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 10m² 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.

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. In addition, it has been established 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. The round house kick was also reported to have the highest velocity by Serina and Lieu, as well as the highest impact force. 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 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.
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 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). Moreover, Kazemi et al. 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. and Verkohshansky. Filimonov et al. 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 Verkoshansky 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. 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.; Ebben). 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. and Verkoshansky). For example, an athlete may perform a set of power snatchs (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.

<table>
<thead>
<tr>
<th>Category</th>
<th>Arm extension</th>
<th>Trunk rotation</th>
<th>Push off with extension of back leg</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masters of sport and candidates for masters of sport</td>
<td>24.12%</td>
<td>37.42%</td>
<td>38.46%</td>
<td>100%</td>
</tr>
<tr>
<td>Class I</td>
<td>25.94%</td>
<td>41.84%</td>
<td>32.22%</td>
<td>100%</td>
</tr>
<tr>
<td>Class II &amp; III</td>
<td>37.99%</td>
<td>45.50%</td>
<td>16.51%</td>
<td>100%</td>
</tr>
</tbody>
</table>
The need to use carryover training for these athletes may be exemplified from Pieter and Pieter,99 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 forces16,19,21 and conservation of energy16,17,122,124 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,16,19 thus minimising ground contact time,16,17,122 increasing energy return (and thus striking force)16,17,122 and rate of force development16 and reducing the duration and metabolic cost of movement.16,17,122,124

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.16,17,122,124 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.45,83,91,102,105,108

For example, Kyrolainen et al.45 reported that 4 months of plyometric training, consisting of various jumping exercises such as drop jumps, hurdle 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.45 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.116 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.16 It may be prudent however, to commence plyometric training with ankle/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.16,17,122 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.
Force Generation Characteristics

Boxing movements (i.e., punches) involve contraction times of 50-250ms and round house kicks have a movement time of 210 – 340ms. As described earlier, GCT during double kicks should (anecdotally) resemble that of sprint running where this has been reported to be 101ms. Taekwondo motor skills therefore, like the vast majority of athletic movements, occur within 250ms to 300ms and the opportunity to develop peak force, which may require up to 600 to 800ms, 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). Because RFD is a function of neuromuscular activation and is representative of an individual’s ability to accelerate objects, many authors recommend ballistic (explosive) training to improve this quality. 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 to 300ms 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 and Hori et al. 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 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 kilogram of body weight. However, during the second pull phase of both the clean and snatch, an average of 52 watts per kilogram of body weight is produced.

It should be noted that a high and positive correlation exists between peak power and maximum strength (r = 0.77-0.94), 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, 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., Harris et al., and Toji et al. 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.

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. and Vandervoort et al. 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. 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. 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...
that each repetition should achieve ≥90% of maximum power output or velocity and that this, anecdotally, is best achieved with the use of 3 repetitions per set, at least 3 minutes rest between sets and a maximum of 5 sets. An additional method to ensure quality of repetitions is through the use of cluster training. This form of training involves interrepetition rest intervals of at least 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. 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). 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., 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 12m² to 10m², 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 et al. 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.

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., who analysed basketball competitions over a 4 year period and reported that aerobic capacity had a significant negative correlation to performance. Castagna et al., also found no correlation with VO₂max 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. 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. 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 Muay 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 that even holding the pads is an effective predictor of performance in combat sports and that 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 due to dehydration, depleted glycogen stores, reduced lean muscle mass and negative mood.

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. Losing karate performance was associated with high scores of confusion, depression, fatigue and tension, coupled with low vigour scores. 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. After all, both contestants likely underwent a RWL intervention.

**Risk of Injury**

Both Pieter and Pieter and Zemper found the lower extremities to incur most injuries during Taekwondo. This is no surprise as Taekwondo is largely characterised by kicking. According to Beis et al., 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., and Koh and Cassidy found middle school boys and girls to be more likely to receive head kicks and incur concussions. Moreover, Koh and Watkins reported the roundhouse kicks and axe kick to be the most often implicated in head blows in adult Taekwondo. Finally, Serina and Lieu 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.

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 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. This is corroborated by Cordes 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.

Furthermore, boxers (and more likely martial arts athletes) tend to use (and therefore develop), the anterior musculature more than the posterior; 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. 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.

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.

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). 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.

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**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.**

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

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Cassidy77 found that those who used blocking skills were less likely to sustain cerebral concussions. Cordes26 also suggests that knockouts resulting from blows to 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 Cassidy77 found that those who used blocking skills were less likely to sustain cerebral concussions. Cordes24 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,13,26,44,51,103,109,119 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 Harman56 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.

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

<table>
<thead>
<tr>
<th>Performance tests and supporting comments (with reference literature where relevant)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Skinfold assessment:</strong> identifies body fat percentage which has been reported to be from 10.9% in high school wrestlers, 25.6% 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.</td>
</tr>
<tr>
<td><strong>Vertical Jump:</strong> measure of lower body power (speed-strength).</td>
</tr>
<tr>
<td><strong>Medicine ball throw:</strong> 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</td>
</tr>
<tr>
<td><strong>Reactive strength index (height jumped ÷ GCT):</strong> as described by Flanagan and Comyns40 and Newton and Dugan,93 this test can provide S&amp;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.03 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.</td>
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<tr>
<td><strong>1RM power clean:</strong> 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.</td>
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<tr>
<td><strong>1RM bench press and back squat:</strong> Evaluation of maximum muscular strength, which as described, is significantly correlated with peak power.</td>
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<tr>
<td><strong>Muscle balance test:</strong> 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&amp;C coach may have to address the pressing to pulling ratio of their training programmes if results deviate from this. The S&amp;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.</td>
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<tr>
<td><strong>Anaerobic Tests:</strong> 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.</td>
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<tr>
<td><strong>Aerobic Tests:</strong> not applicable due to the relatively small contribution of the aerobic energy system.</td>
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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. 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., 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), using body mass only for squat jumps and at 55% 1RM for bench press throws, it is likely that this is of greater theoretical relevance than 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

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

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

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.
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, and may even be increased. 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. 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.

### 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

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