney Olympics, both male winners and non-winners achieved the highest percentage of scoring in round one (43% and 65% respectively). While this may be explained as tactics, it may also suggest the presence and affect of fatigue and the need to develop the anaerobic threshold capacity and recovery rate of these athletes. In addition, comparing the percentage of points scored in the first round versus the last round may provide a fatigue index similar to that reported following field tests of the anaerobic threshold (e.g. repeated sprint tests). This may be used to monitor progression, however, care should be taken when interpreting the results due to a lack of test reliability and the influence of coach tactics.

In summary of the above, interval training may be the optimal intervention to bring about efficacious adaptations within the metabolic system. Anecdotally, sparring may provide the most specificity and result in optimal adaptations in the energy systems for the purposes of competition. However, it is not always reasonable to call on this intervention. Therefore, again anecdotally, it is suggested that coaches use a '5s on, 5s off' protocol termed as 'Combat Intervals'. For this, athletes hit the pad for 5s, and then rest for 5s throughout the entirety of a round. This time frame was chosen to represent the amount of time an athlete may attack for. The pad-man can manipulate each interval by increasing or decreasing the time the athlete is attacking or resting (or both). Empirically, it is challenging for the pad-man to continually use times less than 5s. The pad-man can also change the type of striking combinations between intervals and even attack during the rest period causing the athlete to defend and further increasing the intensity. Finally, it is recommended that the athlete uses 2-hit striking combinations only, thus ensuring a fast and continuing rhythm when attacking the pad. It should be noted that the S&C coach should not be considered responsible for delivering this aspect of training, however, it is important to note that these are suggestions that can be made to the sports coach. The efficacy of combat intervals is currently being investigated within our laboratory to provide a more objective assessment of its validity. Some preliminary findings are illustrated below.

Figure 13 illustrates the heart rate (HR) data of two Mauy Thai (a similar martial art) athletes, performing the combat intervals. The first 3 rounds illustrate the warm-up consisting of skipping, shadow sparring and bag work. Following this, athlete A (yellow line) performs the combat intervals for three rounds, while athlete B (green line) holds the pads. For the final 3 rounds, the athletes switch roles. The graph reveals some significant data to validate the use of combat intervals, especially when these results are compared to data attained on athlete A during a laboratory based VO_{2max} test conducted on a treadmill. The laboratory data revealed that athlete A's HR_{max} was 190bpm and that his lactate threshold was reached at 178bpm. Interestingly, athlete A reached a HR_{max} of 197bpm during the combat intervals and the graph further reveals that a significant portion of the combat intervals was performed above his lactate threshold (i.e. above 178bpm or 90%HR_{max} based on a HR_{max} of 197bpm) and is therefore likely to positively adapt his anaerobic capacity in line with the demands of the sport.[23,15] The higher HR reached during actual performance vs. testing may be due to psychological factors (such as competition arousal and anxiety) and experience reveals that this is not uncommon finding, however, tester error cannot be discounted. In addition, differences in HR_{max} have also been reported during laboratory based maximal exercise protocols.81

The findings above may also support the use of using live HR feedback devices (as used to attain these results), whereby the athletes' HR is immediately and visually available to the coach and athlete, thus facilitating the regulation of training intensity and motivation. Additionally, the tracings can be used to monitor athlete progression with respect to the athlete's ability to recover from intensive bouts. It is further hypothesised that combat intervals may also aid this fundamental quality.

Finally, the graph reveals that even holding the pads creates an intensive workout for the athletes and that the sports coach and S&C coach should be cognisant of this when designing training programmes, as this appears to add a significant amount of volume. This is of additional significance as, in the opinions of the author, these athletes are susceptible to overtraining and this data may help to explain why.

Rapid Weight Loss

Research investigating the consequences of making weight in combat sports such as wrestling[49,61,74,76] and boxing,[55] have shown that RWL is associated with concurrent decrements in performance. This may be due to dehydration,[118] depleted glycogen stores,[24,115] reduced lean muscle mass[75] and negative mood.[55,75,92] Significant to the latter factor, mood has been shown to be an effective predictor of performance in combat sports with 92% of winning and losing performances in karate correctly classified from pre-competition mood.[116] Losing karate performance was associated with high scores of confusion, depression, fatigue and tension, coupled with low vigour scores.[116] There appears an evident paradox therefore, between the combat athletes' perception that RWL is associated with good performance and the research which consistently demonstrates that athletes perform significantly below

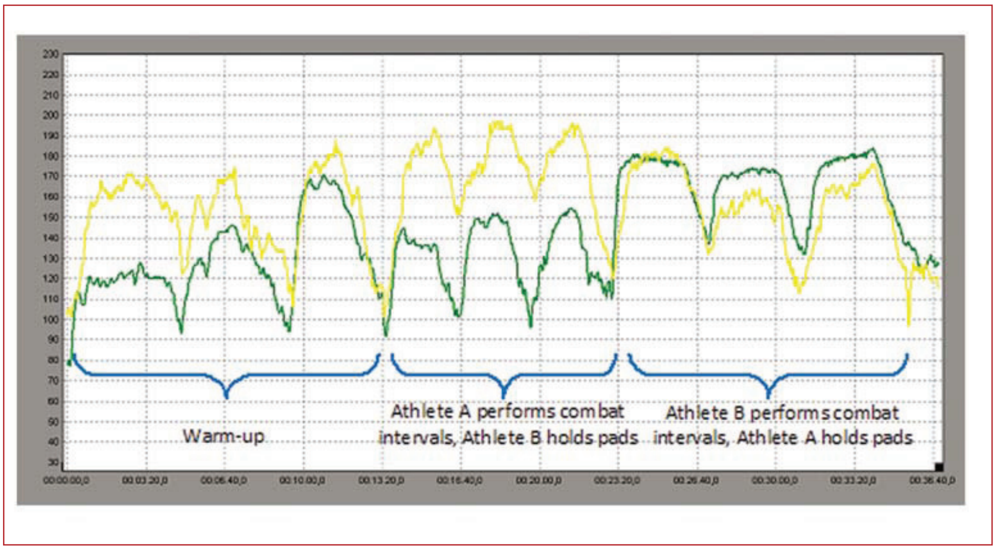


Figure 13. HR tracings recorded during combat intervals. The first 3 rounds illustrate the warm-up. Following this, athlete A (yellow line) performs the combat intervals for three rounds while athlete B (green line) holds the pads. For the final 3 rounds, the athletes switch roles.

expectations. This perception may be explained by the fact that an athlete can win a contest, despite performing below expectations.[55] After all, both contestants likely underwent a RWL intervention.

Risk of Injury

Both Pieter[96] and Pieter and Zemper[100] found the lower extremities to incur most injuries during Taekwondo. This is no surprise as Taekwondo is largely characterised by kicking.[73] According to Beis *et al.*,[14] however, the head and neck appear to incur most of the time-loss injuries (i.e. the athlete must acutely cease both training and competition). In addition, Beis *et al.*,[14] and Koh and Cassidy[77] found middle school boys and girls to be more likely to receive head kicks and incur concussions. Moreover, Koh and Watkinson[79] reported the roundhouse kicks and axe kick to be the most often implicated in head blows in adult Taekwondo. Finally, Serina and Lieu[110] found that thrust kicks (e.g. step side kick and back kick) generate the largest chest compression forces and therefore have the greatest potential for skeletal injury. However, swing kicks (e.g. round house kick and spin round house kick) are faster and have a greater potential for soft tissue damage.[110]

When interpreting and using this data, it is important to be cognisant of the fact that the WTF have recently decided to award 2 points for head kicks and an additional point for knock downs. This is likely to affect injury rate and one may speculate that injuries to the head and neck will increase along with time lost to this injury.

Table 3 illustrates the comparative time-loss injury rates in Taekwondo. It should be noted however, that the data presented in this table are from competitions in which each bout lasted 3 minutes and data was collected previous to the change in points as described above. Both these changes are likely to affect the interpretation of data when attempting to apply the information to training programmes.

If Taekwondo athletes are to use punching skills more often, then coaches must also consider the injury implications to the arm, wrist and hand. Again, deductions based on empirically similar sports, in this case boxing, are required as research for this within Taekwondo appears scarce. Within boxing, injury is more likely at the shoulder, elbow, wrist/hand, low back and neck.[36] This is corroborated by Cordes[26] who suggests that injury occurs primarily at the hand and wrist, followed by the shoulder then elbow.

The author is of the assumption that many of the athletes from which this data was gathered were not undertaking efficacious S&C programmes. With this assumption in mind, strength training may have reduced the incidence of these injuries through its positive adaptations on the structural integrity of all involved joints. For example, as well as an increase in muscle strength, tendon, ligament and cartilage strength would also increase along with bone mineral density.[41,43,112] Furthermore, boxers (and more than likely martial arts athletes) tend to use (and therefore develop), the anterior musculature more than the posterior,[2] thereby leaving them exposed to muscle strains in the weaker muscles. S&C training can ensure the development and maintenance of proper ratios. Most significantly and pertinent to performance, increasing antagonist muscle strength may increase movement speed and accuracy of movement.[70] This has been hypothesised to occur due to alterations in neural firing patterns, leading to a decrease in the braking time and accuracy of the limbs in rapid ballistic movements.[70] Therefore strength balance is needed to break the agonists succinctly in rapid limb movements. When one muscle or movement action is stronger than its antagonist's, performance may be compromised. This is likely to provide the athlete with a greater source of motivation to develop the posterior musculature than that of reducing the risk of injury alone. Moreover, the problem of upper body muscular imbalances may be exacerbated when athletes of this type overemphasise the function of the pectorals.[72] However, the athlete should note that power for upper body striking (i.e. punching) is generated via the powerful extension of the ankle, knee and hip (i.e. triple extension).[10,39,123]

In addition, strength training, unlike sports training (e.g., pad work and sparring) will train the eccentric phase of movement skills. This enhanced eccentric strength may have defensive benefits through absorbing blows.[26] For

Table 3. Comparative time-loss injury rates per 1,000 athlete-exposures (95% CI) in young and adult Taekwondo athletes. Table adapted from Beis et al.[14]

Study	Men (≥ 18 yrs)	Women (≥ 18 yrs)	Jr. boys (14-17 yrs)	Jr. girls (14-17 yrs)	Boys (11-13 yrs)	Girls (11-13 yrs)
Beis et al.[14]	6.85 (1.78-11.92)	2.43 (2.33-7.19)	8.97 (2.76-15.19)	17.01 (6.47-27.55)	6.16 (2.13-10.19)	9.37 (2.88-15.86)
Koh et al.[79]	33.56 (18.85-48.27)	14.22 (2.84-25.60)	-	-	-	-
Pieter and Lufting.[97]	22.90 (9.94-35.86)	9.68 (1.27-20.63)	-	-	-	-
Pieter et al.[99]	27.13 (7.03-47.23)	8.77 (8.42-25.96)	-	-	-	-
Pieter and Zemper.[101]	-	-	25.54 (21.52-29.56)	29.91 (21.27-38.55)	-	-
Zemper and Pieter.[129]	23.58 (5.09-42.07)	13.51 (1.78-28.80)	-	-	-	-

Table 4. Battery of fitness tests suitable for Taekwondo athletes.

Performance tests and supporting comments (with reference literature where relevant)
Skinfold assessment: identifies body fat percentage which has been reported to be from 10.9% in high school wrestlers,25 6.5% in elite level freestyle wrestlers21 and 9.5% in Olympic Kung-Fu athletes.[21] This assessment is to enable the regulation of non-functional mass.
Vertical Jump: measure of lower body power (speed-strength).
Medicine ball throw: this should be conducted in the relevant stance and should mimic the action of the punch. The data can also be used as described by Verkoshansky.[123]
Reactive strength index (height jumped ÷ GCT): as described by Flanagan and Comyns[40] and Newton and Dugan,[93] this test can provide S&C coaches with a good indication of an athletes' SSC ability. The athlete is usually tested over the following drop heights: 30cm, 45cm, 60cm and 75cm.[93] Efficient SSC mechanics should result in greater jump heights from greater drop heights (also reflected by the RSI score). If equipment is not available to measure GCT, the coaches can simply monitor the drop height that produces the greatest vertical displacement.
1RM power clean: this test evaluates the athlete's strength-speed (power under heavy loading), but should only be included once the athlete's technique is of sufficient standard.
1RM bench press and back squat: Evaluation of maximum muscular strength, which as described, is significantly correlated with peak power.
Muscle balance test: Based on the research of Jaric et al.,[70] monitoring the agonist-antagonist strength ratio may prove beneficial not only in injury prevention but for performance enhancement. Baker and Newton.[93] suggest comparing the 1RM bench press (BP) to the 1RM pull-up (PU). The resultant ratio (BP/PU x 100) should be close to 100%. The S&C coach may have to address the pressing to pulling ratio of their training programmes if results deviate from this. The S&C coach should note that the validity of the seated row is contentious due to the force contributed by the leg musculature and back extensors.
Anaerobic Tests: As mentioned above, this is an important variable, and therefore should be tested. However, the coach should look to ensure biomechanical specificity. As no existing repeated sprint tests meet this criteria, the coach may be best advised to compare the amount of striking sequences (a predetermined sequence of kicks and punches) an athlete can complete in a set time (e.g., in 20s over 6 rounds with 30s rest between each bout; i.e., an 'Anaerobic Combat Test'). In addition, the amount of sequences completed in the first round versus the last may provide an estimation of the fatigue index. The same striking sequence should be used during all subsequent tests for purposes of reliability. This test may be best administered by the coach.
Aerobic tests: not applicable due to the relatively small contribution of the aerobic energy system.

example, impact to the brain depends on the acceleration and rapid turn of the head.[26] A stronger neck, especially eccentrically, can help absorb forces. This is also likely to be true of the arms, which are often up to guard the face. Specific to the former point, it may be concluded that Taekwondo athletes perform exercises specifically for the neck. As well as preventing injury, this may also prevent the occurrence of knockouts. Moreover, to help reduce the time-loss injuries in Taekwondo, especially cerebral concussions, Beis *et al*.,[14] suggest that coaches emphasise blocking skills. In agreement, Koh and Cassidy[77] found that those who used blocking skills were less likely to sustain cerebral concussions. Cordes[26] also suggests that knockouts resulting from blows to the thorax or abdomen may be less likely with the addition of strength training.

The S&C coach is also advised to check for movement dysfunctions within the kinetic chain. For example, much research has centred around gluteus medius dysfunctions.[11,32,44,45,103,109,119] However, this, along with many other factors that are likely to contribute to the occurrence and reoccurrence of injury within this sport, is beyond the scope of this article.

Performance Testing

Testing enables coaches to identify the physical capabilities of their athletes. This further enables coaches to monitor the efficacy of their programmes (and adjust accordingly), and make predictions on competition performance. Based on the needs analysis conducted above, a suggested battery of tests has been identified and is illustrated above in table 4.

It is important to conduct the tests in the order described above, as this will reduce the negative effects of accumulated fatigue as the athlete progresses through the testing battery. This is in agreement with Harman[56] who suggests that for these reasons, tests should be conducted in the following order: Non-fatiguing tests (e.g. anthropometry), agility, maximum power and strength, sprint tests, local muscular endurance, anaerobic and then finally aerobic capacity tests.

Strength & Conditioning Programme

The following programme is based on two S&C sessions per week (as this anecdotally appears to be the mean training time allocated/available to S&C training for these athletes), and has been developed based on the reviewed research. Plyometrics, (to develop the SSC mechanism), or carryover training (see previous text), is performed during most rest intervals and the selected drills should be alternated to avoid neural

Table 5. S&C programme for Taekwondo athletes: Two example strength sessions and two example power sessions.

Strength session 1	Strength session 2	Power session 1	Power session 2
*Squat snatch (4 x 2)	*Squat clean & split Jerk (4 x 2)	*Squats (3 x 3)	*Front squats (3 x 3)
Dumbbell chest press (**10°incline) (4 x 4)	Lat pull down or chins (4 x 6)	Power snatch from hang → power split snatch from hang (5 x 3)	Power clean from hang & split Jerk (5 x 3)
Bent over row or seated row (4 x 6)	Dumbbell chest press (**10°incline) (4 x 4)	Squat jumps (5 x 3)	Dumbbell chest press (*10°incline) (3 x 3)
Back squats (4 x 4)	Stiff leg dead lift or Nordics (4 x 6)		

*Key: → = progress to; (Sets x reps); * used to develop/maintain technique and strength/power; ** 10° represents the angle at the shoulder during punching*

Table 6: Example plyometric and carryover drills that can be performed in the rest interval.

Plyometric (SSC) and carryover drills
Lower-body SSC (1 x 3): Ankling (1 repetition = ankling over 4 meters; caption 1) → Jump up to box (gradually increase the height; figure 10) → Drop lands (gradually increase the height; figure 11) → Drop jumps (gradually increase the height) → progress to consecutive jumps (e.g., drop jump followed by jump over 3 x hurdles) → progress to lateral jumps → progress to single leg variants of above
Upper-body SSC (1 x 3): Smith machine bench press throws → Medicine ball throws (in sports stance and mimicking punching techniques) → Medicine ball drops (caption 2) → Push-up claps
Carryover training (1 x 3/per limb): To include all kicking and punching techniques

Key: → = progress to; (Sets x reps)

Caption 2: Medicine ball drops: The S&C coach stands on a box above the athlete, who is lying supine on the ground (head is closest to the box). The S&C coach drops the medicine ball into the arms of the athlete who immediately throws it back up to the S&C coach. The athlete must aim to catch and throw the ball as quickly and as powerfully as possible. Intensity may be increased by increasing the weight of the medicine ball or height of the box.

monotony, thereby ensuring the neuromuscular system is continually challenged to develop. This 'complex training' approach (i.e., performing ballistic exercises in the rest period; referred to as efficiency training) is a valuable tool to S&C coaches who are limited to one or two S&C sessions per week, as it enables them to effectively utilise the rest period without detriment to performance.[34] As previously described, plyometric drills should be logically progressed to ensure appropriate overload and an ethos of quality over quantity should be enforced.

Strength exercises should be prescribed at an intensity slightly below the maximum intensity for that prescription of repetitions. This point was concluded in a meta-analysis conducted by Peterson *et al.*,[95] where it was revealed that training-to-failure does not elicit greater gains than not training-to-failure and in addition, athletes are less likely to over-train. Finally, for all power exercises the load should be varied, as this will also vary the velocity and further increase sport specificity. Although it has been reported that peak power output occurs at 80% 1RM in Olympic lifts (namely the power clean),[28] using body mass only for squat jumps[29,89] and at 55% 1RM for bench press throws,[7] it is likely that this is of greater theoretical relevance that practical significance.

The reader should also note that it is generally recommended to commence resistance training sessions with lower-body exercises (e.g. squats) and ensure that they precede upper-body exercises. In the example below however, (table 5, strength sessions 1 & 2), their placement at the end of the session may be justified by the fact that had they immediately followed the Olympic lift, lower body fatigue may have reduced the intensity (%1RM) with which the squats were performed at. In addition, this sequence may facilitate the build-up of lactate and H+ (as described above), thus promoting the release of anabolic hormones. Due to the significance of relative strength within martial arts, the former two points should be avoided. By separating these two exercises with upper-body exercise, especially the combination of the bench press and seated row, (whereby the legs are under relatively little stress), the lower-body musculature should have undergone sufficient recovery to ensure maximal intensity for the squats.

Finally, it is important to address the issue of flexibility. The athlete and coach should be assured that providing weight training is performed using the full range of motion, flexibility won't be lost[12,71] and may even be increased.[12,87] This can be further corroborated by data collected at one of the Olympic Games whereby weightlifters were second only to gymnasts in a battery of flexibility tests.[71] Moreover, in shoulder flexion, a movement specific to the snatch and jerk, their flexibility was significantly better than any other group. Therefore the persistent myth that weight training negatively affects flexibility is unfounded, and is most likely based on bodybuilding athletes whose excessive hypertrophy may affect the flexibility of that joint.[12]

Conclusion

The vast majority of scientific literature supports the use of S&C training as a means to enhance athletic performance. Programmes can be manipulated to increase both strength and power and neither need be at the expense of an increase in body mass or a loss of speed and flexibility. Moreover, athletes should be critical of some traditional training methods such as long distance running and RWL interventions due to their detrimental effects on performance. In summary, a more scientific approach to performance training is required for these athletes and more objective data is required within the sport of Taekwondo.

References

1. Aagaard, P, Simonsen, EB, Andersen, JL, Magnusson, P and Dyhre-Poulsen, P. Increased rate of force development and neural drive of human skeletal muscle following resistance training. J. App. Physiol. 93: 1318-1326, 2002.
2. Amtmann, JA. Self-reported training methods of mixed martial artists at a regional reality fighting event. J. Strength Cond. Res. 18: 194-196, 2004.
3. Arampatzis, A, Karamanidis, K, Morey-Klapsing, G, De Monte, G, and Stafilidis, S. Mechanical properties of the triceps surae tendon and aponeurosis in relation to intensity of sport activity. J. Biomech. 40: 1946–1952, 2007.
4. Arampatzis, A, Schade, F, Walsh, M, and Bruggemann, GP. Influence of leg stiffness and its effect on myodynamic jumping performance. J. Electromyography and Kinesiology. 11: 355-364, 2001.
5. Artioli, GG, Gualano, B, Franchini, E, Batista, RN, Polacow, VO, and Lancha, AH Jr. Physiological, performance, and nutritional profile of the Brazilian Olympic Wushu (kung-fu) team. J. Strength Cond. Res. 23: 20–25, 2009.
6. Asci, A, and Acikada, C. Power production among different sports with similar maximum strength. J. Strength Cond. Res. 21: 10 - 16, 2007.
7. Baker, D, Nance, S, and Moore, M. The load that maximises the average mechanical power output during explosive bench press throws in highly trained athletes. J. Strength Cond. Res. 15: 20-24, 2001.
8. Baker, D, and Newton, RU. An analysis of the ratio and relationship between upper body pressing and pulling strength. J. Strength Cond. Res. 18: 594–598, 2004.
9. Baker, D, and Newton, RU. Methods to increase the effectiveness of maximal power training for the upper body. Strength Cond. J. 27: 24 – 32, 2005.
10. Bartlett, LR, Storey, MD and Simons, BD. Measurement of upper extremity torque production and its relationship to throwing speed in the competitive athlete. Am. J. Sports Med. 17:89–96. 1989.
11. Beckman SM and Buchanan TS. Ankle inversion injury and hypermobility: effect on hip and ankle muscle electromyography onset latency. Arch. Phys. Med. Rehabil. 76: 1138–43, 1995.
12. Beedle, B, Jessee, C and Stone, MH. Flexibility characteristics among athletes who weight train. J. Appl. Sport Sci. Res. 5: 150-154, 1991.
13. Behm, DG and Sale, DG. Velocity specificity of resistance training. Sports Med. 15:374-388, 1993.
14. Beis, K, Pieter, W, and Abatzides, G. Taekwondo techniques and competition characteristics involved in time-loss injuries. J. Sports. Sci. Med. 6 (CSSI-2), 45-51, 2007.
15. Bishop, D and Claudius, B. Effects of induced metabolic alkalosis on prolonged intermittent-sprint performance. Med. Sci. Sports Exerc. 37: 759-767, 2005.
16. Bobbert, MF, and Casius, LJ. Is the countermovement on jump height due to active state development? Med. Sci. Sport. Exerc. 37: 440-446, 2005.
17. Bobbert, MF, Gerritsen, KGM, Litjens, MCA, and Van Soest, AJ. Why is countermovement jump height greater than squat jump height? Med. Sci. Sport. Exerc. 28: 1402-1412, 1996.
18. Bojsen-Moller, J, Magnnusson, SP, Rasmussen, LR, Kjaer, M, and Aagaard, P. Muscle performance during maximal isometric and dynamic contractions is influenced by the stiffness of tendinous structures. J. Appl. Physiol. 99: 986-994, 2005.
19. Bosco, C, Montanari, G, Ribacchi, R, Giovenali, P, Latteri, F, Iachelli, G, Faina, M, Coli, R, Dal Monte, A, Las Rosa, M, Cortelli, G, and Saibene, F. Relationship between the efficiency of muscular work during jumping and the energetic of running. Eur. J. Appl. Physiol. 56: 138-143, 1987.
20. Bosco, C, Viitalsalo, JT, Komi, PV, and Luhtanen, P. Combined effect of elastic energy and myoelectric potentiation during stretch-shortening cycle exercise. Acta. Physiol. scand. 114: 557-65, 1982.
21. Callan, SD, Brunner, DM, Devolve, KL, Mulligan, SE, Hesson, J, Wilber, RL, and Kearney, JT. Physiological profiles of elite freestyle wrestlers. J. Strength Cond. Res. 14:162–169, 2000.
22. Carey, DG, Drake, MM, Pliego, GJ, and Raymond, RL. Do hockey players need aerobic fitness? Relation between VO2max and fatigue during high-intensity intermittent ice skating. J. strength Cond. Res. 23: 963-966, 2007.
23. Castagna, C, Manzi, V, D'Ottavio, S, Annino, G, Padua, and Bishop, D. Relation between maximal aerobic power and the ability to repeat sprints in young basketball players. J. Strength. Cond. Res. 21: 1172-1176, 2007.
24. Choma, C, Sforzo, G, and Keller H. Impact of rapid weight loss on cognitive function in collegiate wrestlers. Med. Sci. Sports Exerc. 30: 746–9, 1998.
25. Clark, RR, Sullivan, JC, Bartok, CJ, and CarrelL, AL. DXA Provides a Valid Minimum Weight in Wrestlers. Med. Sci. Sports Exerc. 39: 2069–2075, 2007.
26. Cordes, K. Reasons to strength train for amateur boxing. Nat. Strength cond. J. 13: 18-21, 1991.
27. Cormie, P, McCaulley, GO and McBride, JM. Power versus strength–power jump squat training: influence on the load–power relationship. Med. Sci. Sports Exerc. 39: 996–1003, 2007.
28. Cormie, P, McCaulley, GO, Triplett, NT, and McBride, JM. Optimal loading for maximal power output during lower-body resistance exercises. Med. Sci. Sport. Exerc. 39: 340–349, 2007.
29. Coyle, EF, Feiring DC, Rotkis TC, Cote RW 3rd, Roby FB, Lee W, Wilmore JH. Specificity of power improvements through slow and fast isokinetic training. 1981. In: Supertraining. Siff, MC, ed. Denver, CO. Supertraining Institute, 2003.
30. Dalleau, G, Belli, A, Bourdin, M, and Lacour, JR. The

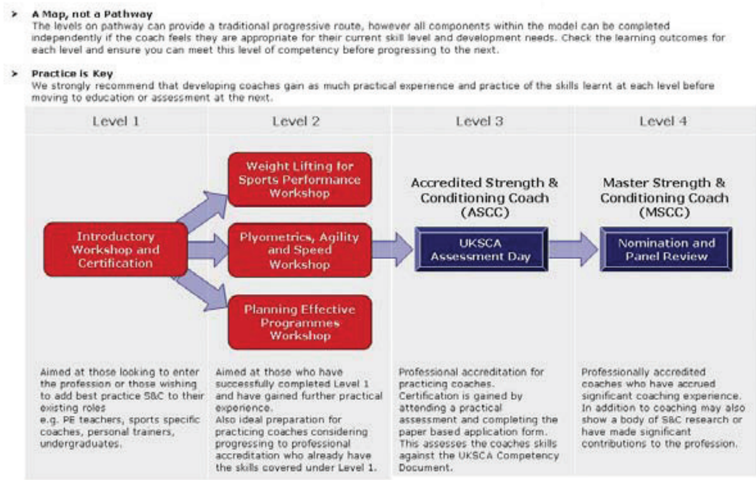
spring-mass model and the energy cost of treadmill running. Eur. J. Appl. Physiol. Occup. Physiol. 77: 257–263, 1998.
31. Docherty, D, Robbins, D, and Hodgson, M. Complex training revisited: A review of its current status as a viable training approach. Strength Cond. J. 26: 52 – 57, 2004.
32. Earl J, Hertel J, and Denegar C. Patterns of dynamic malalignment, muscle activation, joint motion and patellofemoral pain syndrome. J Sport Rehabil 14:215–233, 2005.
33. Ebben, WP. Complex training: A brief review. J. Sport. Sci. Med. 1: 42 – 46, 2002.
34. Ebben, WP, Jensen, RL, and Blackard, DO. Electromyographic and kinetic analysis of complex training variables. J. Strength Cond. Res. 14: 451 - 456, 2000.
35. Edman, KAP. Contractile performance of skeletal muscle fibers. In: Strength and Power in Sport, 2nd ed. Komi, PV, ed. Oxford, UK: Blackwell Science: 114-133, 2003.
36. Estwanik, J. Injuries to the extremities, trunk and head. In: Boxing and Medicine. Cantu, R, ed. Champaign, IL: Human Kinetics, 79-87, 1995.
37. Farley, CT, Blickhan, R, Sato, J, and Taylor, CR. Hopping frequency in humans: a test of how springs set stride frequency in bouncing gaits. J. Appl. Physiol. 191: 2127-2132, 1991.
38. Farley, CT, and Morgenroth, DE. Leg stiffness primarily depends on ankle stiffness during human hopping. J. Biomech. 32: 267-273, 1999.
39. Filimonov, V.I., Kopstev, K.N., Husyanov, Z.M. And Nazarov. Means of increasing strength of the punch. NSCA J. 7: 65-67, 1985.
40. Flanagan, EP, and Comyns, TM. The use of contact time and the reactive strength index to optimise fast stretch-shortening cycle training. Strength Cond. J. 30: 33-38, 2008.
41. Fleck, S, Falkel, J. Value of Resistance Training for the Reduction of Sports Injuries. Sports Med. 3:61-68, 1986.
42. Fleck, SJ, and Kraemer, WJ. Designing Resistance Training Programs. Champaign, IL: Human Kinetics, 209 – 239, 2004.
43. Folland, J, and Williams, A. The Adaptations to Strength Training: Morphological and Neurological Contributions to Increased Strength. Sports Med. 37:145-168, 2007.
44. Fredericson M, Cookingham CL, Chaudhari AM, and Dowdell BC, Oestreicher N, Sahrmann S. Hip abductor weakness in distance runners with iliotibial band syndrome. Clin J Sport Med 10:169– 175, 2000.
45. Friel K, McLean N, Myers C, and Caceres M. Ipsilateral hip abductor weakness after inversion ankle sprain. J Athl Train 41: 74–78, 2006.
46. Gabriel, DA, Kamen, G, and Frost, G. Neural adaptations to resistive exercise. Mechanisms and recommendations for training practices. Sport. Med. 36: 133-149, 2006.
47. Garhammer, J. A review of power output studies of Olympic and powerlifting: methodology, performance prediction, and evaluation tests. J. Strength Cond. Res. 7: 76–89, 1993.
48. Gorden, S.E., Kraemer, W.J., Vos, N.H., Lynch, J.M., and Knuttgen, H.G. Effect of acid base balance on the growth hormone response to acute, high intensity cycle exercise. Journal of Applied Physiology, 76: 821-829, 1994.
49. Guastella, P, Wygand, J, Davy, K, and Pizza, F. The effects of rapid weight loss on aerobic power in high school wrestlers. Med. Sci. Sports. Exerc. 20:S2, 1988.
50. Haff, GG, Stone, MH, O'Bryant, HS, Harman, E, Dinan, C, Johnson, R, and Han, KH. Force-time dependent characteristics of dynamic and isometric muscle actions. J. Strength Cond. Res. 11: 269 - 272, 1997.
51. Haff, GG, Whitley, A, McCoy, LB, O'Bryant, HS, Kilgore, JL, Haff, EE, Pierce, K, and Stone, MH. Effects of different set configurations on barbell velocity and displacement during a clean pull. J. Strength Cond. Res. 17: 95 - 103, 2003.
52. Hakkinen, K, Komi, P and Alen M. Effect of explosive type strength training on isometric force- and relaxation-time, electromyographic and muscle fiber characteristics of leg extensor muscles. Acta Physiol. Scand. 125: 587-600, 1985.
53. Hakkinen, K, Komi, PV and Tesch, PA. Effect of combined concentric and eccentric strength training and detraining on force-time, muscle fiber and metabolic characteristics of leg extensor muscles. Scand. J. Sports Sci. 3: 50-58, 1981.
54. Hakkinen, K., Pakarinen, A., Newton, R.U., and Kraemer, W.J. Acute hormone responses to heavy resistance lower and upper extremity exercise in young versus old men. European J. Appl. Physiol. 77: 312-319, 1998.
55. Hall, CJ, Lane, AM. Effects of rapid weight loss on mood and performance among amateur boxers. British J. Sports Med. 35: 390-395, 2001.
56. Harman, E. Principles of test selection and administration. In: Essentials of Strength Training and Conditioning. Baechle, TR, and Earle, RW, eds. Champaign, IL: Human Kinetics, 237-247, 2008.
57. Harris, GR, Stone, MH, O'Bryant, HS, Proulx, CM, and Johnson, RL. Short-term performance effects of high power, high force, or combined weight-training methods. J. Strength Cond. Res. 14: 14–20, 2000.
58. Hasegawa, H, Yamauchi, T, and Kraemer WJ. Foot strike patterns of runners at 15-km point during an elite level half marathon. J. Strength Cond. Res. 21: 888–893, 2007.
59. Hedrick, A, and Wada H. Weightlifting Movements: Do the Benefits Outweigh the Risks? 30: 26-34, 2008.
60. Heise, GD, and Martin, PE. "Leg spring" characteristics and the aerobic demand of running. Med. Sci. Sport. Exerc. 30: 750-754, 1998.
61. Hickner, R, Horswill, C, Welker, J, Scott, J, Roemmich, JN, Costill, DL. Test development for the study of physical performance in wrestlers following weight loss. Int. J. Sports Med. 12: 557–62, 1991.
62. Hobara, H, Kimura, K, Omuro, K, Gomi, K. Muraoka, T, Iso, S, and Kanosue, K. Determinants of difference in leg stiffness between endurance- and power-trained athletes. J. Biomech. 41: 506-514, 2008.
63. Hoffman, JR. The relationship between aerobic fitness and recovery from high-intensity exercise in infantry soldiers. Mil Med. 162: 484-488, 1997.
64. Hoffman, JR, Fry, AC, Howard, R, Maresh, CM, and Kraemer, WJ. Strength, speed and endurance changes during the course of a division I basketball season. J. App Sports Sci. Res. 5: 144-9, 1991.
65. Hoffman, JR, Tenenbaum, G, Maresh, CM, and Kraemer, WJ. Relationship between athletic performance tests and playing time in elite college basketball players. J. Strength Cond. Res. 10: 67-71, 1996.
66. Hori, N, Newton, RU, Nosaka, K, Stone, MH. Weightlifting exercises enhance athletic performance that requires high-load speed strength. Strength Cond. J. 27(4): 50 – 55, 2005.
67. Hortobagyi, T, Houmard, JA, Stevenson, JR, Fraser, DD, Johns, RA, Israel, RG. The effects of detraining on power athletes. Med. Sci. Sports Exerc. 25: 929-935, 1993.
68. Howard, JD and Enoka, RM. Maximal bilateral contractions are modified by neutrally mediated interlimb effects. J. Appl. Physiol. 70: 306-316, 1991.
69. Janz, J, Dietz, C and Malone, M. Training Explosiveness: Weightlifting and Beyond. 30: 14-22, 2008.
70. Jaric, S, Ropert, R, Kukolj, M, And Ilic, DB. Role of agonist and antagonist muscle strength in rapid movement performance. Eur. J. Appl. Physiol. 71: 464 - 468, 1995.
71. Jensen, C and Fisher, G. Scientific basis of athletic conditioning, 2nd ed. Philadelphia, PA: Lea and Febiger, 1979.

72. Kaufmann, TM. Weight room considerations for the throwing athlete. Strength Cond. J. 21: 7–12, 1999.
73. Kazemi, M, Waalen, J, Morgan, C, and White AR. A profile of Olympic Taekwondo competitors. J. Sport Sci. Med. CSSI, 114-121, 2006.
74. Keller H, Tolly S, and Freedson P. Weight loss in adolescent wrestlers. Pediatr. Exerc. Sci. 6: 212–24, 1994.
75. Kelly, J, Gorney, B, Kalm, K. The effects of a collegiate wrestling season on body composition, cardiovascular fitness, and muscular strength and endurance. Med. Sci. Sports Exerc.10: 119–24, 1978.
76. Klinzing, J, and Karpowicz, W. The effects of rapid weight loss and rehydration on a wrestling performance test. J. Sports Med. Phys. Fitness. 26: 9–12, 1986.
77. Koh, JO, and Cassidy, JD. Incidence study of head blows and concussions in competition Taekwondo. Clin. J. Sport Med. 14: 72-79, 2004.
78. Koh, JO, De Freitas, T, and Watkinson, EJ. Injuries at the 14th World Taekwondo Championships in 1999. Int. J. Appl. Sport. Sci. 13: 33-48, 2001.
79. Koh, JO, and Watkinson, EJ. Video analysis of blows to the head and face at the 1999 World Taekwondo Championships. J. Sport. Med. Phys. Fit. 42: 348-353, 2002.
80. Komi, PV. Stretch-shortening cycle. In: Strength and Power in Sport, 2nd ed. Komi, PV, ed. Oxford, UK: Blakwell Science, 184-202, 2003.
81. Koski, A, Peiffer, J, Edwards, WB, Sept, S, Quintana, R, Parker, DL. Effect of Different Exercise Protocols on: Peak Aerobic Power, VO2max, and Heart Rate Max. Med. Sci. Sport. Ex. Sci. 36: S115, 2004.
82. Kovacs, I, Tihanyi, J, Devita, P, Racz, L, Barrier, J, and Hortobagyi, T. Foot placement modifies kinematics and kinetics during drop jumping. Med. Sci. Sports Exerc. 31: 708-716, 1999.
83. Kubo, K, Kawakami, Y, and Fukunaga, T. Influence of elastic properties of tendon structures on jump performance in humans. J. Appl. Physiol. 87: 2090-2096, 1999.
84. Kuitunen, S, Komi, PV, and Kryolainen, H. Knee and ankle joint stiffness in sprint running. Med. Sci. Sports Exerc. 34: 166–173, 2002.
85. Kyrolainen, H, Komi, PV, and Kim, D.H. Effects of power training on neuromuscular performance and mechanical efficiency. Scand. J. Med. Sci. Sports. 1: 78-87, 1991.
86. Lichtwark, GA, and Wilson, AM. Is Achilles tendon compliance optimised for maximum muscle efficiency during locomotion? J. Biomech. 40: 1768-1775, 2007.
87. Massey, BH and Chaudet, NL. Effects of systematic, heavy resistance exercise on range of movement in young males. Res. Q. 27: 41-51, 1956.
88. McBride, JM, McCaulley, GO, and Cormie, P. Influence of preactivity and eccentric muscle activity on concentric performance during vertical jumping. J. Strength Cond. Res. 23: 750-757, 2008.
89. McBride, JM, Triplett-McBride, T, Davie, A, and Newton, RU. A comparison of strength and power characteristics between power lifters, Olympic lifters and sprinters. J. Strength Cond. Res. 13:58–66, 1999.
90. Mero, A and Komi, PV. Force-, EMG-, and elasticity-velocity relationships at submaximal, maximal and supramaximal running speeds in sprinters. Eur. J. Appl. Physiol. 55: 553-561, 1986.
91. Myer, GD, Ford, KR, Brent, JL, and Hewett, TE. The effects of plyometric vs. dynamic stabilization and balance training on power, balance, and landing force in female athletes. J. Strength Cond. Res. 20: 345–353, 2006.
92. Nelson Steen S, and Brownell, KD. Patterns of weight loss and regain in wrestlers: has the tradition changed? Med. Sci. Sports Exerc. 22: 762–7, 1990.
93. Newton, RU, and Dugan, E. Application of strength diagnosis. Strength Cond. J. 24: 50-59, 2002.
94. Newton, RU, and Kraemer, WJ. Developing explosive muscular power: Implications for a mixed methods training strategy. Strength Cond. J. 16: 20 - 31, 1994.
95. Peterson, MD, Rhea, MR, and Alvar, BA. Applications of the dose-response for muscular strength development: A review of meta-analytic efficacy and reliability for designing training prescription. J. Strength Cond. Res. 19: 950–958, 2005.
96. Pieter, W. Injuries in young Taekwondo athletes. Med. Sci. Sport. Exerc. 34 (S1): 66, 2002.
97. Pieter, W, and Lufting, R. Injuries at the 1991 Taekwondo World Championships. J. Sport. Trauma. Related Res. 16: 49-57, 1994.
98. Pieter, F, and Pieter, W. Speed and force in selected Taekwondo techniques. Biol. Sport. 12: 257-266, 1995.
99. Pieter, W, Van Ryssegem, G, Lufting, R, and Heijmans, J. Injury situation and injury mechanism at the 1993 European Taekwondo Cup. J. Human Move. Stud. 28: 1-24, 1995.
100. Pieter, W, and Zemper, ED. Injury rates in children participating in Taekwondo competition. J. Trauma: Injury, Infection, and Critical Care. 43: 89-95, 1997.
101. Pieter, W, and Zemper, ED. Time-loss injuries in Junior Olympic Taekwondo athletes. Sport. Exerc. Injury. 3: 37-42, 1997.
102. Potteiger, JA, Lockwood, RH, Haub, MD, Dolezal, BA, Almuzaini, KS, Schroeder, JM, and Zebas, CJ. Muscle power and fiber characteristics following 8 weeks of plyometric training. J. Strength Cond. Res. 13: 275–279, 1999.
103. Presswood, L, Cronin, J, Keogh, JWL, and Whatman, C. Gluteus medius: applied anatomy, dysfunction, assessment, and progressive strengthening. Strength Cond. J. 30: 41-53, 2008.
104. Ratmess, NA. Adaptations to anaerobic training programs. In: Essentials of Strength Training and Conditioning. Baechle, TR, and Earle, RW, eds. Champaign, IL: Human Kinetics, 93-119, 2008.
105. Rimmer, E and Sleivert, G. Effects of a plyometrics intervention program on sprint performance. J Strength Cond Res 14: 295–301, 2000.
106. Sale, DG. Neural adaptation to strength training. In: Strength and Power in Sport, 2nd ed. Komi, PV, ed. London: Blackwell Scientific, 249–265, 2003.
107. Schmidtbleicher, D. Training for power events. In: Strength and Power in Sport. P.V. Komi, ed. London: Blackwell Scientific, 381–395, 1992.
108. Schmidtbleicher, D, Gollhofer, A, and Frick, U. Effects of stretch shortening time training on the performance capability and innervation characteristics of leg extensor muscles. In DeGroot, G, Hollander, A, Huijing, P, and Van Ingen Schenau, G. (eds.). Biomechanics XI-A, Vol 7-A: 185-189. Amsterdam: Free University Press, 1988.
109. Schmitz R, Riemann B, and Thompson T. Gluteus medius activity during isometric closed-chain hip rotation. J. Sport Rehabil. 11:179–188, 2002.
110. Serina, RE, and Lieu, KD. Thoracic injury potential of basic competition Taekwondo kicks. J. Biomech. 24: 951-960, 1991.
111. Spurrs, RW, Murphy, AJ, and Watsford,ML. The effect of plyometric training on distance running performance. Eur. J. Appl. Physiol. 89: 1–7, 2003.
112. Stone, M. Implications for connective tissue and bone alterations resulting from resistance exercise training. Med. Sci. Sports Exerc. 20:S162-S168, 1988.
113. Stone MH, Pierce KC, Sands WA and Stone ME. Weightlifting: a brief overview. Strength Cond. J. 28: 50–66, 2006.
114. Taniguchi, Y. Relationship between modifications of

bilateral deficit in upper and lower limb by resistance training. Eur. J. Appl. Physiol. 78: 226-230, 1998.
115. Tarnopolsky, M, Cipriano, N, Woodcraft, C, Pulkkinen, WJ, Robinson, DC, Henderson, JM, MacDougall, JD. Effects of rapid weight loss and wrestling on muscle glycogen concentration. Clin. J. Sports Med. 6: 78–84, 1996.
116. Terry P, and Slade A. Discriminant capability of psychological state measures in predicting performance outcome in karate competition. Percept. Mot. Skills. 81: 275–86, 1995.
117. Toji, H, Suei, K, and Kaneko, M. Effects of combined training loads on relations among force, velocity, and power development. Can. J. Appl. Physiol. 22:328–336, 1997.
118. Torranin, C, Smith, P, and Byrd, R. The effect of acute thermal dehydration and rapid rehydration on isometric and isotonic endurance. J. Sports Med. Phys. Fitness. 19: 1–9, 1979.
119. Tyson AD. The hip and its relationship to patellofemoral pain. Strength Cond. J. 20: 67–68, 1998.
120. Vandervoort, AA, Sale, D and Moroz, J. Comparison of motor unit activation during unilateral and bilateral leg extension. 1984. In: Supertraining. Siff, MC, ed. Denver, CO. Supertraining Institute, 2003.
121. Van Dieen, JH, Ogita, F, Haan, A. Reduced neural drive in bilateral exertions: a performance-limited factor. Med. Sci. Sports. Exerc. 35: 111-118, 2003.
122. Verkhoshansky, YV. Quickness and velocity in sports movements. IAAF Quaterly: new studies in athletics. 11: 29-37, 1996.
123. Verkohshansky, YV. Fundamentals of special strength training in sport. 1977. In: Supertraining. Siff, MC, ed. Denver, CO: Supertraining Institute, 113, 2003.
124. Voigt, M, Bojsen-Moller, F, Simonsen, EB, and Dyhre-Poulsen, P. The influence of tendon Youngs modulus, dimensions and instantaneous moment arms on the efficiency of human movement. J. Biomech. 28: 281-291, 1995.
125. Winchester, JB, McBride, JM, Maher, MA, Mikat, RP, Allen, BK, Kline, DE, and McGuigan, MR. Eight weeks of ballistic exercise improves power independently of changes in strength and muscle fiber type expression. J. Strength Cond. Res. 22: 1728–1734, 2008.
126. Yu-Hsiang, N, Jung-San, C, and Wen-Tzu, T. The comparison of kinematics characteristics of two roundhouse kicking techniques in elite Taekwondo athletes. Mech. Sport Exerc. 39: S478, 2007.
127. Zatsiorsky, VM. Biomechanics of strength and strength training. In: Strength and Power in Sport, 2nd ed. Komi, PV, ed. Oxford, UK: Blackwell Science: 114-133, 2003.
128. Zatsiorsky, VM, and Kraemer, WJ. Science and practice of strength training. Champaign, IL: Human Kinetics, 33-39, 2006.
129. Zemper, ED, and Pieter, W. Injury rates during the 1988 US Olympic Team Trials for Taekwondo. Brit. J. Sport. Med. 23: 161-164, 1989.

UKSCA NEWS *continued from page 3*

UKSCA COACH DEVELOPMENT MAP



UKSCA PLANNING EFFECTIVE PROGRAMMES WORKSHOP

The next workshop in the UKSCA's 'Education & Development Map' will be a 2-day workshop on **Planning Effective Programmes for Sports Performance**.

This workshop is currently being developed by a working group led by our new Director of Education & Training, Stuart Yule. The development process will also involve current UKSCA Assessors and Tutors to ensure the content reflects current best practice, supported by scientific evidence. The first workshop will appear in our 2010 schedule and will sit alongside the existing 'Weight Lifting' and 'Plyometric, Agility and Speed' workshops to support coaches working towards their accreditation.

UKSCA'S INTRODUCTION TO STRENGTH & CONDITIONING (LEVEL 1) WORKSHOP AND CERTIFICATION – NEXT STEPS

By the end of 2009, over 300 coaches will have gone through our 'Introduction to S&C Workshop and Certification'. This has been designed to focus on developing key practical coaching skills, giving coaches the ability to add essential strength and conditioning skills to their current coaching practice. This workshop was developed specifically for those looking to enter the profession and wanting a clear and progressive development pathway or those wishing to add best practice strength and conditioning to their existing roles e.g. PE teachers, sports specific coaches, personal trainers, undergraduate students etc. In addition to running our own workshops under the UKSCA banner, we are also working alongside a number of NGBs and education establishments to develop joint workshops. In 2009, over 200 people attended these type of workshops and we have plans to expand this next year too. By working in this way, we are able to reach a wider variety of people who may not normally attend the UKSCA workshops. These events have the same learning outcomes and quality of tutors, (and are therefore endorsed by the UKSCA), however, it is possible for them to be amended slightly to fit into existing coach education programmes, as well as being able to add more sport specific content to meet the needs of each NGB. If you work in HE, for an NGB or feel that working alongside the UKSCA in this way could be of benefit to you or your organisation, then please contact the office for further information.