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INSIDE

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In this, the first editorial since the UKSCA Conference (a review of which will appear in the winter edition), we can again reflect on the diverse work being carried out in the field of strength and conditioning. What is always interesting is how great coaches and practitioners often have differing philosophies about how to best develop athletes and use a range of methods to achieve their goals, each achieving high levels of success. As autumn approaches, and much of the UK takes on a shade of grey, it is a good time to reflect on these messages and to look at how to implement information and methodologies into our programme. Perhaps one of the challenges is that we often divide our world into contraries, seeing methods and philosophies as black or white, and judging programmes and coaches based upon this categorisation. Indeed, empirical research often expands on this view, requiring us to differentiate between different methods or approaches. However, our role as coaches is to maximise performance, and this may require the search for a complementary approach to training rather than a strict categorisation. The search for effective integration of a range of proven methods and philosophies may be the key to constantly improving our practice, and grey may indeed be the colour we need to focus on, rather than an obsession with black and white.

This issue's articles further emphasise the divergent range of subject areas covered under the broad umbrella of strength and conditioning. Dr Paul Gamble presents the second part of his extensive article on physical preparation for netball. This part presents the practical application of the theoretical issues covered in the previous edition of Professional Strength and Conditioning, and is a really welcome addition to the sparse literature on this sport. Aerobic fitness development is another area often overlooked in strength and conditioning literature. However, following on from Dan Baker's article in the previous edition, we have another excellent article on this topic. Anthony Turner and Liam Kilduff have looked at the challenges of defining and developing aerobic fitness, and have used a range of studies to summarise effective methods of developing this capacity. The third main article is from Graham Turner, a former board member of the UKSCA. Graham's article looks at lower limb asymmetry and musculo-skeletal loading, and the problems of assessing and dealing with these issues.

The coaching column in this edition expands on the complementary opportunities for training inputs. It presents three different approaches to skill development and looks at the opportunities for coaches to exploit the advantages of these through effective combinations of methods. The Performance Nutrition column again delivers in its aim of keeping our membership up to date with the latest development in this rapidly changing area. Two great stalwarts of Professional Strength and Conditioning, Graeme Close and James Morton have written an update on the latest advice on carbohydrate intake during exercise and the role of sugar based drinks.

Ian Jeffreys

Editor

UKSCA NEWS

UKSCA'S 8TH ANNUAL CONFERENCE

Next year's annual conference will be held in September – venue and exact date will be confirmed in the next few weeks. Due to the 2012 Olympics and Paralympics taking place in the summer, we have moved the conference back until after the Games, as we know the run up to the Games will be a busy time for many members. We hope that this move will not only allow more members to attend, but also enable us to incorporate sessions from coaches involved in the Team GB medal success haul!

UKSCA'S MASTER COACH ACCREDITATION PROJECT

Led by Board member Gil Stevenson, the project is underway to develop a proposal for the creation of a UKSCA Master Coach award/qualification as a progression from the ASCC professional accreditation. 26 accredited members have expressed an interest to contribute to this proposal and the views of that group are currently being collated to form a discussion document, which will be presented to the Board in December. Until the criteria and assessment process for this new award/qualification are agreed, then it is difficult to determine an exact launch date for the new award, but it is planned to be sometime in 2012. If you would like to be involved in the project, please contact Gil by email – **Gil@uksca.org.uk**

UKSCA'S YOUTH TRAINING SPECIAL INTEREST GROUP

Convened in early October by new Board member Rhodri Lloyd, the UKSCA's Youth Training Special Interest Group (YTSIG) already has over 200 members. The scope of the SIG will include strength and conditioning provision to athletes up to the ages of 18 years and has the stated aims to:

- Enhance interest and involvement in youth strength and conditioning provision
- Disseminate and highlight key research relating to young athlete development
- Promote good practice when working with young athletes
- Share current ideas and training concepts
- Serve as a network to enable the formalisation of working professional relationships
- Enable members to network with international colleagues and additional Youth training SIGs around the World
- Keep members up to date with respect to developments within the UKSCA pertaining to youth training

The first newsletter has been distributed to members and the first online monthly discussion topic concerning the importance of Fundamental Movement Skills is already underway with members contributing their thoughts and ideas. Each topic will run for a month, the discussion will then be summarised in the newsletter and a new topic launched the following month. Membership to this SIG is free and available to all UKSCA members. To join, please email **Rhodri@uksca.org.uk** with YTSIG Membership Request in the subject field and your member number.

Defining and Developing the Aerobic Capacity

Anthony Turner, MSc, ASCC, **Liam Kilduff,** PhD

Dr. Liam Kilduff is a senior lecturer at Swansea University. He is a BASES Accredited Sports and Exercise Scientist (Physiology-Research) and works with a number of high profile sporting organisations within the UK and internationally. His research focuses on the areas of preconditioning and recovery in elite athletes.

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

For many sports, the aerobic capacity of an athlete dictates success. Obvious examples include long distance events such as the marathon, Tour de France and Nordic skiing. Furthermore, for sports such as soccer and rugby, which also contain a plethora of high-intensity anaerobic bouts, aerobic capacity is still deemed a significant physiological determinant to success. For example, it has been shown repeatedly that aerobic capacity is positively related to the distance covered, time on the ball and number of sprints (including repeated sprint ability) during a soccer match.[14,15,47,67]

Therefore, for sports such as the aforementioned, which largely depend on the aerobic capacity of an athlete, knowledge of how best to develop this component of fitness is essential. The aim of this article therefore, is to briefly discuss its associated training protocols and thus make recommendations based on the evidence herein. This discussion will be preceded by a definition of terms and a review of the physiological mechanisms associated with its development.

Determinants of Aerobic Capacity

It is widely acknowledged that an athlete's aerobic capacity is determined by three key variables:[43,48,31,73]

1. Maximal oxygen uptake (VO_2max)
2. Lactate threshold
3. Economy of movement

A change in either of these variables will affect performance and thus each will be discussed in turn.

VO_2max

The VO_2max (also referred to as maximal aerobic power) may be defined as the maximum amount of oxygen that can be used by the body, and is perhaps best defined by the Fick equation: $VO_2 = Q \times \alpha\text{-}vO_2diff$, where Q symbolises cardiac output and $\alpha\text{-}vO_2diff$ represents the difference between arterial (a) and venous (v) O_2 content and thus reflects the ability of the skeletal muscles to extract and use O_2.

It has been suggested that VO_2max is probably the most important factor determining success in aerobic endurance sports.[5,81] Results as high as 94 ml/kg/min have been noted in Nordic skiers[101] and world renowned Tour de France Champion Lance Armstrong had a reported VO_2max of 81.2 ml/kg/min.[20] *Table 1* identifies VO_2max values from various athlete populations.[101] It is also important to note that within the same person, VO_2max is specific to a given activity[45] and therefore to obtain relevant values, emphasis should be placed on testing in activity specific modes.[90]

As illustrated by the Fick equation, VO_2max is determined by both central (Q) and peripheral *($\alpha\text{-}vO_2diff$)* factors, and for a long time, many investigators sought to identify which yielded the greatest impact. Then, in 1985, Saltin *et al,*.[80] conducted what is regarded by some as the definitive experiment. These investigators observed what happens when a subject does maximal aerobic exercise using only a small muscle mass, in this case, knee extensions with only one leg. This exercise (and test set-up) allowed a

Table 1. VO_2max values (ml/kg/min) from various athlete populations. Adapted from Wilmore and Costill.[101]

Sport or Group	Age	Males	Females
Non-athletes	20-29	43-52	33-42
Bicycling	18-26	62-74	47-57
Orienteering	20-60	47-53	46-60
Rowing	20-35	60-72	58-65
Alpine skiing	18-30	57-68	50-55
Nordic skiing	20-28	65-94	60-75
Track and field (running)	18-39	60-85	50-75

greater percentage of the cardiac output to be directed to the isolated quadriceps. Consequently, its O_2 uptake increased 2–3 fold when compared to the same muscle during a whole-body maximum effort. The investigators thus concluded that skeletal muscle has a tremendous capacity for increasing blood flow and VO_2 uptake, which far exceeds the pumping capacity of the heart during maximal whole-body exercise. Therefore, this investigation showed that VO_2max is constrained by O_2 delivery (central factors) and not by the mitochondria's ability to consume O_2 (peripheral factors).

With this limitation believed to be fully elucidated,[45,99] attention then turned to which of its variables exerted the greatest influence: heart rate (HR) or stroke volume (SV) (recall that O_2 delivery is determined by cardiac output expressed as Q = HR x SV). However, due to considerably less variation in maximal HR,[7] SV was logically assumed responsible. Indeed, studies by Gledhill *et al*.,[38] Helgerud *et al*.,[45] and Zhou *et al*.,[103] supported this contention. These investigators showed that while in sedentary and moderately trained subjects, SV demonstrated the classically reported levelling off (at around 40% VO_2max or 120bpm), SV increased up to VO_2max in well-trained subjects *(Figure 1)*. Thus, for this population, changes in VO_2max correspond with changes in SV, indicating a close link between the two.[45]

Lactate Threshold

As illustrated in *Figure 2*, the lactate curve produces 2 breakpoints and thus both require a definition of terms. The first breakpoint is termed the lactate threshold (LT) and marks a 1mM increase in blood lactate above resting levels (or 2.5 mmol/L).[60,84] The second break point is termed the onset of blood lactate accumulations (OBLA) and occurs at a fixed lactate value of 4mM.[60,84] Both breakpoints represent the balance between lactate production and removal and provide an indication of energy supply derived from anaerobic metabolism, which may induce fatigue.[27] In addition, these values determine the fraction (percentage) of VO_2max that can be sustained for an extended period of time. For example, Dumke *et al*.,[27] showed that the LT predicted 60min cycle time, while OBLA predicted 30min cycle time. Moreover, the velocity at the LT is considered a strong predictor of performance.[7,27,32,57] Furthermore, it is postulated that athletes with a high LT are able to distribute the same work rate (VO_2) over a larger muscle mass, resulting in less loading on the fibers recruited to do the work.[52] This larger muscle mass also increases the mass of mitochondria sharing in the production of ATP by oxidative phosphorylation and therefore contributes to the performance VO_2 (described later in this text).[22,23]

Some researchers contend that because there is a narrow range of VO_2max values within elite athletes[12,16] this variable cannot effectively differentiate performance.[10,12] Instead, for this athlete population, blood lactate breakpoints are more indicative. For example, OBLA, pre and post training,[3] has a higher correlation with distance running time (0.91-0.96) than VO_2max (O.8-0.91).[17,18,32]

A further problem with defining an athlete's aerobic capacity by using only VO_2max, is that lower VO_2max values may be compensated for by an athlete's enhanced ability to tolerate or remove lactate, and thus work at a higher percentage of their maximum aerobic power.[12,19,85] For example, Dumke *et al*.,[27] reported that the blood lactate levels of athletes undertaking 30 and 60 minute time trials are highly variable (1.8 - 10.9 and 1.2 - 9.1 mM respectively) and supports further evidence which indicates that athletes can maintain efforts which result in blood lactate levels of ≥6 mmol/L for ≥ 30mins.[42,69] More recently then, and significant to this, athletes and coaches have been advised to use the 'performance VO_2'[7,10,22] which describes the fraction of VO_2max an athlete can sustain during an endurance event (thus accounting for both variables).

Figure 1. Changes in SV. While in untrained and moderately trained subjects SV demonstrated the classical levelling off, SV increases up to VO_2max in elite athletes. Based on the data of Zhou et al.[103]

Figure 2: Lactate break points. The first breakpoint is termed the lactate threshold (LT) and marks a 1mM increase in blood lactate above resting levels. The second break point is termed OBLA and occurs at a fixed lactate value of 4mM.

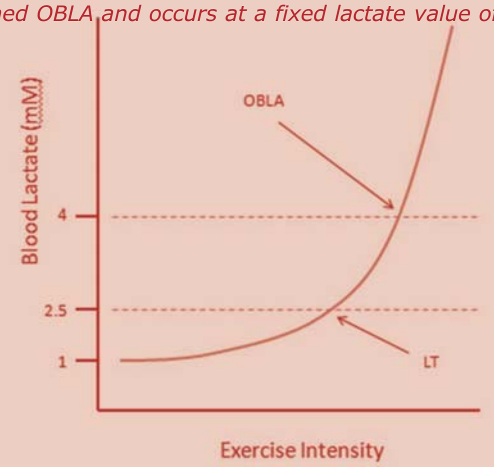


Fig 3. Schematic of the 'performance VO2' adapted from Bassett and Howley[8] which describes the fraction of VO_2max an athlete can sustain during an endurance event. This, coupled with movement economy, affects long distance performance.

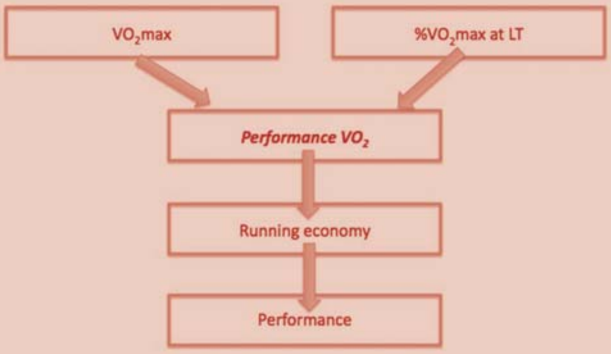
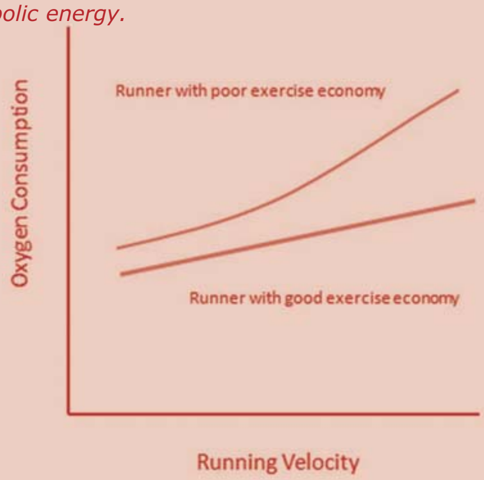


Figure 4: Running economy. Runners with good exercise economy can run at the same absolute velocity using less metabolic energy.



To further explain the multi-factorial dependence of aerobic performance, Bassett and Howley[7] provide the following example. To complete a 2:15 marathon, a VO_2 of about 60 mL/kg/min must be maintained throughout the run. However, since the marathon is typically run at about 80–85% of VO_2max, the athlete requires a VO_2max of around 70.5–75 mL/kg/min. Therefore, while the VO_2max sets the upper limit for energy production in endurance events, it does not determine the final performance.[7] This is also largely shaped by movement economy[7] as well as the fraction of VO_2max that can be maintained (LT).[8] So again, and as is the case with VO_2max, the ability of OBLA and LT to predict steady-state performance may be in question.[27]

Movement Economy

While movement economy affects the aerobic capacity of athletes from all sporting disciplines, this review article will describe it with respect to running.

An athlete's actual running velocity is realised by the rate of oxidative ATP generation (the performance VO_2), and the individual's ability to translate this energy into performance, i.e., running economy.[22,24] Like LT, running economy (RE) explains some of the difference between athletes with similar VO_2max values.[8] For example, a strong correlation (r = 0.82) exists between RE and 10km times in a group of runners with similar VO_2max values but with a range of 10km times.[16] In addition, a 20% difference has been reported between the least and most economical runners in any group (elite vs. trained vs. untrained)[22] and in athletes with a similar VO_2max.[46]

RE may be defined as the cost of O_2 to complete a sub-maximal task.[46] It is also commonly defined as the steady-rate VO_2 in ml/Kg/min at a standard velocity or as an energy cost of running per metre[7,43] and is shown by plotting oxygen uptake (mL/kg/min) versus running velocity (m/min)[7] *(see Figure 4)*.

As illustrated in *Figure 4*, the cost to complete a task is reduced (indicating an enhanced RE) in advanced athletes and has been largely correlated to training years (r = 0.62).[66] Furthermore, RE is positively affected by the proportion of Type I fibers[75,92] and by anthropometric, biomechanical and technical factors.[6] With respect to training, it has been reported to be improved through high-intensity interval training,[68] strength and power training (including plyometrics)[56,71,82,86,95] and increases in rate of force development.[48,49] These improvements are generally attributable to improvements in neuromuscular functioning, including motor unit recruitment and reduced ground contact time.[59] For example, in a study by Storen *et al.*,[89] well-trained long-distance runners completed a heavy strength training protocol for 8 weeks, following which, time to exhaustion at maximal aerobic speed increased by 72s or 21.3%. This was despite no changes in body weight, VO_2max, LT velocity, or LT as % of VO_2max. They therefore attributed this to the noted 5% improvement in RE consequent to the strength training intervention. Pate & Kiuska[73] summarise that RE is affected by the following variables:

- Metabolic adaptations such as increased mitochondria and oxidative enzymes
- Through more efficient technique such as a reduction in vertical oscillations thus leading to less energy wasted on braking forces
- Increasing the stiffness of the muscles and thereby increasing energy return

Significant to the latter, Verkhoshanky[97] and Voigt *et al.*,[98] reported that stiffness in the muscle-tendon complex can recover approximately 60% of mechanical energy, thereby leaving only 40% to be replenished by metabolic processes during the following cycle.

Developing the Aerobic Capacity

The following sections briefly describe some of the more novel, and perhaps non-traditional training methods to increase aerobic capacity. This discussion, however, will first be preceded by a brief description of the common training zones, intensities and volumes of endurance athletes.

The Aerobic Training Zones

Aerobic athletes typically work off a 3-zone scale *(Figure 5)*, which is defined by physiological markers, i.e., LT, OBLA and VO_2max, or a 5 zone scale *(Table 2)* which is divided up by the wisdom of many years of scientific investigations. *Table 3* identifies a range of training sessions which may be considered appropriate to each zone of this 5-zone scale. Furthermore, an 8-zone scale can also be used in which zones 6-8

Table 2. 5-zone aerobic training scale based on numerous years of scientific testing. Adapted from Seiler and Tonnessen.[83]

Training Zone	VO_2 (%max)	HR (%max)	Lactate (mmol/L)	Session Duration
1	50-65	60-75	1-1.5	1-6h
2	66-80	75-85	1.5-2.5	1-3h
3	81-87	85-90	2.5-4	50-90min
4	88-93	90-95	4-6	30-60min
5	94-100	95-100	6-10	15-30min

Table 3. Example training sessions of the 5-zone scale. Adapted from Seiler and Tonnessen[83]

Zone	Zone	Example training sessions	Session duration
1	50-65	Continuous bouts	60-360min
2	66-80	Continuous bouts	60-180min
3	81-87	>LT 40-60min 2 x 25min, 5min rec 6 x 15min, 2min rec 5 x 10min, 2min rec 8 x 8min, 2min rec	50-90min
4	88-93	30-40mins OBLA 10 x 6min, 3min rec 8 x 5min, 3min rec 15 x 3min, 1min rec 40 x 1min, 30sec rec	30-60min
5	94-100	6 x 5mins, 3min rec 6 x 4min, 4min rec 8 x 3min, 2min rec	24-30min

(anaerobic zones) are used to define very high intensity sprint, anaerobic capacity, and strength training respectively.[83]

The 80-20 Rule for Intensity

In an excellent review by Seiler and Tonnessen,[83] in which the training practices of the world's best endurance athletes were identified, it was reported that ≈ 80 % of training sessions are performed at intensities <LT (or zone 1 i.e., ≤2mM), while the remaining 20% of sessions are distributed between training at or near OBLA (zone 2 i.e., 4mM) and interval training at 90-100% VO_2max (zone 3). As an example, an elite athlete training 10-12 times per week is likely to train ≥LT 1-3 times per week.[83] It is not clear why this training distribution is preferred, but Foster *et al*.,[34] suggests that it is possibly linked to competition pacing strategies and Seiler and Tonnessen[83] point out that perhaps it is linked to maximal fat utilisation as most of zone one training appears to be conducted at ≈ 60-65% VO_2max.

Training Volume

Typically, the training volume of endurance athletes is very high and differs substantially across endurance sports (Figure 6). For example, an elite cyclist may be on the bike for up to 30 hours/week, while a marathoner may run as much as 15 hours/week.[83] Seiler and Tonnessen[83] suggest that this is perhaps explained by the difference in loading stress that is applied to the joints and have reported a strong inverse relationship between training volume and quantity of eccentric or ballistic stress, which may explain the differences seen between running and cycling or swimming *(Table 4)*.

Novel Solutions for Increasing VO_2max and LT

While the most common method (>80%) to enhance aerobic capacity is undoubtedly via running distances at a moderate intensity (zone 1), this may not be the most effective. For example, in a group of fifty-five

Figure 5. 3-zone training scale used by aerobic athletes which is defined by the physiological markers, LT, OBLA and VO_2max. Adapted from Seiler and Tonnessen.[83]

Table 4. Example annual training volume from various endurance sports. Based on the work of Seiler and Tonnessen,[83] who suggest that training volume is inversely related to loading stress.

Training Volume (hrs)	Training Volume (hrs)
Distance Running	500
Orienteering	600
Cross-country skiing	900
Rowing	1000
Cycling	1100
Swimming	1200

moderately trained male subjects, Helgerud *et al.*,[45] found that high intensity endurance training is significantly more effective than moderate- and low-intensity training in improving VO_2max *(Table 5)* and that intensity and volume of training are not interchangeable. This is in agreement with several other studies,[35,61] including those examining athletes with an already high VO_2max[45] and indeed with studies concluding that intensity of training cannot be compensated for by longer duration.[91,100]

Also of interest, and in line with several other studies,[44,67,73] Helgerud *et al.*,[45] found no change in LT as a % of VO_2max (although all groups significantly improved running velocity at LT by an average of 9.6%), and thus concluded that by virtue of increasing VO_2max, LT would also increase.

In summary, it may be contended that higher intensities elicit greater improvements in VO_2max than lower intensities[30,39,45,64,102] with intervals performed at near-max intensity being most effective.[39] It may therefore be recommended that once athletes have undergone sufficient endurance training (perhaps utilising the conventional continuous-moderate intensity protocols), they should incorporate a larger volume (>20%) of high-intensity interval training and possibly for purposes of variation, alternate between the 15x15 and 4x4 methods described below in *Table 5*.

Central and Peripheral Adaptations

Arguments to support the inclusion of both CT (continuous training) and HIIT (high intensity interval training) may lie with the differing adaptations which are thought to occur with each (i.e., peripheral or central adaptations). Currently however, studies continue to report mixed results regarding the impact that CT vs HIIT has on peripheral (a-vO_2diff) and central (Q) adaptations. While this is likely a consequence of the array of training interventions used within each study, this interaction is perhaps best summarised by Helgerud *et al.*,[45] who reports that when differences are observed, they tend to suggest that CT promotes greater peripheral adaptations and HIIT promotes greater central adaptations.

More recent research by MacPherson *et al.*,[65] however, suggests to the contrary. In this study, varsity men and women (n=10 per group; 24yrs) trained 3/week for 6 weeks with either HIIT (30 sec all-out run sprints, 4-6 bouts/session and 4 min recovery/bout) or CT (65% VO_2max for 30-60 min). Results revealed that Qmax increased (P=0.01) with CT by 9.5% but not with HIIT. Furthermore, a-vO_2 diff increased by 7.1% with HIIT but not with CT. Therefore, while both groups demonstrated similar improvements in VO_2max and 2000m run time (5-6%), each achieved this via different physiological adaptations.

It is important to note however, that the HIIT training described above differs significantly from that used by Helgerud *et al.*,[45] whereby longer work intervals were utilised (and thus a lower intensity) as well as a larger volume of training undertaken. The peripheral only adaptations seen with the maximal HIIT training therefore, may be due to the abrupt drop in O_2 partial pressure at the muscle (due to a reduction in blood flow to the exercising muscle), which would in turn terminate exercise prior to reaching a volume threshold of HIIT that may be required to sufficiently stress the pumping capacity of the heart (and induce central adaptations). Indeed, MacPherson *et al.*,[65] concluded that to maximise both central and peripheral training adaptations, either longer intervals of HIIT (presumably similar to that of Helgerud *et al.*,[45]) should be incorporated, or a mix of HIIT (utilising max effort intervals) and CT would be required as maximal intensity intervals appear to only target the periphery.

Strength and Power Training

An equally novel training concept is that increases in strength (utilising heavy loads of ≥85%1RM) may enhance endurance performance. This is through decreasing the relative force (% of max) applied during the loading phases,[74,88] thereby leading to a reduced metabolic demand for the same force output and creating a motor unit reserve available for additional work.[88] In addition, because increases in strength are often accompanied by increases in power and rate of force development (RFD)[1] there would likely be an increase in blood flow[88] and thus an enhancement of muscle oxygenation and the exchange of substrates/metabolites.[70] This may be explained by the fact that fewer motor units will be recruited for a given force output/work rate[88] and due to enhances in RFD, thereby reducing contraction time, and thus increasing relaxation time when oxygenation and substrate exchange occurs.

The Strength and Conditioning Coach should note however, that a common resistance training strategy is to shorten the rest interval between sets and exercises under the assumption that this will further enhance the aerobic stimulus. However, this may be contended[62,76] as if rest periods are too short (≤30 seconds), loading is likely to be compromised, thereby diminishing gains in strength, power and RFD.[88] In addition, because one of the principle adaptations responsible for these benefits is an increase in number (and size) of Type IIa fibers (with a concomitant decrease in the proportion of type IIx) which have a high glycolytic and oxidative potential and are relatively fatigue resistant, a high load is required. Readers are recommended to the paper of Anderson and Aagaard[4] and Turner[93] for details pertaining to the volume load prescription. Based on this review, *Table 6* illustrates a sample of resistance training sessions.

As previously mentioned, muscle-tendon stiffness is fundamental to RE. Within the discipline of strength and conditioning, it is largely acknowledged that this 'stiffness' is best developed through plyometrics and readers are directed to the work of Turner and Jeffreys[94] for details pertaining to this. Based on this review, *Table 7* illustrates a progression of plyometric

Table 5. Training Systems used by Helgerud et al.,[45] to enhance aerobic capacity

Training Group	Protocol	Pre-training VO_2max	Post-Training VO_2max
Long slow distance running (LSD)	Continuous run at 70% HRmax (137 ±7 bpm) for 45 min.	55.8 ± 6.6 (ml/kg/min)	56.8 ± 6.3 (ml/kg/min)
Lactate threshold running (LT)	Continuous run at lactate threshold (85% HRmax, 171 ± 10 bpm) for 24.25 min.	59.6 ± 7.6 (ml/kg/min)	60.8 ± 7.1 (ml/kg/min)
15/15 interval running (15/15)	47 repetitions of 15-s intervals at 90–95% HRmax (180 to 190 ± 6 bpm) with 15-s of active resting periods at warm-up velocity, corresponding to 70% HRmax (140 ± 6 bpm) between.	60.5 ± 5.4 (ml/kg/min)	64.4 ± 4.4 (ml/kg/min) 5.5% increase
4 x 4-min interval running (4 x 4 min)	4 x 4-min interval training at 90–95% HRmax (180 to 190 ± 5 bpm) with 3 min of active resting periods at 70% HRmax (140 ±6 bpm) between each interval.	55.5 ± 7.4 (ml/kg/min)	60.4 ± 7.3 (ml/kg/min) 7.3% increase

Table 6. Two example strength sessions and two example power sessions. Strength exercises are performed to or near repetition maximum while power exercises are performed at variable loads to ensure full coverage of the force velocity curve; 3-5mins rest between sets is advised.[93]

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 (4 x 4)	Bent over row (4 x 4)	Power snatch from hang → power split snatch from hang (5 x 3)	Power clean from hang (5 x 3)
Back squats (4 x 4)	Front squat (4 x4)	Stiff leg dead lift or Nordics (4 x 4)	Split Jerk (5 x 3)
Nordics (4x4)	Stiff leg dead lift (4 x 4)	Plyometric drills (see Table 6)	

*Key: → = progress to; (Sets x reps); * used to develop/maintain technique and strength/power*

drills which should be gradually and logically (i.e., when the athlete is competent at the preceding drill) added to the athletes resistance training programme. Moreover, these drills will also help enhance the athlete's RFD by mimicking the short contraction times and ground contact times produced while running.

Volume Load of Strength and Power Training

It is important to note, that strength, power and plyometrics training should not just simply be added to the existing training schedule. For example, Bastiaans *et al*.,[9] and Paavolainen *et al*.,[71] replaced 37% of total endurance training time with strength training. This protocol was able to preserve if not enhance the ability to maintain high power outputs, at least for short periods, and thus translate into factors associated with enhanced endurance performance (based on the 1hr time trials).[88] Therefore these studies replaced some of the endurance training with strength training, rather than simply adding to it. In summary, these reports also contest the commonly held belief that concurrent strength and aerobic training compromises athletic development. While this may be true for strength and power athletes, it can be noted that this is not the case for aerobic athletes.

Conclusion

The aerobic capacity is determined by three factors: 1) VO_2max, 2) LT and 3) ME, and each one should be targeted to optimise aerobic development. It appears that VO_2max and LT can be adapted simultaneously and may be best trained utilising a higher volume of high intensity intervals (such as the 4 x 4 method described above) than is currently recommended (i.e., >20%). While RE is positively affected by experience, gains to this component can be exacerbated through resistance training emphasising high intensity compound exercises and high power/velocity lifts (ballistic exercises). These should be further supplemented with drills which enhance the SSC mechanism, and thus further improve stride propulsion and economy. In summary, it appears that the 8 zone scale of aerobic training may better suit the more novel methods of training aerobic endurance athletes. Finally, one can only provide a highly speculative recommendation of volume distribution, but the evidence herein may suggest that CT, HIIT and strength and power training should each share approximately one third of the training volume. Of course, this statement requires further investigation before such a radical and novel change can be validated; at present, a change in this way amongst elite athletes appears very distant.

Table 7: Example plyometric drills that can be performed in the rest intervals of a resistance training programme or as part of a separate plyometrics based session.

Plyometric drills
Lower-body SSC (1 x 3): Ankling (1 repetition = ankling over 4meters) → Jump up to box (gradually increase the height) →Drop lands (gradually increase the height) →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

Key: → = progress to; (Sets x reps); To ensure quality of effort, each session should be limited to around 50 contacts

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KEISER

Physical Preparation for Netball – Part 2: Approaching Programme Design

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Introduction

Despite enjoying widespread popularity (notably in Australia and New Zealand, South Africa, the Caribbean nations and the United Kingdom) there is very little published research upon which to base training prescription for netball. This lack of studies to inform evidence-based practice is particularly unhelpful in view of the prevalence of lower limb injury among netball players at all levels (see Part 1 of this article in Issue No. 22). The following article summarises the data available for netball and reviews relevant findings from other sports. Recommendations are provided with regard to best practice for preparing netball players to successfully compete in the sport without undue risk of injury.

1. Approaching Physical Preparation for Netball

The stated objectives of physical preparation for netball – i.e. safeguarding against injury and improving performance – would appear to encompass three major aspects:

a. Strength training – including speed-strength development and plyometrics

b. Metabolic conditioning

c. Neuromuscular and movement skills training

In addition, targeted training interventions appear to be warranted in order to specifically address the types of injuries and associated risk factors characteristically observed in netball. As summarised in Part 1 of this article, common sites of injury documented in netball include ankle, knee, lower back and shoulder.

It has been highlighted by a study of netball players competing at national level that in order to be effective, physical preparation must not be conducted in isolation.[11] Training should rather be delivered in the context of the sport and the identified needs of each individual player, and undertaken in collaboration with coaching staff and medical support team. The importance of taking a multidimensional approach to physical preparation is also highlighted by the finding that strength training interventions which have been employed in isolation have reported little or no significant effect on measures of lower limb injury risk.[24] Similarly, movement skills instruction and feedback alone had limited effect on certain measures, specifically hip abduction and ground reaction forces.[24] Conversely, employing strength and movement skills training modalities in combination is found to have an additive effect, which was reflected in a much more significant positive impact across a wider range of kinetic and kinematic measures associated with lower limb injury risk.

Consistent with the primary objective of physical preparation for netball being guarding against injury, the logical first step when undertaking players' physical preparation is to conduct a musculoskeletal screening and dynamic profile.[11] This process should ideally be conducted jointly by both physiotherapist and strength and conditioning specialist. The initial musculoskeletal assessment will naturally be led by the physiotherapist, and will include standard clinical tests of passive joint integrity and range of motion. The second part – the dynamic profile – might then be led by the strength and conditioning specialist but jointly scored by both practitioners,

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and should consist of selected movement-based screens from the literature.[17] For example, one such screen that would appear to merit inclusion is the Star Excursion Balance Test.[6] This test requires the athlete to maintain their centre of balance within a fixed base of support (the supporting foot) whilst reaching out the opposite leg in various directions, which is reflective of balance demands on court. This dual approach including both clinical musculoskeletal and dynamic assessments will allow the identification of both mechanical factors (e.g. joint laxity, passive joint function) and functional instability under active conditions (e.g. impaired proprioception, balance, postural control) that have been implicated in lower limb injury in particular.[34]

Hypermobility has been identified as an intrinsic injury risk factor associated with increased injury rates among junior netball players.[53] This risk factor would be easily identified during players' initial musculoskeletal screening. Players exhibiting hypermobility around these joints would be susceptible to exposing connective tissue structures to joint ranges of motion in which they are placed under excessive strain. Such ligament laxity is also associated with decreased proprioception and kinaesthetic sense around the joints affected.[53] The interaction of these two factors readily explains the greater incidence of lower limb injury in particular suffered by netball players with hypermobility. Accordingly, where hypermobility is identified during the player's initial musculoskeletal screening there is a need for added emphasis on development of lower limb strength, postural control, proprioception and dynamic stabilisation in order to augment active stability provided to lower limb joints to compensate. Movement skills training will also help the player to avoid particular postures and lower limb biomechanics on court that place excessive stress on lower limb joint structures.[21,26,42]

2. Strength Training

2.1 Aims of Strength Training

Development of general strength for fundamental athletic movements – i.e. variations of squat, lunge movements etc – is necessary to underpin movement skills instruction with regard to 'safe' posture and lower limb alignment during activities on court. The integral role of strength training with respect to addressing lower limb injury risk has been highlighted by a recent study which identified that the effectiveness of movement instruction and feedback alone was limited in the absence of concurrent strength training.[24] It appears that development of lower limb force generating capabilities via strength training improves the athlete's capacity to make the necessary adjustments in posture and lower limb mechanics during athletic movements as instructed.[24] These findings underline the importance of concurrent strength training to support neuromuscular and movement skills training with regard to addressing lower limb injury risk factors.[28]

Following a period of general strength development appropriate to the requirements of the individual player, specific development of eccentric strength and eccentric speed-strength of lower limb kinetic chain would also appear necessary. There are obvious benefits to be derived from training these capacities as a means to develop the player's ability to absorb both impact forces when landing and torques generated during change of direction movements. To this end, speed-strength and plyometric exercises should be progressively introduced once the player reaches an appropriate stage in their physical development.

In addition to lower limb strength development for improved lower limb control and biomechanics, the other major objective of strength training for netball players is performance enhancement, which will necessarily include upper-body strength and speed-strength development. In addition to developing strength and speed-strength of agonist muscles involved in the passing and shooting movements that occur in netball, upper body strength development should also address the muscles that stabilise the shoulder girdle during these skill movements.

2.2 Exercise Selection

Players might be introduced to variations of the squat movement during their early preparation particular during off-season/preseason with the objective of developing general strength and postural control. As players' physical preparation progresses consideration must be given to the observation that training responses with respect to lower limb neuromuscular control appear to be movement task specific. Given that players rarely perform movement on court from an equal weight-bearing bilateral stance, it follows that there will therefore be a progression from bilateral strength training exercises to an increasing emphasis on exercises performed from a unilateral base of support. Exercises might include single-leg squat, backward and forward lunge with barbell, including variations with the barbell racked either across the front or the back of the shoulders. Variations of the step up exercise offer a means to develop gluteal muscle recruitment; this would appear important in view of the quadriceps/low back dominance often exhibited by female athletes.[22] Finally, to transfer strength development to multi-directional movements performed on court, lunge movements in a variety of directions; likewise variations of the step up exercises (e.g. lateral step up) might be considered.

From the point of view of developing strength and power for ball skills on court, upper body strength training exercises should include pushing lifts – for example variations of the push up as well as free weight exercises such as dumbbell bench and shoulder press. In addition pulling movements should also be included in players' upper body strength training. This is important for a variety of purposes including addressing/avoiding muscle imbalances, developing postural control around the shoulder girdle (scapular stabilisation) and the role of the mid back muscles in providing tension to the 'corset' of muscles that brace the trunk.[43]

Finally, alternate and single-limb exercises (for both upper and lower body) have advantages for concurrent development of postural control, lumbopelvic stability and torsional stability in particular.[44]

2.3 Speed-Strength Training

Jumping is a key movement for netball particularly for the positions that contest possession in the D area in the vicinity of the posts. Speed-strength exercises such as jump squats and Olympic-style lifts are proven modalities for developing vertical jump height and concentric power output.[23, 57] Versions of plyometric exercises that involve only the concentric part of the movement such as jump and bound movements executed from the floor or using a box without any preceding eccentric action can similarly be used to

Table 1 – Sample Off-Season/Early Preseason Training Cycle.

STRENGTH TRAINING	**Frequency:** 4 per week: 2 whole-body 1 upper-body 1 shoulder maintenance	**Example Whole-body Workout** 8RM; 3 Sets	**Upper-body Workout** 10RM; 5 Sets
	Intensity: 7-10RM (all lifts) **Volume:** 3-5 sets	Front Squat Push Up onto BOSU Ball Dumbbell Step Up with Hip Flexion Alternate Arm Cable Lat-Pulldown Dumbbell Split Squat Single-leg Good Morning	Suspended Row (feet supported on Swiss Ball) Incline DB Bench Press Alternate Arm Cable Lat-Pulldown Standing DB Shoulder-Press One-arm Dumbbell Row Bench Dips (feet supported on Swiss Ball)
	Workout Format: Circuit		
	Rest: Short rest (<60sec) between lifts Core work (~2 mins) between (circuit) sets		
Metabolic Conditioning		Long aerobic interval training. Combination of cross-training modes and running conditioning.	
Movement Skills Training		Instruction of fundamental movement skills. Self-paced. No read/reaction element.	

Table 2 – Sample Mid-Late Preseason Training Cycle.

STRENGTH TRAINING	**Frequency:** 3 per week: 2 whole-body 1 shoulder maintenance	**Example Whole-body Workout** 6RM; 3 Sets	**Upper-body Workout** 8RM; 3 Sets
	Intensity: 5-7RM multi-joint lifts 8RM assistance lifts **Volume:** 3-4 Sets	Jump Squat Single-arm Cable Row Front Racked Backward Lunge Push Press Front Racked Barbell Step Up Single-leg Barbell Straight-Legged Deadlift	Cable External Rotation Alternate Arm Incline DB Bench Press Assisted Narrow-grip Chins Dumbbell Pull Over Prone Dumbbell Lateral Raise Alternate Arm Dumbbell Full Can Raise
	Workout Format: 2x 3-lift Complexes		
	Rest: Short rest (<60sec) between lifts Core work (~2 mins) between (complex) sets		
Metabolic Conditioning		Progression aerobic interval to anaerobic interval training modes to repeated sprint conditioning late preseason. Combination of conditioning modes including skill-based games and conditioning drills at appropriate intensities.	
Movement Skills Training		Progression of technique development drills and instruction/development of acceleration mechanics mid-preseason, followed by introduction to higher velocity acceleration drills. Progression of change of direction movement skill drills, including simple reaction tasks, followed by gradual introduction of 'read/react' agility drills.	

Table 3 – Sample In-Season Training Cycle.

STRENGTH TRAINING	**Frequency:** 3 per week 2 whole-body 1 shoulder maintenance	**Example Whole-body Workout** 5RM; 3 Sets	**Upper-body Workout** 6RM; 3 Sets
	Intensity: 4-6RM (all lifts **Volume:** 3-4 sets **Workout Format:** 2x 3-lift Complexes **Rest:** Complete (self-selected) rest between consecutive lifts Core work (~2 mins) between (complex) sets	Power Clean ONE ARM Incline Dumbbell Bench Press Box-to-Box Drop Jump Loaded Split Bounds Single-leg Single-arm Dumbbell Row Front Racked Barbell Lateral Step Up	Prone Dumbbell 90-degree External Rotation Suspended Push Up on Rings Alternate Arm Cable-Reverse Fly Cable Diagonal Pulley ONE ARM Dumbbell Empty Can Raise Single-leg Cable Straight-arm Pulldown
Metabolic Conditioning		Cycling of aerobic interval training, anaerobic interval training and repeated sprint conditioning. Combination of conditioning games, skill-based conditioning drills, and movement-specific high-intensity conditioning drills, depending on respective block.	
Movement Skills Training		Progression to more challenging and context specific reactive agility drills and partner drills.	

develop concentric speed-strength for both bilateral and unilateral jump movements.

In terms of exercise selection, whilst developing power expression is important to a varying degree depending on the playing position, concentric power and reactive speed-strength are required in a variety of horizontal directions. This will necessitate speed-strength exercises that allow power to be developed in a horizontal as well as a vertical direction. Examples include variations of horizontal (bilateral and unilateral) jumps and bounds from a stationary start.[18]

Eccentric speed-strength is another important aspect which can be developed by using drop-and-hold landing movements, progressing drop height and moving from bilateral to unilateral landings in a variety of directions. The latter progressions in particular allow eccentric speed strength and dynamic stabilisation to be developed concurrently.

2.4 Plyometrics

Plyometrics offer development of both reactive strength (i.e. capacity for rapid transition from eccentric into concentric movement) and mechanical and neural elements of the stretch-shortening cycle (SSC) for both vertical and horizontal jumping and bounding movements on court. Players' plyometric training might follow a progression from slow SSC movements – for example countermovement jump – to fast SSC exercises such as drop jumps or cyclic bounding movements that emphasise short ground contact time. In much the same way as for strength training, plyometric training should also feature a progression from bilateral to unilateral jumping and bounding movements given the specific nature of training effects with respect to inter-muscular coordination.

3. Metabolic Conditioning

In view of the intermittent nature of activity in netball, it follows that metabolic conditioning for the sport should similarly follow an intermittent or interval framework. Metabolic conditioning for elite netball players might therefore comprise a combination of methods, including aerobic interval training, anaerobic interval training and repeated sprint conditioning.[15]

Practically through the course of the training year players' metabolic conditioning will encompass an array of conditioning modes. Cross training modes will feature predominantly during the off-season and early preseason; these sessions will also follow an interval format. However as the season approaches a combination of interval conditioning, tactical metabolic conditioning, and skill-based conditioning games will be employed to provide metabolic conditioning that is specific to the needs of the sport.[15]

Interval conditioning will tend to follow a progression from aerobic interval conditioning to anaerobic intervals and finally repeated sprint conditioning. Incorporating relevant movement skills into metabolic conditioning also provides the opportunity to reinforce correct and safe movement mechanics under conditions of fatigue. Tactical Metabolic Conditioning is another approach that may be used, which involves modelling conditioning upon observed patterns of work-to-rest identified from competitive matches[15] – albeit this will require prior investigation given the sparsity of data available for the sport. Finally, skill-based conditioning games not only incorporate relevant movement skills, ball skills and tactical elements but also offer advantages in terms of motivation and compliance.[15] That said, the effectiveness of this training mode is dependent on imposing appropriate constraints.[50] Players should also be monitored during all sessions to objectively evaluate work rate, which requires access to the necessary equipment such as heart rate monitors.[15]

4. Neuromuscular and Movement Skills Training

The major objectives of movement skills training for netball are to instil safe movement strategies, improve players' athleticism and develop the change of direction movement abilities that underpin agility. As discussed in the first part of this article, targeted neuromuscular training interventions are critical in view of the deficits in lower limb control that are characteristically seen among female athletes.[17]

4.1 Postural Control

Postural control and balance abilities comprise input from visual, vestibular and somatosensory systems.[6] Postural control also involves the various elements that comprise lumbopelvic stability. A key element that contributes to lumbopelvic stability is the hip musculature of the supporting limb(s) during weight-bearing, which is particularly vital to postural control under both static and dynamic conditions. However, lumbopelvic stability also comprises the 'local' stabilising system of deep postural muscles and the 'corset' formed by abdominal muscles, low and mid back muscles and thoracolumbar fascia. The critical role played by the trunk muscles with respect to postural control is underlined by the observation that ability to control motion and orientation of the trunk during athletic movement impacts upon joint kinetics and kinematics throughout the lower limb kinetic chain – in particular at the knee joint but also the ankle joint.[29] Postural control and lumbopelvic stability similarly directly impact upon incidence of low back pain and injury.

Practically, 'sensorimotor training' to develop postural control or balance will consist of a range of single-limb support tasks that impose appropriate constraints to develop particular components of static balance either independently or in combination.[17] For example, single-limb balance tasks performed on a stable surface with eyes closed or turning the head are designed to specifically develop the vestibular input to postural control. Many practitioners progress the demand of the balance task by moving onto labile surfaces – such as balance disk or wobble board. A variety of single limb balance tasks with different constraints may be employed during athletes' training, however exercise selection should also feature relevant balance tasks on a stable surface similar to that found on court. One such balance task that might be considered is an adaptation of the Star Excursion Balance test.[6] The balance abilities required by this activity was reported to be relatively distinct from other measures of static balance in a study of female athletes, including female college soccer and basketball players.[6]

4.2 Dynamic Stabilisation

Dynamic stabilisation can be defined as the capacity of the athlete to maintain balance during the transition from motion to a static posture[7] – for example retaining postural control when landing from a hop or jump. This capability has obvious application for netball given that players are required to land and hold a stationary posture from a variety of hop, step, bound and jump movements within one and a half steps every time they take possession of the ball. Dynamic stabilisation is identified as a discrete ability that is distinct from static balance or postural control.[7] The aspects of executing a landing and decelerating the athlete's own momentum in order to come to a complete stop impose additional demands, in terms of strength and neuromuscular control, to those required for maintaining the athlete's centre of mass within a fixed base of support under static conditions.[59]

Developing dynamic stabilisation will require dedicated training in order to develop the feed-forward control capacities involved in landing tasks.[17] A study that employed a training intervention focussing on relevant exercises with elite female soccer players reported a significant reduction in a range of lower limb muscle and tendon injuries.[38] Further, this study identified that a dose-response relationship appeared to exist with dynamic stabilisation training with respect to injury reduction. That is, the greater the duration of sessions

Table 4 – Sample Peaking (In-Season) Training Cycle.

STRENGTH TRAINING	**Frequency:** 1 per week 1 whole body 1 shoulder maintenance	**Example Whole-body Workout** 4RM; 3 Sets	**Upper-body Workout** 6RM; 3 Sets
	Intensity: 4-5RM (all lifts) **Volume:** 3-4 Sets **Workout Format:** 2x 3-lift Complexes (whole body); Circuit (shoulder workout) **Rest:** Complete rest between consecutive lifts Core work (~2 mins) between (complex) sets	Split Jerk Cable Resisted Alternate Knee/Shoulder Flexion Horizontal Bounds Barbell BOUND Step Up Ballistic Push Up (lower leg supported on BOSU Ball) Compass Bounds landing on BOSU Ball	Single-leg Cable 90-degree External-Rotation Dumbbell Pull-over with Alternating Hip Flexion Cable Reverse Diagonal Pulley CLOCK Push Up ONE ARM Bent-over Dumbbell Raise Prone DB Overhead Full Can Raise
Metabolic Conditioning		Repeated sprint conditioning. Movement-specific high-intensity conditioning drills.	
Movement Skills Training		High-intensity game-related acceleration drills and game-related specific reactive agility and partner drills.	

with the training intervention during the study period, the greater the apparent reduction in injury incidence.[38]

A first step when training to develop dynamic stabilisation should involve instructing players on safe landing mechanics, including optimal lower limb alignment and posture. This has been observed to be an important part of successful interventions to reduce lower limb injury – notably knee injury – in female athletes.[28] Once these movement abilities have been developed under controlled conditions, such as dropping into a single-leg landing from a low box, training exercises can be progressed to incorporate constraints and movements similar to those experienced during game conditions. For example, the same themes in terms of safe landing postures and lower limb alignment can be transferred to drills that feature the variety of landing movements that players are observed to employ on court.[48]

4.3 Specific Movement Skills Development

Ultimately, the final progression for the bounding and landing drills described above is to execute these movements on court and incorporate intercepting a ball. This will facilitate best transfer of dynamic stabilisation and neuromuscular control to the specific jump-landing activities that feature in netball. Similarly, the evasive and tracking movements that feature in netball should also be developed in an appropriate way. Modifying change of direction movement technique via movement skills instruction has been shown to have the capacity to reduce potentially injurious loading on the knee joint.[10] As the athletes' movement skills advance, the drills employed to develop change of direction movement abilities should progressively incorporate the constraints and context in which these movements are executed on court. Similarly movement mechanics differ under pre-planned versus unanticipated conditions.[4] Progressions should therefore include withdrawing the ability for players to anticipate movement responses and incorporating the elements of decision making as encountered on court.[19]

5 Specific Training Interventions to Target Common Netball Injuries

Initial screening will help identify intrinsic injury risk factors for each individual player. This will include the player's injury history, hypermobility or joint laxity, conversely any deficits in mobility and stability, and imbalances in muscle function that may predispose the player to injury. Knowledge of common injuries and associated injury mechanisms will then help identify extrinsic risk factors associated with competing in the sport of netball.[16] Presented here is a summary of investigations involving netball players and data from other female team sports that highlight the injuries that netball players appear most predisposed to sustaining.

5.1 Ankle

Given the high incidence of ankle sprain injury – and high incidence of recurrence with this injury – it will be common for netball players at elite level to have a history of previous ankle sprain injury. Taping the lower limb and ankle joint is often employed particularly for players with previous ankle sprain injury as a means to augment proprioception due to the cutaneous stimulation provided.[33]

Afferent input from mechanoreceptors within the muscles associated with the ankle joint serve the dominant role in providing the athlete with a sense of joint position and kinaesthetic awareness.[30] Development of this afferent pathway is particularly crucial for players with previous ankle injury, which often disrupts sensory input from joint receptors – leading to an increased need for compensatory input. Appropriate strength training and neuromuscular training modes can provide development of proprioception provided by muscle mechanoreceptors. In accordance with this a variety of strength training and neuromuscular training interventions have been shown to improve measures of proprioception and ankle joint position sense specifically.[30]

Balance training including various exercises in a single-leg stance should similarly be used to develop the various systems that contribute to postural control and static balance. Exercises incorporating labile surfaces (wobble boards, balance disks etc) can be employed, however ultimately, exercises on a solid surface similar to that found on court should be used to help facilitate transfer of proprioception and neuromuscular training effects. There is also a need for specific development of dynamic stabilisation.[16] Feed-forward control of ankle stabilisers during the preparatory phase prior to touchdown during landing or stopping movements is suggested to be the more important factor in improving active stabilisation for those with chronic ankle stability.[30] This would appear to be a learned effect and thus amenable to development via repeated exposure to relevant movements in conjunction with appropriate coaching.

5.2 Knee

In view of the 'ACL-agonist' role of the hamstring muscles[26] and the plateau observed in hamstring strength scores among females following puberty in the absence of corrective strength training[2], it follows that hamstring strength development should receive appropriate focus in players' strength training. Appropriate (particularly unilateral) strength training is likewise identified as serving an important role in supporting development of lower limb neuromuscular control.[25]

Eccentric strength training is often employed for specific development of medial quadriceps (VMO) and patella tendon as part of the rehabilitation for patellar tendinopathy.[62] A range of training modes have been employed, including controlled eccentric knee flexion movements as well as rapid drop squats or drop jump landings.[58] Unilateral single-leg squat protocols have proven efficacy. These exercises typically performed on a decline surface, maintaining an upright posture with minimal forward torso lean and neutral lower limb alignment so that the supporting knee remains in line with the toes.[58]

A biomechanical analysis identified that employing a decline surface with a minimum angle of 15-degrees serves to specifically load the patella tendon, which appears to explain the superior effectiveness of decline squats in comparison to eccentric squats performed on a flat surface.[62] There does appear to be an optimal range of motion for the exercise – descending to a knee flexion angle of 60-degrees. Beyond this range forces placed upon the patellofemoral joint increase to a greater extent than patellar tendon forces.[62] In symptomatic athletes, the depth will initially be governed by pain experienced during the movement – it is typically recommended to work just into the range where the movement becomes painful.[58] Within the specific range of motion, progression can be achieved by adding external load, for example using dumbbells held at the sides or supported upon the shoulders. Adding a 10kg load via a backpack was shown to increase knee movement of force by 23%.[62] It is important however that an upright torso posture is maintained when external loading is added, in order that appropriate moments of force through the lower limb joints are maintained during the movement.

Developing strength, endurance and neuromuscular control of the muscles that stabilise the trunk appears to be a critical aspect of reducing non-contact knee injury risk for netball players. Capacity to control trunk position and orientation has been implicated in ACL injury mechanism with females athletes[61] and a similar association is also reported between reduced lateral trunk strength and patellar tendinopathy.[9]

The hip muscles' role in providing lumbopelvic stability and controlling lower limb alignment in single-leg stance and athletic movements and its influence on knee joint loads has been identified as an important aspect in the mechanisms of both knee ligament injury[41] and patellar tendinopathy.[5,9] Much the same approach to training for static balance/postural control and specific development of dynamic stabilisation as that suggested for ankle injury prevention can achieve similar benefits for reducing non-contact knee injury risk. This has been shown to be an important aspect of training interventions to reduce rates of ACL injury among female athletes.[28] Similarly, this form of training has also been shown to reduce the incidence of patellar tendinopathy among elite female soccer players.[38]

Finally a key aspect of interventions to reduce lower limb injury is movement skills development, including instruction and reinforcement of 'safe' posture and lower limb alignment during landing and change of direction activities. Appropriate exercises with an emphasis on correct posture and technique can be incorporated into players' practice sessions. A study of female basketball players showed that a 20-minute movement preparation protocol performed prior to players' on court practice sessions effected significant improvements in lower limb kinetics and kinematics.[42] The effectiveness of this approach is underscored by a study of female soccer players that employed a movement preparation protocol in a similar way and likewise observed significant reductions in the incidence of non-contact ACL injury.[21]

5.3 Lower Back

Deficits identified during players' initial screening in any one of the components that contribute to lumbopelvic stability should be addressed in order to guard against low back pain and injury. For all players there is a need for development of strength, endurance and neuromuscular control of the muscles that stabilise the trunk. Training might include appropriate strength training exercises that emphasise bracing the trunk and controlling lumbopelvic posture in addition to more conventional core stability exercises performed from the floor and also labile surfaces and devices such as balance balls and stability balls. A postural stability and dynamic stabilisation training intervention was also associated with significant decreases in (non-contact) lower back injury in a sample of elite female soccer players.[38] It follows that this form of training would appear to be an important component of physical development with respect to protecting against low back pain and injury.

One key movement strategy for sparing the spine is to move from the hips in order that the players are better able to maintain a neutral spine position during movements on court. This is of course contingent on the athlete possessing the necessary hip mobility and strength to be able to move in this way. Accordingly, flexibility training and strength development for these hip muscles incorporating appropriate movements should be an important focus for netball players' training.

5.4 Shoulder

Regardless of whether there is a previous history of shoulder issues it seems prudent that a dedicated shoulder maintenance session is included in the training week for all players throughout the training year. Players' initial musculoskeletal and movement screening can be used to identify any risk factors to be addressed. In those with current or previous shoulder pain and instability the player's history and ongoing assessment can help guide their corrective training and shoulder development work.

Exercise selection will in general address the scapula stabiliser muscles and the rotator cuff. Specifically, middle and lower trapezius, rhomboids and serratus anterior are key muscles to be developed.[12,13] Exercises should similarly focus on developing kinaesthetic sense of scapula position. As for rotator cuff development, exercise selection should address all rotator cuff muscles; however the external rotators (predominantly infraspinatus and teres minor) appear to require special attention as these muscles are subjected to particular stress in throwing sports. Evidence of specific atrophy of the infraspinatus muscle accompanied by reduced external rotation strength scores in overhead striking athletes (beach volleyball players)[39] further suggests a need for specific development. This is likely to be the case particularly for those playing positions that contest for possession of the ball overhead, and execute one-handed over-arm passes, on a frequent basis.

There are a number of different exercises reported to successfully elicit significant activation of each of the four rotator cuff muscles either alone or in combination – see Escamilla *et al* (2009) for a review. Once isolated exercises for specific development of rotator cuff muscles have been introduced, more complex exercises can be included in players' training which allows greater force development.[20] Resistance in the form of either free weights (e.g. dumbbells) or cable machines are generally preferable for these exercises as they avoid the adverse length-tension relationship associated with resistance bands or tubing as well as providing greater ease of progressing load. Exercises for the scapula stabilisers should include rowing and pulling exercises that focus on retracting and adducting the scapula – for example cable and dumbbell rows, cable lat pull-down exercise, and both standard and supine variations of the pull up – as well as exercises that focus on controlled scapular protraction, such as the 'push up plus' and dumbbell pull over exercises.[12]

6 Conclusions

There would appear to be multiple components that should be incorporated into netball players' training. These include appropriate strength training and metabolic conditioning as well as neuromuscular training comprising elements of postural control, dynamic stabilisation and movement skill development. In addition, targeted training interventions have been described that might be included to specifically address the types of injuries and associated risk factors characteristically observed in netball – including ankle, knee, low back and shoulder. There remains a critical need for further studies that specifically focus on netball, particularly at elite level.

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An update on carbohydrate intake during exercise: are sugary drinks still the key to prolonged performance?

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Introduction

It has been over 15 years since we first heard that Lucozade Sport results in a 33% improvement in exercise capacity.[14] Since this paper, there has been an explosion in the amount of products on the market, all designed with the intent of preventing hypoglycemia (low blood sugar) and providing additional CHO supply for energy production during exercise. This article will take a critical look at the classic and contemporary literature and try to answer the question, "Are sugary drinks still the key to prolonged performance". The type of sugar will be addressed as well as the form (liquid, gel or solid) and the best rate of ingestion during a variety of sporting settings.

Background

Unlike the storage of fat, the body can only store a limited amount of carbohydrate. Classical studies have clearly demonstrated that the consumption of a high carbohydrate diet (8-10 $g.kg^{-1}$ body mass) is able to fully load muscle glycogen stores (approximately 100 $mmol.kg^{-1}$ wet weight, *Figure 1*), equating to approximately 300-400 g of muscle glycogen. Additionally, the body can store approximately 80-110 g of glycogen in the liver, giving a total glycogen storage capacity of only 400-500 g, enough to fuel approximately 60-90 minutes of high intensity exercise. The effects of commencing exercise with high glycogen stores on exercise performance and capacity are of course well documented. For example, classical studies from Bengt Saltin *(Table 1)*, utilising biopsies from professional soccer players, demonstrated that some players started games with low muscle glycogen as a result of inadequate CHO intake in the days leading to the game and this had major detrimental effects on performance.[18]

Carbohydrate Provision During Exercise

The limited capacity to store CHO presents a major problem for athletes. Exercising for approximately 60-90 minutes, (especially if

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	High CHO	Low CHO
Number of Players	5	4
Pre Game Muscle Glycogen (mmol.kg^{-1} wet weight)	96	45
Half-time Muscle Glycogen (mmol.kg^{-1} wet weight)	32	6
Post Game Muscle Glycogen (mmol.kg^{-1} wet weight)	9	0
Distance covered in 1st half	6,100 metres	5,100 metres
Distance covered in 2nd half	5,900 metres	4,100 metres
% game walking	27	50
% game sprinting	24	15

Table 1. Effect of starting a football game with either high muscle glycogen or low muscle glycogen on match performance. The athletes did not deplete glycogen on purpose, but rather started the game this way due to poor pre game nutrition. Table adapted from Saltin.[18]

the exercise is intermittent high intensity exercise), can deplete muscle glycogen stores resulting in premature fatigue even if glycogen stores are full prior to commencing exercise *(Figure 2)*. In this regard, it is therefore beneficial to provide exogenous carbohydrates during exercise, so as to provide additional substrate supply. Early studies[7,13] during the 1924 and 1925 Boston marathons were, indeed, quick to recognise that endurance performance was directly related to blood glucose concentration, and more importantly, these studies established that fatigue could be delayed by simply providing exogenous CHO during the race. Since these studies, there have been numerous reports in the literature that exogenous CHO can increase endurance capacity (time to exhaustion) and decrease perceptions of effort[4] *(Figure 3)*. The precise mechanisms underpinning enhanced performance with exogenous CHO provision may be due to a combination of factors, including: prevention of hypoglycaemia, maintenance of high CHO oxidation rates, muscle glycogen sparing and effects on the central nervous system (for a review see Karelis *et al*.[11])

Figure 1. Relationship between dietary carbohydrate intake and muscle glycogen content. Note that 8-10g.kg^{-1} body mass results in maximum storage with no further gains from consuming 10-12g.kg^{-1}. Figure adapted from Burke et al.[1]

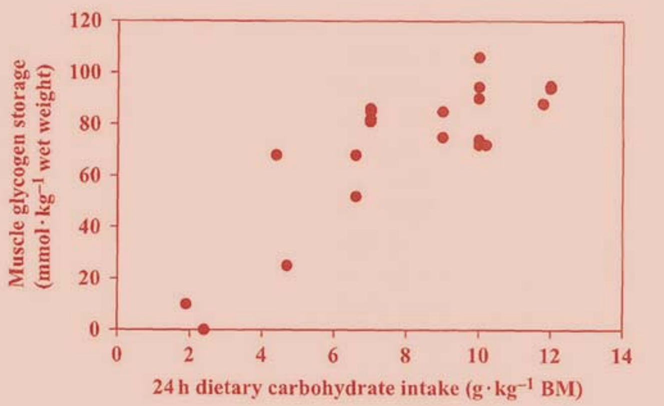
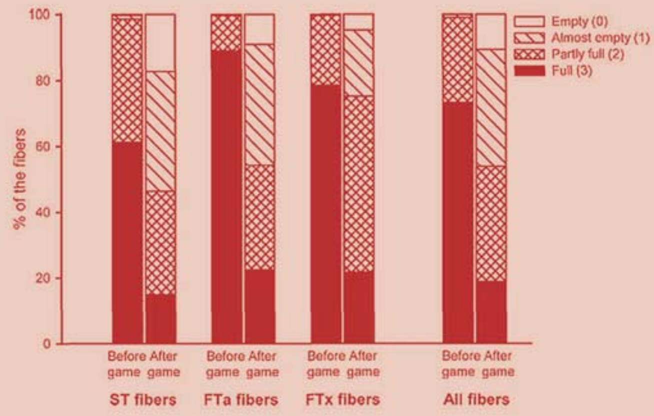


Figure 2. – Relative glycogen content in Type I, IIa and IIx fibers as well as all fibers before and after a soccer game. Figure adapted from Figure 2, Krustrup et al.[12]



How much CHO is required during exercise?

The amount of exogenous CHO given to an athlete during exercise largely depends on the exogenous oxidation rate of CHO. For many years, the general advice has been to consume 30-60g of exogenous CHO per hour[5] and this figure is still recommended by many sports nutritionists and cited in many leading textbooks. The rationale for this figure is in accordance with the fact that the maximum exogenous oxidation rate of glucose is approximately 1g.min^{-1}, or 60g.hr^{-1} *(see Figure 4)*, although dietary surveys of elite athletes have revealed that often endurance athletes consume far in excess of 30-60 g.hr^{-1}. More recently, researchers have become interested in whether the maximal rates of exogenous CHO oxidation can be augmented through co-ingesting different types of CHO with the traditional intakes of glucose that is present in most commercial sports drinks.

Source of CHO intake during exercise – the emerging role of 'multiple transporter' carbohydrates.

Over the past 10 years, there has been a growing interest in the maximum rate of exogenous CHO oxidation during exercise, leading to serious questions being raised about the often cited 1g.min^{-1} maximum CHO oxidation rate. To understand maximum CHO

Figure 3. Effects of exogenous CHO provision on time to fatigue and perception of effort. Note that provision of CHO not only increases time to exhaustion by 1 hour but also decreases the perceptions of effort in the later stages of the exercise. Figure adapted from Coyle et al.[4]

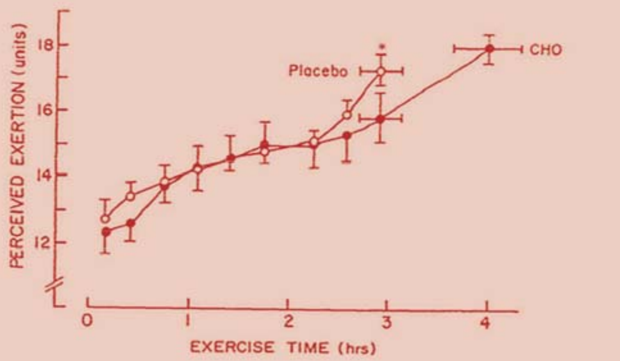
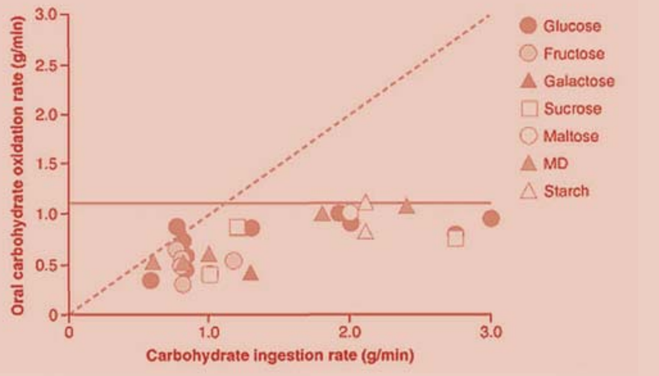


Figure 4. Maximum rate of exogenous CHO oxidation following ingestion of various forms of CHO intake. Note that despite intakes increasing to 3 $g.min^{-1}$ maximum rates are 1 g,min^{-1}. Figure adapted from Jeukendrup and Gleeson.[9]



oxidation rates, it is important to understand what limits this. Recently, this question has been addressed in an eloquent series of studies from Asker Jeukendrup's lab in Birmingham, which reported that it is the intestinal absorption of CHO, which is the rate-limiting step (for a review see Jeukendrup).[9] The most crucial observation from these studies was that, whilst the glucose oxidation rate is limited by a sodium-dependent glucose transporter (SGLT1), other sugars, such as fructose, are limited by another transport mechanism (GLUT5 in the case of fructose). This observation therefore, explains why some athletes are able to tolerate (and benefit from) consuming more than 60 $g.hr^{-1}$ of exogenous CHO when they consume a drink that contains various sources of carbohydrate *(see Figure 5)*. Many sports drinks now take advantage of this by producing products containing "multiple transporter carbohydrates" and in doing so, exogenous CHO oxidation rates can increase from 1 to in excess of $1.5g.min^{-1}$.[8] Such feeding strategies are perhaps most appropriate for ultra-endurance events, given that saturation of gut glucose transporters would be unlikely in athletes competing in shorter events, especially if access to additional CHO is limited (e.g. team sports where fluid breaks are limited to unscheduled breaks in play and half-time). A new set of guidelines have now been proposed regarding CHO provision during exercise, based on data presented on multiple transporter carbohydrates; for a review see Burke *et al*.[2] As opposed to the original rigid guidelines, the new recommendations are dictated by the duration and type of exercise.

Figure 5. The effects of feeding low and high dose glucose and combined glucose and fructose on peak exogenous CHO oxidation rates. Figure adapted from Jeukendrup and Gleeson.[9]

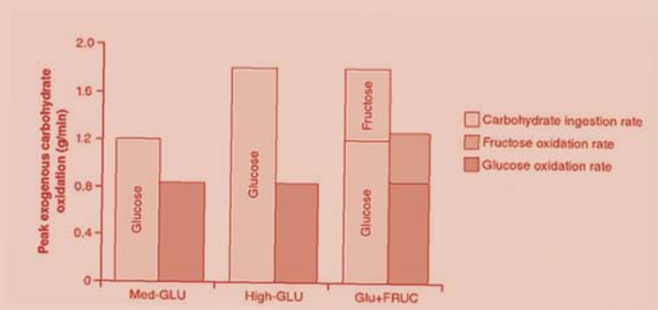


Figure 6. CHO can be taken in many forms during exercise with there being no difference in maximum oxidation rates. Personal preference regarding GI discomfort,

Figure 7. During prolonged exercise some athletes prefer to eat some food as opposed to reliance on drinks as this can reduce nausea and increase feelings of fullness.

Solid, liquid or gel?

There does not appear to be any difference in the exogenous oxidation rates between gels, bars or drinks,[15;16] so the form of the CHO provision is largely dependent upon the athlete and their own personal preference. It may therefore, be prudent to provide access to all 3 energy sources during exercise, so as to cater for individual athlete preferences and thus promote CHO intake *(Figure 6)*. Liquid provision of CHO has the advantage of preventing dehydration at the same time as providing energy, whereas gels are easier to carry and can be consumed much quicker. Many athletes during ultra endurance events can get a feeling of nausea if the CHO is purely provided in drinks and gels and therefore, some carbohydrate containing foods (such as cereal bars or even white bread sandwiches) are recommended in such situations *(Figure 7)*.

Practical advice regarding CHO intake in relation to length of exercise

Events 1 hr or less – Such events are unlikely to deplete muscle glycogen and therefore the need to provide CHO may not be necessary. However, it is very important for the S&C professional to consider what is the true duration of the exercise in question. For

Race Length	Recommended Carbohydrate Intake	Source
Short (less than 1hr)	0-30g/hr or even mouth wash	High GI (glucose or maltodextrin)
Medium (1-2 hrs)	60g/hr	High GI (glucose or maltodextrin) (1-2 x 500ml bottles of lucozade sport) or appropriate gels/food
Very Long (2+ hrs)	90g/hr	Combination of glucose and fructose (2:1 ratio), 60g glucose, 30g fructose

Table 2. Recommended carbohydrate intake during a race and suggested type of carbohydrate for mountain bike riders.

example, a rugby game involves 2 x 40 minute periods of exercise, however, once a 30-minute warm up has been accounted for, plus 5 minutes per half of stoppage time, what could be classed as 80 minutes of exercise would be more like 120 minutes.

Despite the fact that CHO availability may not be limiting in events < 60 minutes, Carter *et al.*,[3] demonstrated that CHO infusion did not improve performance in short duration events *but* CHO ingestion did. This led to a fascinating hypothesis that, in such situations, CHO provision could be working through non-metabolic pathways, likely involving the CNS *via* receptors in the mouth and oral space modifying motor output.[10] Studies have since reported that *mouth rinsing* with CHO beverages can improve performance during exercise lasting less than 1 hour. This has led to some athletes using CHO mouth washes during short duration exercise. However, it should be stressed that the performance enhancing effects of mouth rinsing are only apparent when the exercise is commenced in the fasted state[17] and thus, further research is required to fully investigate the efficacy of this approach. If CHO is consumed in this situation, the source should be from high GI CHO such as glucose or maltodextrins.

Events lasting 1-2 hours – In medium duration events, there is unquestionable evidence that exogenous CHO provision can delay fatigue. Provision of 60 g per hour in the *form* of glucose or maltodextrin is recommended. The form of the CHO is largely dependent upon personal preference and mode of exercise. For example, runners may prefer to ingest this in the form of drinks where as cyclists often utilise CHO gels and snack based foods.

Events lasting over 2 hours – During long duration events athletes may benefit from consuming 90 g.hr^{-1} and therefore this must be composed of multiple transporter CHO. Studies have shown that a glucose/fructose combination in a 2:1 ratio (60g glucose with 30g fructose) improves performance more than the ingestion of glucose alone.[6] Many products are now available in drinks, bars or gels, and it has been documented that such products are well tolerated by athletes.[2]

Conclusion

Although the provision of exogenous CHO during exercise to delay fatigue has been practiced for almost a century,[7] recent advances in our understanding of CHO oxidation rates has provided exciting and fresh ideas. It could be stated that "sugary drinks" are still the key to enhancing athletic performance, although careful consideration to the design of the drink is clearly warranted. Furthermore, in some situations we may not even have to swallow the drink to achieve the performance benefit!

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Lower Limb Asymmetry and Musculo-Skeletal Loading

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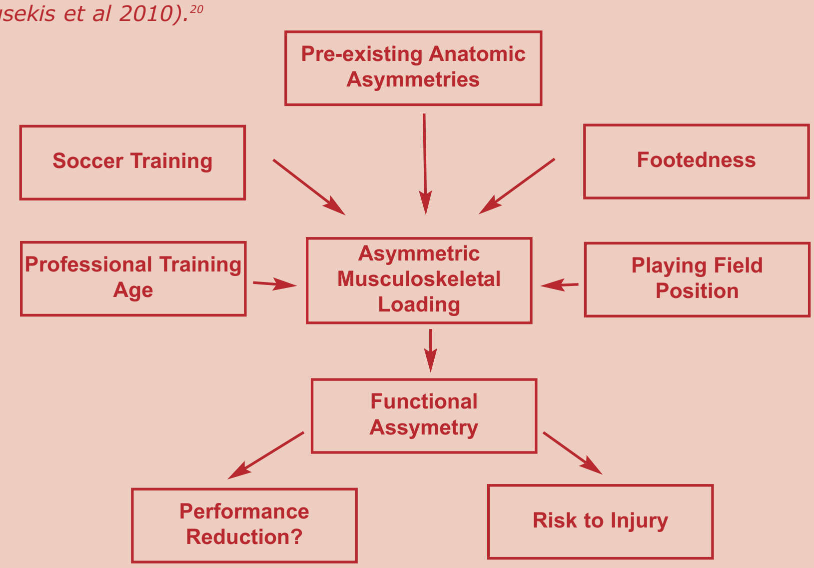
Introduction

The symmetrical structure of the human body is designed for efficient load distribution during functional activity.[23] Anatomic asymmetry alters the distribution and magnitude of mechanical stress within the body,[45] and skeletal imbalance influences the congruity of associated joints. Execution of sporting movement relies upon maintenance of balance and posture during anti-gravitational activity.[40,51] Motor control is subject to lateral bias and conditioning that reinforces bias increases exposure to asymmetric stress.[6,41] A combination of high training volume and mal alignment is indicated as an anatomic risk factor for overuse injury.[1,13,20,42,45,57]

Nature of the Problem

Asymmetric musculo-skeletal development is attributed to the influence of genetic inheritance, limb dominance and environmental stimuli. For the athlete, individuality of physical development is inextricably tied to the development of technical ability in conjunction with exposure to the demands of the training and performance environment. Lower limb muscle imbalance can be addressed with specific rehabilitation and strength and conditioning sessions,[11] however osseous asymmetry of the lower limb may present a complicating factor. Quantification of the contribution of asymmetric intrinsic and extrinsic factors to a dose response relationship within musculo-skeletal loading is problematic. Longitudinal studies relating the length of the femur and tibia to skeletal age have produced data which validates norm values, for growth of the lower limb.[48] However norm values do not allude to the epidemiology of asymmetric development and aetiological research has not focused on lower limb asymmetry during ontogeny in the absence of identifiable pathology. Current research examining the causality of functional asymmetry conceives that pre-existing anatomic asymmetry may influence unilateral lower limb sports performance *(see Figure 1)*.[20]

Figure 1. Theoretical model of factors associated with functional asymmetry in soccer (Fousekis et al 2010).[20]



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Conversely, research that correlates athletes from lateral dominant sports with skeletal asymmetry suggests that asymmetric lower body postures may influence the prevalence and magnitude of asymmetric anatomy.[4] Therefore, where asymmetry is present the success of individually prescribed training intervention relies upon accurate identification and consideration of the relationship between musculo-skeletal loading and individual anatomy.

The strength and conditioning training environment is structured to facilitate optimal musculo skeletal adaptation, however technical practice that subjects the athlete to prolonged exposure to asymmetric stress can effect chronic adaptation.[46,58] The Functional Movement Screen has been developed to identify movement inefficiency requiring clinical or coach intervention.[12] For the lower limb bilateral functional mobility and stability of the hips, knees and ankles is assessed by the 'Hurdle Step' *(see Figure 2)*. Following assessment, accurate identification of the aetiology of functional asymmetry is key to appropriate management of lower limb inequality.

Movement efficiency may be compromised by leg length inequality (LLI) however LLI may manifest through structural or functional inequality. Detrimental biomechanical implications have been documented for the lumbar spine,[27,29] the hip,[28, 30] the knee,[5,22,29,37,47] and the foot.[19,58]

Leg Length Inequality

There are three types of LLI and accurate identification is distinguished by observation of anatomical characteristics rather than symptoms.[35,46]

1 Anatomical short leg

Anatomical short leg consists of an actual difference in length of the bony components of the lower limb. This may be compensated for by a functional adaptation at the ankle, knee, hip or spine.

2 Functional short leg

Functional short leg is not a difference in bone length but an inequality that occurs secondary to a rotated pelvis and is accompanied by associated postural characteristics.

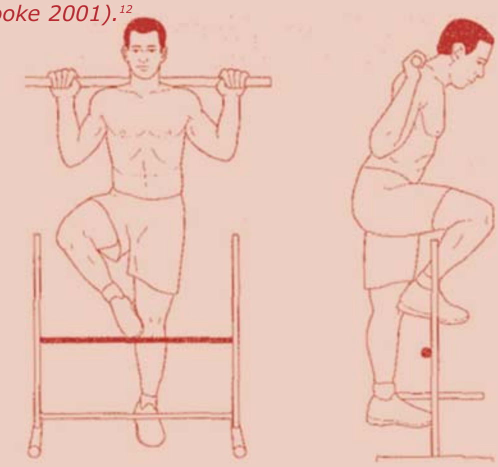
3 Environmental LLI

Environmental LLI is a condition which afflicts road runners where inequality is attributed to the effect of running on a camber.

Incidence

Early research estimated that LLI occurred in between 4% and 8% of the general population,[10,49] but more recent investigation has found that LLI is a normal variant.[22] Knutson's[43] review found that the prevalence of anatomic inequality was 90%; the left leg was anatomically longer more often; and that the mean magnitude of anatomic inequality was 5.2mm. Reports of LLI of up to 10mm[9] are not uncommon; however there is not a stable relationship between magnitude of inequality and clinical significance. Rush and Steiner's study of RAF servicemen,[49] found that differences of 11mm or more were clinically significant whereas Knutson[43] found that for most people, anatomic LLI did not become clinically significant until the magnitude reached approx 20mm. Association with musculo-skeletal dysfunction of the spine or lower extremity has however been found with a significantly lower, (5mm or less) LLI.[23]

Figure 2. The Hurdle Step is used to assess bilateral mobility and stability of the hips, knees, and ankles (Taken from Cooke 2001).[12]



Research implies a relationship between structure and function and suggests that increases in frequency and magnitude of load will magnify the effects of LLI.[57] The implication for the athlete is that training load could cause an otherwise subclinical asymmetry to become symptomatic. This is borne out by evidence that demonstrates that minor LLI can cause significant symptoms for the active athlete,[57] and have a relatively greater clinical significance.[58]

Assessment

Leg length inequality may be detected within the pre-habilitation screening process or during an assessment of injury. Detection and accurate measurement of unequal leg length has been subject to a number of clinical procedures. The instrument most commonly used for anthropometric measurements is the tape.[47] Anatomical landmarks act as points of reference and leg length is recorded as the distance between anterior superior iliac spine and the tip of the medial malleolus.[10] This method attempts to identify anatomical short leg by requiring the athlete to lay supine on a couch during measurement. On the couch the influence of weight bearing on postural characteristics is removed therefore reliability of measurement is enhanced.

Leg length measurements taken in standing athletes measure the distance from superior anterior iliac spine to the floor.[53] This method is unable to measure the discrepancy between the bones of the lower limb but can reveal LLI that presents as a postural manifestation. Asymmetry due to functional short leg may also be identified during assessment that utilises closed kinetic chain exercise or a functional movement screen. Additionally the Strength and Conditioning Coach may become aware of related postural deficiencies when coaching movement. During assessment the reliability of normal standing posture may be compromised by unequal weight distribution through the feet due to pain, therefore injury status must be verified.[19]

Assessment of LLI in lying and standing both depend upon accurate location of superficial bony points and can therefore be prone to inter trial and inter examiner variability.[10,18,31,46] Muscular development or obesity can hinder accurate identification of bony prominences,[26] whilst the effect of inequalities of calcification on one side of the body due to injury cannot be quantified. Inability to palpate the heads of the femur necessitates the use of the anatomy of the pelvis as the proximal

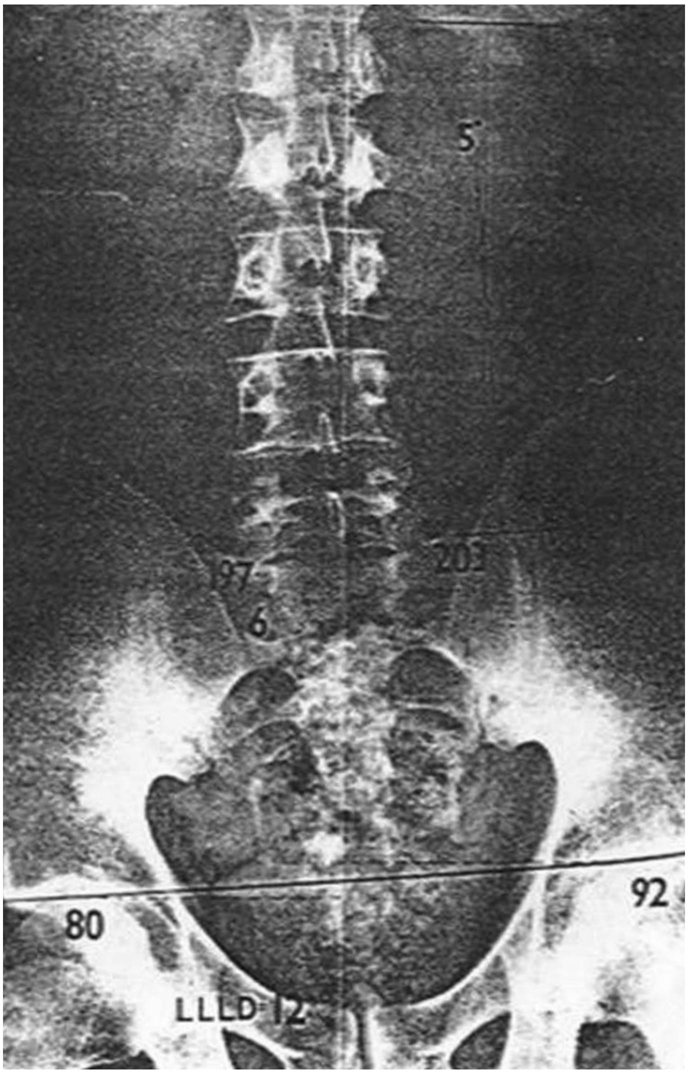


Figure 3. Case A, a 27 yr old male (Taken from Giles & Taylor).[26]

marker. Whilst inclusion of iliac crest palpation as a selection factor may improve the possibility of discrepancy detection, ironically this method relies upon presupposition of symmetry of the iliac.[10]

Examination of the anatomy of the pelvis has found that iliac asymmetries are highly common *(see Figure 3)*.[23,26,41] Attempts to improve the accuracy of tape measurement led to the design of a pelvic levelling device. This was intended to remove the influence of posture on pelvic tilt, however radiological comparison found that this method was also limited by the difficulty in locating anatomical points through subcutaneous tissue.[33] Presupposition of symmetry of the iliac remains a barrier to reliability and accurate measurement can also be threatened by an incorrect attempt to level asymmetric anatomy. Even if the pelvis is symmetric and anatomical landmarks are accurately identified, error can still be caused by the path of the tape through bowing, due to inequalities in muscle girth.[47]

Re-measurement studies have challenged the reliability of measurement with the anthropometric tape, identifying measurement error of + or - 10mm.[23] However orthopaedic examinations continue to use the tape because of its simplicity,[46,50] and research has confirmed that where the examiner is trained and the athlete is asymptomatic the tape method is reliable.[3]

Environmental LLI is less prevalent and may not be identifiable through assessment with the tape. Environmental LLI may be suspected when symptoms of overuse manifest as pain or discomfort in the back or lower limb and persist despite medical therapy. When training history is scrutinised the constituents of training volume may reveal how training progression has contributed to asymmetric loading which exceeds physiological tolerance.

Radiology

Radiological assessment of LLI seeks to eliminate the complicating influence of postural characteristics but examination that focuses upon isolated anatomical features also has limitations. Differences in femoral head height can contribute to an inequality but LLI may also be caused by iliac hypoplasia.[18] Examination of the sacral base has demonstrated that iliac asymmetry does not lead to a discrepancy at iliac levels that is equal to the discrepancy at the femoral heads.[10] The complexity of assessment is compounded by pelvic torsion. Accurate assessment requires identification of the influence of pelvic torsion on the symmetry of the sacro-iliac joint,[17] and whilst pelvic tilt may be identified when the athlete is standing it will usually disappear when the athlete sits.[19]

Pathology

Transient asymmetry has been observed during maturation by Ingelmark,[41] who found that symmetry at adolescence was preceded by a longer right leg at 2 yrs old for 80% of the children measured. Giles and Taylor[26] state that asymmetric growth is common and represents varying rates of maturation between paired bones. If therefore, asymmetric musculo skeletal development is remediated through maturation, this suggests that manipulation of mechanical stress may exacerbate or attenuate asymmetry. Consideration of this mechanism is therefore critical to the development of the talented young athlete where early sport specialisation habituates unilateral movement patterns.

The development of one-sided dominance is an integral component of childhood. One-sided dominance in lower limbs has been shown to correlate with a highly significant difference in limb weight, ($P = 0.001$) suggesting that the dominance of the contra-lateral cerebral hemisphere may contribute to asymmetric development.[8] Comparison of the weight of bone within the limbs has recorded a heavier left femur, (with the left side being considered the dominant lower limb, indicated by preferential use in acts of strength, for most persons) in most instances. Examination of dominant limbs in acts of strength has recorded increased limb weight through muscular hypertrophy, accompanied by accelerated anatomical growth due to increased exposure to mechanical load.[41]

Where there is no difference in the length of the skeletal components of the lower limbs, functional shortening may occur secondary to rotation of the hip *(see Figure 4)*. Functional shortening is attributed to joint contractures and/or axial malalignments, including scoliosis.[46] Abnormal positioning of the hip is due to muscle spasm or abnormal external rotation of one foot, which causes rotation of the pelvis.[35] Limb dominance is a significant contributor to musculo skeletal asymmetry and has significant implications for the long term development of the athlete undertaking technical practice where there is a tendency to favour one limb either for strength or technical execution or both.[20] The evidence in the literature supports the concept of an anatomic functional relationship where asymmetric stress causes musculo-skeletal dysfunction and postural adaptation leads to LLI as a secondary condition.

Research using electromyography has demonstrated a significant increase in the activity of several muscle groups where LLI was less than 10mm,[22] making it impossible to maintain a complete resting position. Whilst analysis demonstrates a possible association between relatively small LLI and asymmetric paraspinal muscle activities,[53] research examining the aetiology of backache presented with common clinical symptoms suggests that for the general population LLI is not a significant causal factor.[19,35]

Biomechanical Implications of Asymmetry for the Sports Performer

Asymmetry of motion segments and muscles create imperfect torsions which manifest as scoliosis deformities.[2] A higher incidence of functional scoliosis has been reported for athletes, the development of which is thought to be secondary to increased unilateral torque forces.[50] Biomechanical assessment of a group of footballers found that in 16 subjects who exhibited a marked scoliosis, 12 of them kicked only or mainly with one foot.[63] Research has found that in swimmers there are adaptive changes in muscles to meet specific repetitive functional demands.[50]

Biomechanical implications compel further study, for research has shown that in functional scoliosis that compensates for LLI, side bending compresses the concave side of the disc and coupled with axial rotation this presents a load that is known to be damaging to the disc.[23] Giles[25] found a significant difference between lumbosacral facetal joint angles (mean=7.1) on the long leg side and the short leg side in patients with a LLI. Friberg's[23] research suggests that asymmetric stress is likely and this may be a cause of chronic low back pain, which could cause further degenerative changes in the spine.

Scoliosis begins to form between the ages of 7 and 10.[41] As LLIs are common in the general population and subtle scoliosis is frequently associated, identification may only be significant for individuals who are subject to high levels of asymmetric stress at an early age.[53] Research suggests that an examination of musculo-skeletal symmetry of the spine for athletes that are subject to asymmetric stress but do not present a LLI, could identify the existence of a causal relationship between asymmetric stress, lower back pain and functional LLI.

As a functional LLI is established the existence of pain and fatigue is attributed to functional attempts to level the pelvis.[56] Research examining the precise mechanics of functional adaptation offers varying explanations. Gurney *et al*[36] suggest that quadriceps activity increases in an attempt to reduce disparity by maintenance of slight flexion during the stance phase, whilst Gofton[30] states that the presence of abductor stress with osteo-arthritis of the hip suggests a causal relationship with LLI due to the increased force exerted by the abductors when weight is borne on the longer leg. Abnormal gait through LLI subjects the hip joint of the longer leg to abnormal adduction stress resulting in osteo-arthritis of the hip joint,[28,30] and leads to a significant increase of arthritis of the knee on the long side which is attributed to over stressing by the hip on the short side.[15,19] LLI has also been linked to the outcome and location of stress fracture.[22] Where the performance athlete is subject to intense exposure to high levels of mechanical stress successful management requires management and/or correction of asymmetric stress that causes anatomic deviation from normal symmetry.[58]

Intervention

Surgical intervention for anatomic short leg during growth is problematic. The efficacy of surgical lengthening is reduced by an inability to accurately predict the resultant rate of growth of the epiphyseal plate, whilst the accuracy of epiphyseodosis is undermined by the ability to ensure cessation of growth prior to permanent fusion.[40] Successful treatment of anatomic short leg relies upon the use of a lift under the foot of the short leg to improve disparity and relieve pain.[23,29,49,55,56] The significance of early identification and intervention is evidenced by age related outcome.

Pre and post natal studies suggest that lateralisation, preference for use of one foot or leg, results from a combination of asymmetric brain development and preferential repetition.[38] Although neuromuscular plasticity remains, children enter movement education with structural asymmetries and differential competence in lateral fundamental motor skills having already developed competence in lateralised preferences, (the choice for one side of the body to learn or perform motor skills).[42]

Examination of young athletes lower muscle morphology has demonstrated significant differences compared to non-athletes. Young athletes exhibit larger mean values for total quadriceps values and although values are similar between sides, individual muscle volumes differ significantly.[59] Tate *et al's* sample demonstrated that in the dominant leg vastus medialis exhibited larger muscle volume, whereas in the non-dominant leg, vastus lateralis presented larger volume, thus inferring a relationship between the development of asymmetric functional efficiency and lateral preference task dependency.[59] Although the development of lateral preference is influenced by

Figure 4. (Taken from Fisk & Baigent).[19]

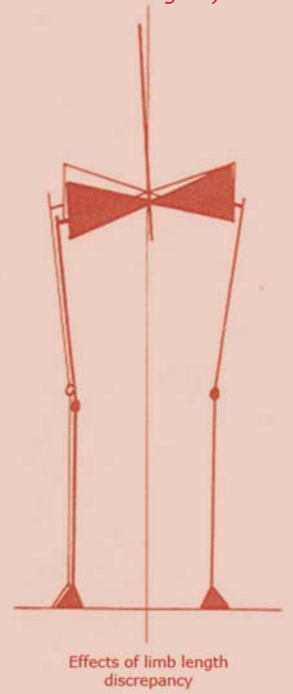
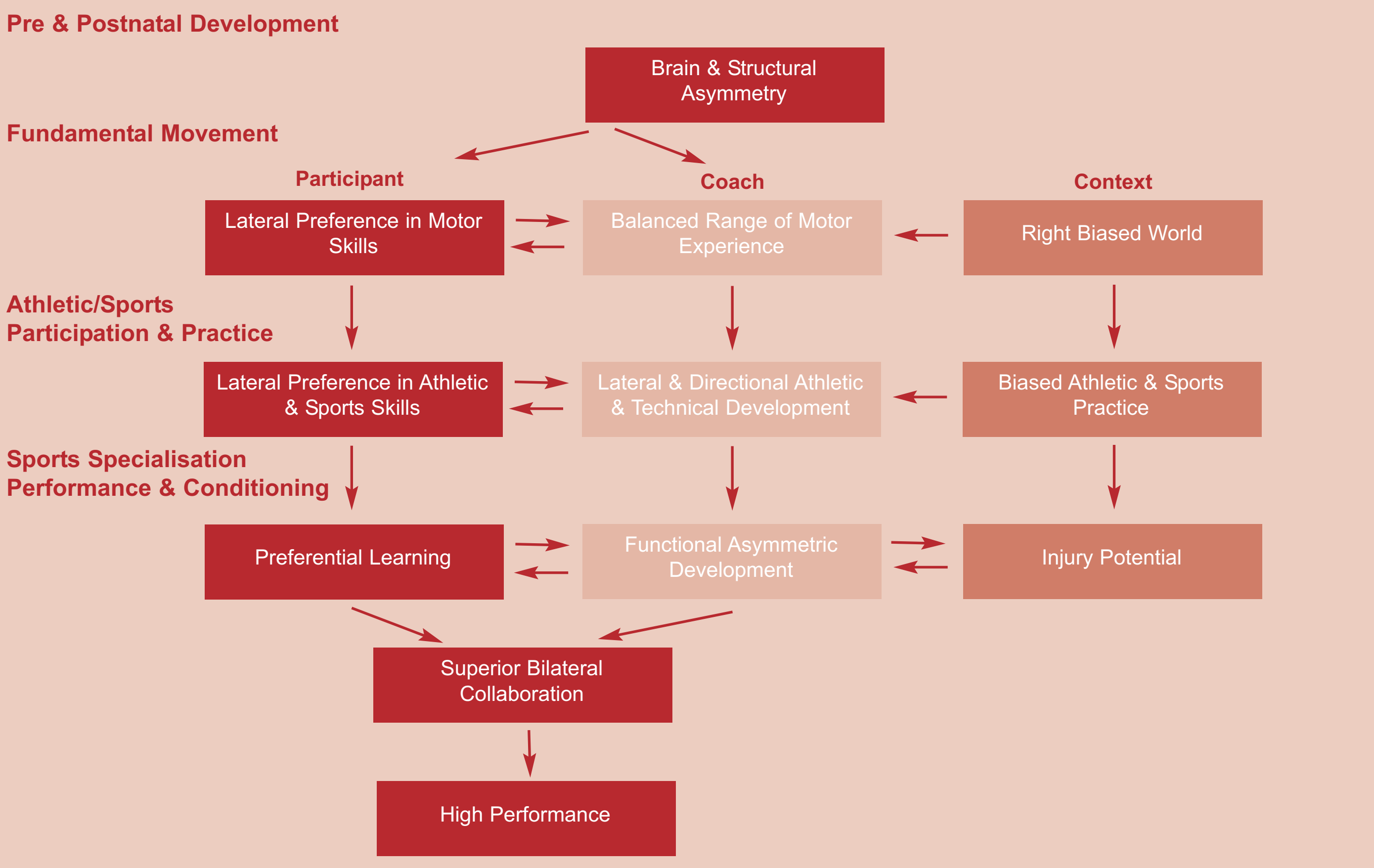


Figure 5. Participant Development Laterality Model Turner 2011, (derived from Kimmerle 2010).[42]



gender, developmental characteristics and task complexity,[7] in the lower limb preference changes due to task complexity, because bimanual foot use requires bilateral collaboration between the mobilising and stabilising functions of each leg. This process poses significant challenge to the coach as s/he works to improve performance.

To aid this process the author has used Kimmerle's Laterality Model[42] to derive a Participant Development Laterality Model (PDLM) *(see Figure 5)* and thus facilitate high performance for both participant and coach. The PDLM demonstrates inter-relationships between participant, coach and context, positions the coach as the pivot in the developmental process, and proposes pedagogic priorities at each stage of participation.

The coach must identify athlete lateral preference and recognise his/her responsibility to expose the participant to a balanced range of motor experience. What the coach may not perceive is the extent to which his/her own lateral preference has been influenced by the right biased world and how this now impacts upon his/her coaching practice.

Pedagogical studies have demonstrated that there is a right bias to demonstration causing athletes to expect demonstrations from the right and to practice more on the right.[42] For the Strength and Conditioning Coach this has specific relevance to practice and s/he must promote optimal lateral balance within training and performance by coaching reps, sets and directional movements that start and finish using alternate side selection. Consequently combinations should challenge right biased athletic and sports coaching conventions that threaten to increase injury potential.

By the time an athlete has chosen to specialise in a specific sport, lateral preference is usually well established and differences between lower limbs may be resistant to structural change.[60] Sport specific demands require performers to develop competent functional asymmetry and a reciprocal coaching style must recognise each individuals physiological, psychological, technical and tactical needs. Ultimately facilitation of optimal performance relies upon skilled stabilising and mobilising function in the lower limbs, through development of bilateral collaboration.[42] This has specific implications for the Strength and Conditioning Coach who must appreciate how coaching intervention can impact structural and/or functional asymmetry of the lower limb.

In cycling, pedalling asymmetry is related to limb preference and the preferred leg tends to be capable of producing greater force regardless of changes in cadence.[7] Symmetry has been shown to improve when performers pedal at significantly higher frequencies or with increased force.[6] In running, symmetry is correlated with level of performance, distance and running speed and reduced by contextual interference from ground surface irregularity.[7] This presents a dichotomy for the Strength and Conditioning Coach for the evidence related to these activities suggests that the appearance of symmetrical kinematics may only manifest towards the extremes of capacity. As a consequence any intervention in technique for the improvement of symmetry must be carefully coached to ensure that increased load in joints, connective tissue and muscles does not increase injury risk. In running, foot pronation compensates for anatomical abnormality by movement of the sub-talar joint to attenuate shock. Therefore one way that the coach can prevent injury is to ensure that each participant does not practice or perform in worn down footwear.[61] This will help facilitate rear foot symmetry and avoid reinforcement of asymmetric stress.[62]

Where a shoe raise is used, results show that the effect on scoliosis seems subject to age related flexibility of the lumbar spine and a positive effect on angle of curvature has been observed.[27] An effective orthotic will reduce pelvic torsion and lower proprioceptive triggers, relieving painful muscular contraction.[43] This remedy must however be used cautiously. Altered joint congruency can lead to contra indication and osteophyte formation in the hip has been shown to hinder replacement of the head of the femur to its normal position with correction by a lift often leading to groin pain.[30]

Ultimately effective management requires accurate and timely identification. When structural asymmetry is suspected assessment should attempt to eliminate leg-length alignment asymmetry due to supra-pelvic muscular hypertonicity (increased tension) before attending to treatment of anatomic leg-length inequality.[44,46] Where hypertonicity is present the Strength and Conditioning Coach may need to work in partnership with a Physiotherapist to ensure release of the paired hypotonic muscle, (the muscle held on stretch). For the corresponding hypertonic muscle restoration of contractile function will then facilitate effective strengthening.

Conclusion

When planning to strengthen sports specific function the Strength and Conditioning Coach must consider the symmetry of musculo-skeletal development and functional demand. Development of fundamental movement skill is essential to build the foundation of balance and motor control and progression to athletic and technical practice must include lateral and directional development. Transition to sport specialisation may then be accompanied by the development of functional asymmetry where strength and conditioning programme design ensures balanced levels of musculo skeletal loading. Functional asymmetry will develop in response to three different types of demand: directional (left vs. right), fluctuating (dominant vs. non dominant) and absolute (left vs. right).[20] Optimal physical preparation will rely upon needs analysis that identifies the kinesiological implications of sport specific functional asymmetry and conditioning that recognises the significance of musculo skeletal loading for the individual athlete.

Where movement dysfunction is present the need for accurate detection of anatomic asymmetry becomes critical. Reliable assessment must examine a range of musculo-skeletal factors. Scoliosis, pelvic tilt, hip, knee and ankle joint asymmetries signify the multifactorial nature of anatomic asymmetry and LLI. For the athlete the relationship between intrinsic and extrinsic aetiological factors demonstrates a process that can be accelerated beyond a threshold value that precludes injury, in response to the level of athletic training and performance.[47] Injury risk will be determined by the interaction between predisposition of the musculo-skeletal system and the level of asymmetric functional demand. Early identification and management of causal factors is paramount for treatment of movement dysfunction with a shoe raise commonly only addressing symptoms once degenerative change has already occurred.

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Utilising A Range Of Motor Learning Methods In The Development Of Physical Skills

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The Strength and Conditioning Coach is responsible for the physical preparation of athletes. This preparation involves the development of a wide range of physical variables, with the relative importance of each depending upon the specific sport involved, and the capabilities of the athlete. It must always be remembered that the aim of the athlete is to enhance their levels of sports performance, and this requires the application of these physical capacities directly into the performance of their sport. Additionally, this has to be performed under the pressure of competition. In this way, an important part of the S&C coach's role requires the development of stable physical skills that are able to transfer directly to competition and withstand the pressures of the high performance environment. Given this requirement for skill development, it is useful for the S&C coach to have a basic knowledge of approaches to skill development. This article will outline three common approaches to skill development and suggest advantages and disadvantages of each approach.

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Characteristics of skilled performance

The precise nature of skilled performance will vary from sport to sport. However, there are a few key characteristics of skilled performance that provide a valuable insight into the role of skill in performance. Expert performance depends upon making effective decisions, or the ability to make the best choice between a set of alternatives[4], and this capacity is critical in sport and draws on perceptual and cognitive skills as well as physiological capacities. In this way, while physical capacities will underpin effective performance, they cannot guarantee a higher level of performance unless they can be transferred. This requires that athletes are able to integrate these physical capacities directly into the sport, and develop high levels of movement effectiveness and efficiency. This is reflected by the fact that higher jump performances can be achieved with a lower EMG activity as skill levels develop,[19] (while typical thought would suggest that higher EMG activity should result in a higher jump performance). Indeed, this efficiency of movement is highlighted by the fact that elite performance has often been presented as an autonomous process, where athlete's movements are highly automated and require little conscious effort of explicit attention to perform and control skills.[4]

However, while this state of automated action may be ideal in performance, it may not promote an ideal learning environment. Ericson,[3] found that experts in any fields rarely let their actions become fully automated during practice. Instead, they find ways of improving the cognitive effort utilised in practice. Cognitive effort is the mental work that leads to high levels of decision making, anticipation, planning, regulation and interpretation of motor performance.[11] Permanent gains in skilled performance capacity are only achieved when cognitive and physical training occur in tandem.[17] This is the concept of deliberate practice, which has been presented as a key determinant of elite performance. Much of the reasoning behind these strategies depends upon the nature of brain function. The brain is fundamentally a pattern forming self-organised system governed by potentially discoverable non-linear dynamical laws.[10] Within the brain the areas responsible for pattern recognition and those responsible for the automation of action are different.[13] This requires the development of synaptic linkages between these areas. These synaptic linkages are best developed where a rich learning environment is provided[2] and where the challenges of cognition and physical actions are combined,[9] helping develop key synaptic linkages required for high level performance. This combination of physical and cognitive effort ensures that the athlete lays down the required neural networks, which underpin improvements in motor performance.[17] Therefore, effective physical development programmes need to encourage and foster cognitive effort, in addition to physical performance. Exercise modalities and coaching interventions that encourage this combination are therefore a key tool for any coach.

Approaches to skill development

A number of approaches to skill development are available to the coach. The most common ones utilised in skill development, and which have been applied to physical training are:

1. The behavioural approach
2. The dynamic systems approach
3. The constraints based approach

Behavioural approach

Behaviourism has evolved out of the work of Skinner[15] and Thorndike,[16] and plays a large role in many strength and conditioning practices. This approach assumes that a response will become a habit as a consequence of the number of times it is associated with a given stimulus.[11] These methods have been typically utilised in strength and conditioning where development of skills have occurred in closed conditions for a given number of repetitions in a blocked and repetitive manner.[6] Behavioural methods can elicit impressive gains in performance in the short term, and athletes achieve a high level of performance in these initial stages.[17] However, they are not as effective for the retaining of skills in the longer term,[11] and particularly in open performance environments. This is especially the case when unusual, difficult or stressful conditions are encountered.[18] Athletes trained in a behavioural fashion do not develop the higher order cognitive skills needed to understand their own performance, and to be able to explain good or poor performances.[17] The behavioural approach can have advantages in terms of developing initial skills (especially when utilising the key coaching tools outlined later), but distinct disadvantages in developing these beyond the initial stages of learning.[6] This lack of cognitive effort during many closed skill exercises is abundantly clear when watching many training sessions, where athletes perform their exercises with little thought required.

However, there are methods by which some of the disadvantages of the behavioural approach can be minimised, and these all involve adding a level of cognitive requirements to the exercises. These involve modifications to the way exercises are structured, as well as through modifications of coaching inputs which can increase the cognitive requirements. The exercise modifications include the addition of variable and random practice to the exercises. Variable practice refers to the practicing of a single class of skills in a range of environments.[6] For example the same agility movements can be practiced over a range of different distances and/or directions. Random practice on the other hand refers to where different classes of movements are combined within the same practice element.[6] For example, where three different speed drills are performed, they are performed in a random order, rather than where each exercise is performed successively for the required repetitions before moving on to the next.

In terms of coaching input, the use of questioning techniques is a very useful tool for the coach. Rather than giving the athlete details on their performance, the use of an effective question requires the athlete to reflect upon their own performance and try to come up with the answer. However, this approach does require a great deal of skill and knowledge on behalf of the coach to be optimally effective. The use of questioning should not be restricted to enhancing the behavioural approach and should be seen as a key tool to develop for effective coaching.

Dynamic systems approach

The dynamic systems approach to motor learning asserts that movement patterns arise from the organisation of the neuromuscular system in response to biomechanical factors, morphological factors, environmental factors, and task constraints.[1] Skill is thought to emerge when the individual is able to control the degrees of freedom of a movement.[10] This method has been proposed as an effective method of developing agility[5] and may also have application in other areas of performance. The dynamic systems approach requires the application of a progressive series of exercises, that sequentially add to movement complexity via freezing, freeing and then exploiting degrees of freedom, as required in sports performance.[17] This approach fits in with the self organising nature of the human brain, and is often used to explain the locomotor development of humans from crawling to toddling to walking and finally running, with the self organisation occurring as a spontaneous pattern formation.[10] This approach can have great potential in developing effective skill learning environments. For example, in terms of agility development, the freeing of degrees of freedom is an excellent method of movement progression, developing basic movements through increasingly open challenges.[6,7,15] However, dynamical systems models tend to neglect, or minimise, the role of cognitions and attention in human learning and the performance of complex movement patterns and skills, which are now recognised as important elements of skill development.[14] Therefore, used in isolation, this method may not allow performance to be maximised in sports where decision making, and the associated perceptive and cognitive requirements, are important.

Constraints based approach

This approach to skill development attempts to combine a number of approaches, and remove some of the disadvantages associated with the two earlier systems.[12] Here three key constraints (organismic, task and environment) interact to determine the optimal patterns of co-ordination and control for any activity.[12] Organismic constraints are those that reside within the athlete, and are the traditional focus of strength and conditioning and include elements such as force capacities, speed capacities etc. However, the application of skill will ultimately also depend upon the environment in which it is performed, and the precise task that the athlete has to perform.[9,12] The environmental constraints will include elements such as playing surface, temperature, wind, gravity etc, all of which interact to determine the nature of skill application.[9] The task constraints include the goal of the task (what the athlete is trying to achieve), the rules that govern the task itself and any specific equipment used in the completion of the task.[9,12] An important benefit if using this approach to look at performance levels is that it highlights the fact that organismic constraints alone will not totally dictate the level of performance. This focus on a specific activity is crucial to effective skill development and emphasises the importance of moving towards a task-based approach.[9] Another important aspect to consider is that this approach involves a perception-action cycle that seeks information from the external environment and processes this to elicit the appropriate response.[12] This model lends itself ideally to agility exercises, as the perception-action requirements are naturally present and developed, and the response specific to the required task, but can also be applied when looking to ensure transfer of other fitness parameters into performance. However, effective use of this approach does have a number of essential pre-requisites. Firstly it requires the athlete possesses the ability to be able to make effective decisions, and this may require a base level of performance prior to it being optimally effective. Secondly it requires high order coaching skills, which can facilitate the athlete making effective decisions, and this must be based upon the coach possessing an intricate knowledge of performance related aspects on which to draw during a session. Similarly, it requires the ability to effectively analyse performance and effectively direct athlete's attention to the key elements that will allow them to make effective performance decisions.

The integration of methods

It is important to remember that each of the above methods have both strengths and weaknesses. These will very much depend upon the training age and capacity of the athlete and upon the skill to be developed. One of the key roles of the strength and conditioning coach is to provide an appropriate learning environment commensurate with the precise requirements of the athlete. As coaches it is all too easy to take an either/or approach, with discussion focussing on which method to use, rather than on how best to combine methods. This either/or mentality also pervades research where, due to the nature of research designs, the focus has largely been on the comparisons between methods, and decision made based upon the sole application of a single approach. In all likelihood the most efficacious approach will be one of integration. Understanding the advantages and disadvantages of all learning approaches can allow the S&C coach to effectively integrate all methods effectively to provide a level of stimulus that maximises skill level performance. This integration can occur through both long term and short term planning. For example, the behaviourist approach can facilitate short term learning, and while this can be the basis of introductory approaches, it can also be supplemented by the other methods, to remove some of the key disadvantages associated with this approach. This combination of approaches can occur within a single session and also within a range of training phases. Similarly, advanced performance requires high levels of cognitive effort and may benefit from the use of constraints led approach, but even at this advanced level, the addition of a behaviourist approach can facilitate the honing of fundamental technique.

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