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While the focus of the last edition was looking back over the previous year, this editorial is very much about looking forward and exploring new developments. With this in mind, this edition sees a brand new development for Professional Strength and Conditioning. Rather than our traditional diverse articles and columns approach, we have produced an edition totally devoted to one element of performance – speed.

Speed has long been seen as one of the great differentials between performance levels in many sports, and how many of us will have been approached with the question, "can you make me faster?" The development of speed is always a prime concern in strength and conditioning, and the aim of this edition is to provide information that will challenge traditional thinking and provide coaches with key thoughts and messages with which to enhance speed training programmes.

In introducing this issue, I cannot overemphasise the role played by Jon Goodwin in its inception, development and production. Jon, who is currently programme leader for the MSc in strength and conditioning at St Mary's University, is one of the real good guys in the industry. Unbelievably hard working and professional, Jon has played a key role in the UKSCA's development and was pivotal in the setting up of the UKSCA's Plyometric, Agility and Speed workshop. The idea of the speed issue came about while talking to Jon and Ben Rosenblatt one evening at the NSCA's National Conference in Orlando. Jon had just given an excellent speed development presentation on behalf of the UKSCA at the conference. This synthesised the latest research into speed development into key take home messages for coaches – ideas that would make an ideal Journal article. As we talked, I hoped Jon would agree to write the presentation as an article for the Journal, but a few hours later this had developed into devoting a whole issue of the Journal to speed. Jon's drive, enthusiasm and persuasive powers were immediately evident, with Ben immediately commandeered to produce an article. Numerous phonecalls, writing and editing hours later, the result is the current issue.

The articles themselves address a wide area of speed development. Jon's article investigates the limits to maximum speed expression, and provides key take home messages for coaches. Jared Deacon, a past national sprint champion, has produced a piece that covers acceleration, from both a theoretical and applied perspective. This also provides excellent hands on

advice for developing effective acceleration capacities. James Wild and his colleagues from St Mary's, have written an article that covers the biomechanical aspects of acceleration and maximum speed, and similarly produce excellent training advice based on this analysis. The development of physical capacities is a key part of speed training and Ben Rosenblatt's article looks at the application of weightlifting techniques to speed development. One of the challenges in speed development is how to programme this training appropriately. Nick Cooper, an experienced track and S&C coach, addresses this issue and makes some excellent recommendations as to how to optimise the programming of speed training. Finally, the interview this month is with Michael Afilaka, a highly knowledgeable and experienced UKA track coach, who gives some excellent insight into speed development at the elite level.

The next edition will revert to the traditional format, but if the feedback on this special edition is favourable, then future editions may be able to cover specific topics. Members are encouraged to feedback on the issue and to suggest future special edition ideas.

Ian Jeffreys

Editor

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Maximum Velocity is When We Can No Longer Accelerate

Using biomechanics to inform speed development

Jon Goodwin, MSc, PGCHE, ASCC, CSCS

A strength and conditioning coach's toolbox is packed full of skills from a wide spectrum of specialities. An awareness of physiology informs our understanding of adaptation through gene expression and metabolic function; skill acquisition informs our practice structure and coaching behaviour; psychology does some of the same and helps us improve relationships, adherence, motivation and manage arousal. All these things are essential, but for me the biggest area that informs my grasp of strength and conditioning is biomechanics. In particular in the development of an explicit motor ability such as sprinting, almost all of my coaching decisions, bar the importance of cycling of stress, are informed by biomechanics. An example is the way in which we characterise what maximum velocity sprinting is. It may seem like an obvious statement and it's not a typical definition, but maximum velocity sprinting is when we can no longer accelerate.

Accelerating to maximum speed

The reason this statement is important is that it focuses on the difference between accelerating and maximal sprinting. Again, not that it is something that coaches don't consider, but it is a mechanical consideration of the differing constraints of these two skills that should eventually inform coaches of the limiting factors to performance and therefore, the beneficial qualities we need to develop in our athletes. To enable us to progress with this analysis we need to set the basic ground rules. Fortunately, Newton did the job for us many years ago and gave us some simple rules that work consistently on the scales we are talking about here. We only generate some acceleration, either linear or angular, when we have a force applied to us from the external environment. Further, the acceleration we see is specific to the direction and magnitude of the force applied.

In considering these rules we need to understand the environmental constraints that restrict our motion. Essentially, there is only one constraint that we are continually subject to – a gravitational force causing a linear acceleration towards the earth of $9.81 m/s^2$. Bearing this constraint in mind, our athlete needs to set about achieving their movement goals in as short a time as possible. Principally, this means providing the maximal rate of acceleration in a horizontal (with respect to the earth) direction.

So, there is a simple performance predicate for our athlete. With a limited capacity for leg extension force production, they need to apply as much force as possible, as quickly as they can in a horizontal direction. More specifically, they need to accumulate horizontal propulsive impulse at as high a rate as possible. In an ideal world this means aligning the limbs to apply force most effectively in a horizontal direction only. However, with our initial constraint of having to overcome gravity, this is not possible. Our limbs have to be directed such that our force production has a vertical component large enough, so that in the stance time available, they develop sufficient vertical impulse to halt the fall towards the earth and project the athlete into the air for long enough to reposition the limbs for the next step *(Figure 1)*.

Jon Goodwin is the Programme Director for the BSc and MSc programme in strength and conditioning at St Marys University College and a UKSCA tutor. He has been involved in coaching athletics and strength and conditioning for over a decade having worked with athletes at all levels of performance. Jon is also currently a PhD candidate at Imperial College researching sprint mechanics.

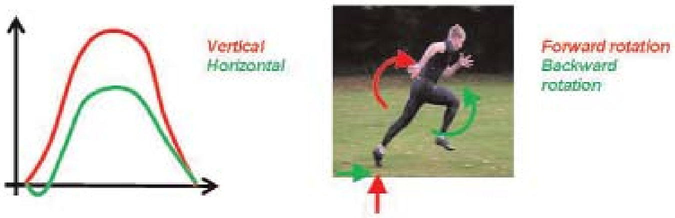

Figure 1. Force production and resulting rotational torques during acceleration.

Many coaches are confused by rotational components of motion at this stage, however analysis of rotation here is straight forward. Rotational acceleration can only be caused by external forces applied at a distance from the centre of mass. Therefore, the only forces able to cause rotation are the horizontal and vertical reaction forces experienced at the stance foot *(Figure 1*). Increased leg extension force means that a flatter angle of push is possible since the vertical component can be retained at a sufficient magnitude, whilst the larger remaining force is directed horizontally. At this stage we end up with several important practical outcomes:

1. To allow rotational control, the angle of forward lean achievable is directly dependant on the pushing capability of the athlete through triple extension of the lower limb. More leg extension force means that, after overcoming gravity, more force is 'left over' to be directed horizontally. With a larger horizontal force the athlete must lean further forward so that the rotational torques about the centre of mass are balanced. An important coaching implication here is that it is probably inappropriate to push weaker athletes to try to achieve a classic 45° angle of body lean since they are physically incapable of doing so, lacking the necessary force production capabilities. That is to say, the angle of body lean is a consequence of force production ability, not vice versa.
2. To maximise the capacity to express horizontal impulse we should minimise (within the constraints of our limb recovery rate and mechanical capacity to express force) our flight time, so that we spend more time on the ground expressing propulsive forces and less time floating in the air undergoing no horizontal acceleration. This is evident in athletes with approximately a 50% larger relative proportion of stride time spent on the ground during acceleration phase compared to maximum speed.[2]

Understanding the progression to maximal speed is therefore an exercise in tracking changes in the movement outcomes we wish to achieve, along with the constraints placed upon us. Whilst our aims remain unchanged (to accelerate horizontally at as high a rate as possible), our constraints progressively change from this point forward. Gravity continues to impact our athlete in a stable and predictable manner, but the velocity of horizontal travel as we accelerate is rapidly changing. Considering that athletes have a fixed limb length and therefore limited contact length, (CL – the distance travelled by COM whilst the foot is in contact with the ground – basically, how far you reach out in front and push off behind. *Figure 3.)*, means that ground contact time of the athlete is progressively going to be reduced. The outcome of this is straightforward, considering the time dependant force generating capabilities of the musculoskeletal system. With a limited capacity for rate of force development, as contact time is progressively reduced then the ability to express leg extension force is similarly reduced. This is combined with the fact that peak vertical force must progressively increase as the vertical impulse necessary to generate a flight phase needs to be generated in shorter and shorter times as we approach maximal velocities *(Figure 2)*. As peak vertical RFD is reached, and peak vertical force fails to rise further, the athlete will progressively lose vertical impulse as ground contact time continues to fall, gradually causing a reduction in flight times as we approach maximal velocity.

Our athlete is then on an inescapable route to a limit velocity. This limit velocity is theoretically described as the point where contact time is so short that all of our leg extension effort must be directed vertically to do the job of overcoming our downward acceleration due to gravity. At this stage we are passing over the ground so fast that we have no remaining leg extension force and so are unable to provide any acceleration. In reality, athletes cannot reach this point but getting close to it is our coaching target. This inherently means minimising braking and propulsive forces during stance such that contact time can be minimised. The question then is, can we further increase our rates of force production on landing, whilst reducing the horizontal force component such that all effort can be directed at reducing contact time *(Figure 2. Question mark)*? This mechanical description is visible in practice where sprint performance is strongly related to the expression of required vertical impulse in less time.[8] In practice, minimising ground contact time is a function of increasing the stiffness response of the leg and more specifically, the knee and ankle.[1,5] This brings further practical implications to the fore:

3. Attempting to coach athletes technically to increase their push off or drive phase of their gate cycle is rooted in trying to cause horizontal propulsive phase to dominate over braking forces. This is tantamount to coaching athletes to be trying to continue to accelerate. It should be apparent that attempts to force further acceleration when an athlete is running at maximal velocity can only result in suboptimal stride mechanics and reduced performance. At some point we have to accept an athlete is at maximal velocity and therein rehearse mechanics that are optimised for constant velocity running i.e. not trying to continue to accelerate. At this point, a long push off does not appear to represent the appropriate strategy, a point which concurs with evidence that sprinters start reducing their force production once the support knee passes under the hip.[6] This idea is in line with the popularisation of a coaching focus on 'front side mechanics' and leads us away from coaching cues to focus on full extension of the stance leg in the latter stages of stance.

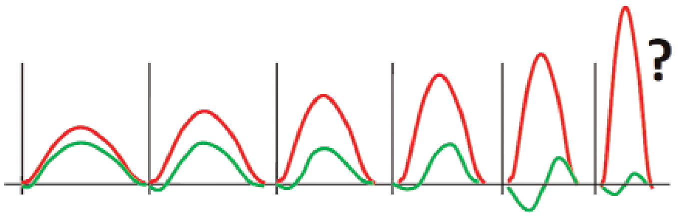

Figure 2. Changes in general ground force profile through acceleration to maximal velocity.

4. With stiffness capabilities of the leg being essential, we need to consider the avenues available for enhancing general function to achieve this. Key outcomes to do this include increases in eccentric and maximal isometric strength, improvements in pre-activation and motor unit co-ordination and optimised tendon compliance. Importantly, qualities such as power are likely less important here since little of the force production about the ankle or knee will take place in the concentric domain. This is in contrast to the acceleration phase where active muscular power production around the knee and ankle is likely to play a larger role.

Why stride length and stride rate are limited tools

Importantly, in trying to describe meaningful variables that define running velocity, we require two variables to incorporate both displacement and time. The most common pair of variables to coaches are stride length and stride rate. The multiple of these variables offer a mathematically precise and appealing description of running velocity. This is based on an assumption that stride length and stride rate are not just mathematically related to running velocity, but are causal in nature. This is an assumption that appears likely to hold little weight, and with regard to coaching these variables, may well have limited value. Stride length is largely a function of flight time and velocity (athlete undergoing projectile motion) with contact length delivering the additional distance. Since flight times are largely fixed during sprinting, regardless of ability,[9] this means stride length is largely a function of the velocity of the athletes during the flight phase. This is to say that stride length is best considered a function of velocity rather than the other way around. Similarly, stride rate is a function of contact time and flight time, making contact time the primary determinant of cadence. Additional practical implications are then:

5. Strategies to directly impact on stride length offer limited resolution of stimulus and adaptation and are likely to lead to sub optimal outcomes. Commonly, athletes trying to increase stride length do so by adopting over striding mechanics. Equally, technical practices to increase stride rate are likely to result in reduced ground forces and sub optimally shortened flight times.

What remains is a demand to uncover a partner variable to associate with contact time, such as to be able to describe velocity. Since the stance phase represents the only time where external forces other than gravity can be applied to the athlete, logic leads us to this period. In fact the answer comes from analysing assumptions made earlier in this discussion. Previously, contact length was assumed to be anthropometrically fixed (i.e. the longer your legs, the longer your contact length). This however, is not strictly true, since athletes can modify their contact length by travelling their centre of mass at different heights and altering their hip and knee angles at ground strike and toe off *(Figure 3.)*. The relation between contact length and contact time would appear to be useful from a coaching perspective since it offers causal mechanisms at which coaches can direct training stimuli and intended adaptations, which, with regards to reducing contact time, have been listed already. In relation to contact length, we need to consider the mechanical demands created by using longer contact lengths.

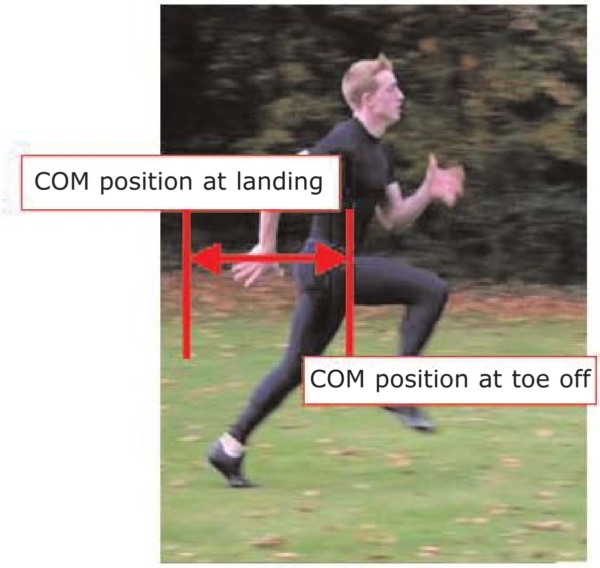

Figure 3. Contact length. Distance travelled by the centre of mass during stance. A lowered centre of mass height will increase contact length.

If the leg is considered to operate in a similar manner to a spring, *(Figure 4.)*, and to reduce ground contact time we are training this spring to have the potential to be more stiff, then increasing the stiffness and increasing the contact length both have the effect of increasing the work done in the horizontal direction *(Figure 5.)*. Clearly this has negative implications and is a primary reason why typical coaching strategies involve minimising the contact distance in front of the centre of mass. However, the leg spring is asymmetric in its behaviour (behaviour in the first and second half of stance is not identical), and braking forces on landing are not solely the product of the contact

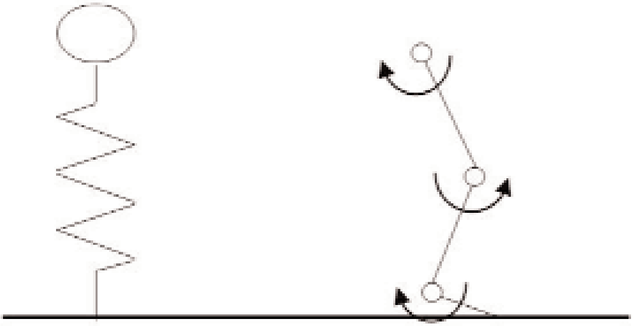

Figure 4. Spring mass characterisation of the leg compared to torque driven joints in triple extension.

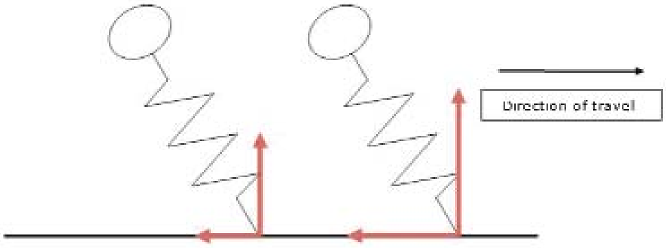

Figure 5. The problem of having a super stiff spring. Horizontal forces are increased and we see unnecessary deceleration in early stance and reacceleration in late stance.

distance in front of the centre of mass, but also of the capacity to drive the leg spring backwards on landing, (potentially a function of the magnitude of hip extension velocity and force produced just prior to and following landing). Potentially therefore, power production about the hip may well reduce the propensity for braking force production and allow the maintenance or even extension of contact length which, when combined with abbreviated contact times, will directly allow higher velocities of travel. The role of hip power in addition to knee and ankle stiffness has previously been discussed in the research literature[4,5] and is described in another article in this edition.

6. Modalities to enhance power output around the hip might complement those focussed on knee and ankle stiffness. Common choices might typically involve activities such as deadlifts, weightlifting, plyometrics or special strength exercises like hip thrusts.
7. Contact lengths need only change by 1-2cm to have a substantial impact on sprint time, all else being equal. Athletes already operating at subtly longer contact lengths would more likely benefit from stimuli focussed at reductions in contact time, or vice versa. Attempting to make technical changes to these variables is likely to drive the athlete unnecessarily into a cognitive state when their current movement choice may simply be the result of the distribution of their strength qualities and their ability to cope with this. For this reason, modifications are often likely better driven by changes in strength qualities as opposed to attempts at direct technical intervention.

Theoretical rationales for sound technique

Having made an attempt to understand the global limiting tasks at hand, we need further analysis at a musculoskeletal level to grasp the internal mechanics that will allow the body to achieve its required force output. Importantly, this ties to the mechanical considerations of technique, an area more familiar to most coaches. Technique, or our movement kinematics, has no direct function since it does not contain information of the forces governing whole body motion. However, secondarily our movement kinematics impact on our kinetics, on the forces we are able to express through our musculoskeletal system and the stresses our tissues are placed under. Analysis of sound technique must therefore be rooted in explanations of how technical modifications will either enhance ground force production, manage the distribution of rotational kinetic energy, or reduce stresses likely to lead to injury. Rationales as to these outcomes can be reasonably made for a majority of common technical coaching cues, and along with such analysis comes additional programming implications for the strength and conditioning coach. These will be the subjects of a later article.

Understanding coping

Athletes come to sprint training with a range of functional limitations. Classically, general sprint related strength and conditioning programmes, if holistic in nature, result in the progressive removal of limiting factors. However, this approach lacks specific focus and therein suffers a degree of inefficiency. Whilst many technical issues can often be corrected with a simple cue during sprint training, many others are the result of general functional inadequacies. In such cases, the track may not represent the best place to make corrections, and instead athletes' specific weaknesses should be the focus of attention. Strength and conditioning coaches need to develop observation and analysis skills to 'see' how athletes' movement strategies during sprinting can often highlight their specific weaknesses.

Examples include:

- athletes adopting over striding mechanics because they lack the knee and ankle stiffness qualities necessary to tolerate briefer contact times. Over striding mechanics represents a strategy for them to obtain longer contact times.
- athletes with longer contact lengths and a hip dominant running pattern at maximum speed (high maximum velocity built on hip power production), but lacking the knee and ankle pushing strength necessary during starting (relatively poor acceleration ability).
- athletes popping up early in a drive phase due to a lack in general leg extension force capacity.
- athletes who accelerate technically well but lose knee lift during late acceleration due to a lack of hip mobility.

Most of our athletes exhibit some type of coping strategies in their movement and it is the role of the S&C coach to see these and be able to analyse them appropriately. This allows focussed S&C programmes to be deployed that will not only prepare the athlete in a general way for performance, but specifically eradicate the limitations that cause the athlete to seek out movement strategies to cope.

Why running faster is not the same as being a faster runner

Similarly, understanding athlete coping strategies can help us to interpret the findings of research studies in the area. For example, Brughelli *et al.*[3] recently demonstrated that as athletes approached top velocity, the horizontal propulsive ground forces they produced increased. They concluded therefore, that the production of horizontal force was central to peak maximal velocity running. However, this implies that the changes seen in running mechanics when running at 80% and 100% of top speed represent the same mechanical outcomes necessitated to improve maximal running speed by 25%. This seems unlikely since it only describes the comparative control strategies of runners at a range of speeds, when they are under varying relative force production constraints. An alternative interpretation of these findings is that at submaximal constant velocities (treadmill running at a constant 50%, 60%, 70% etc of maximum speed), athletes are easily able to manage their vertical force production demands and so develop minimal braking forces. This likewise means they also have no need for propulsive forces to maintain their constant speed. However, when travelling at velocities approaching and including maximal sprinting, the task of developing appropriate vertical impulse becomes a limiting challenge for the athlete, leading them to increase braking and propulsive forces to allow velocity to be maintained by stalling the impending reduction in ground contact time. The appearance of increasing propulsive impulse when running at higher constant

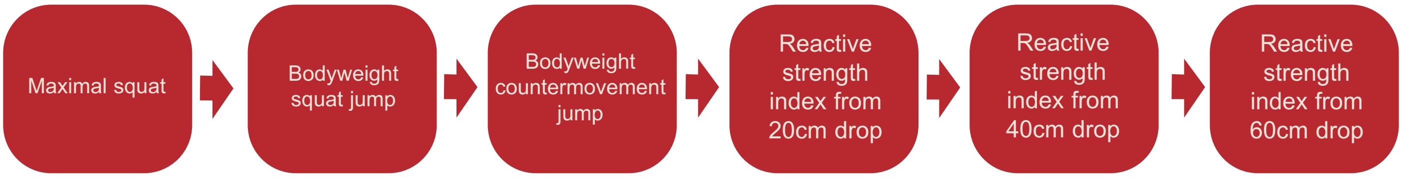

Figure 6. Leg extension force production under varying constraints.

speeds is therein a marker of attempts to cope with abbreviated ground contact time, and of approaching limit velocity in athletes. Similarly, a trend in this study for peak vertical force to increase little at 80% and 100% of maximal speed concurs with the fact that flight times are reduced in absolute terms at higher velocities. It would seem that an inability of athletes to continue to increase peak vertical force production gradually reduces available vertical impulse until airtime reaches a practical minimum. The athletes cannot run any faster because they won't be able to generate sufficient airtime to recover their swing leg.

Where is your athlete now?

Designing effective programmes for individual athletes is a function of both understanding the demands of their sport and also their current developmental status in relation to those demands. Examples are given here of some simple strategies to glean a manageable grasp of the athlete's status that might input to the design of the programme. These examples are based on a demand for coaches to understand the status of their athlete with the constraints of both restricted time and restricted access to laboratories or expensive testing equipment and expertise.

Triple extension ratios

The capacity to express leg extension force under varying constraints is a function of the athlete's local muscular and central nervous system status. Assessing the athlete's ability to express force under various constraints can inform us of the status of these systems. *Figure 6.* illustrates a continuum of leg extension constraints. Interpreting these is a process of consideration of muscle mechanics and neuromuscular function. General normative values for these ratios are not presented here since they should generally come from comparisons within homogenous groups. That is to say you should compare your front row forwards to one another in your cohort and across players of similar ability in your sport setting, and not to a general population or a population of non-specific athletes.

Ratio 1 – Squat to squat jump – Higher ratio means issues with rate of force development and/or with force production at higher contraction velocities (power).

Ratio 2 – Squat jump to CM jump – Lower ratio means issues with rate of force development.

Ratio 3 – CM jump to RSI from 20cms; RSI from 20cms drop jump to RSI from 40cms; RSI from 40 to RSI from 60cms – maintenance of the ratio indicates the capacity to deal with eccentric demands. At some point this ratio increases substantially when the higher height exceeds the capabilities of the athlete. If the ratio elevates substantially in the CM to 20 ratio, this represents poor eccentric control. If it remains more stable through to the 40 to 60 ratio, or even the 60 to 80 ratio, then better eccentric control is being exhibited.

Across this series of ratios, a picture is built up of the athlete's abilities from maximal strength to RFD to eccentric/reactive ability. This can inform programming decisions as to the general developmental needs of the athlete.

Joint function ratios

Similarly other ratios can inform the relative nature of your athlete's capabilities and therefore where their weaknesses may lie. In all cases, vice versa ratios indicate a flip in the relationship described.

Ratio 1 – Split squat to back squat – A high ratio indicates excellent steering control about the lower limb joints.

Ratio 2 – Deadlift to squat – A high ratio indicates the back and hip outperforming the knee in relation to maximal strength.

Ratio 3 – Contact length to contact time – A high ratio indicates hip function dominating over the capacity to generate stiffness at the knee and ankle.

Ratio 4 – Bound distance to repeat hurdle jump height – A high ratio indicates hip function dominating over the capacity to generate stiffness at the knee and ankle. Distances are normalised to leg length in this example.

Driving change through strength and conditioning

A better understanding of the constraints placed on the athlete during maximal sprinting and what factors may individually restrict performance, enables the strength and conditioning coach to make more efficient programming decisions. Importantly, to better inform coaching decisions and to optimise our organisation of exercise selection, we need more sport science research on training modalities and exercises to better describe the torque demands and EMG responses elicited. Nonetheless, in the absence of sufficient evidence it is incumbent on coaches to apply some basic science, common sense and experience to determine an appropriate strategy to achieve desired adaptations. In this vein, some coaching supposition leads here to recommendations on general athletic development for speed.

Commonly our general triple extension leg strength is deemed key and is a focus of most strength and

Lifting	**Lifting**	**Running**	**Plyometrics**
• Split Squat • Back Squat	• Deadlift • Front squat	• Contact length • Contact time	• Normalised bound distance • Bounce height

Figure 7. Leg extension force with differing joint emphasis.

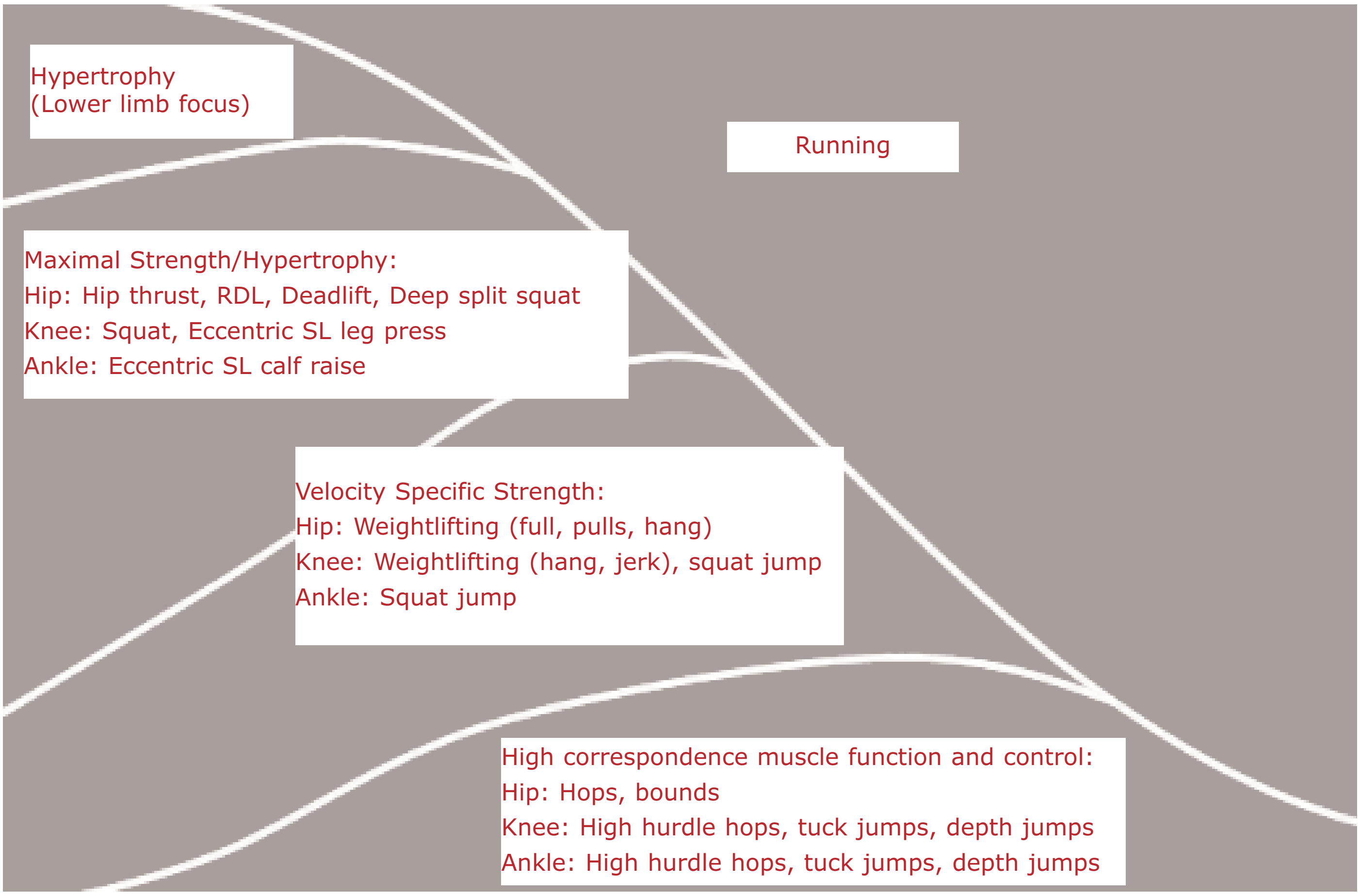

Fig 8. The shift of emphasis in general training.

conditioning programmes. A simple example of where this general strength development becomes evidently appropriate is in the clear relationship between muscle mass and maximal running speed across a heterogeneous group of athletes.[7] However, considering the foregoing discussion, greater precision in our choices is necessary to benefit athletes on an individual basis. Therefore, without considering athlete specifics, injury prevention or the cycling of stress, some simple general recommendations might include a periodisation of exercise selection as highlighted in *Figure 8*. Here the time frame is open to scaling and the starting percentage of time spent on S&C over running is not identified, (the figure does not represent 100% of training being S&C based at the start). About the hip, the exercise selection tends towards the end production of high power outputs, whereas about the knee and ankle it focuses on the development of stiffness. It is important to note that these exercise selections and classification are, in the absence of a strong body of research on the characteristics of training activities, (an area of sport science that needs to be addressed), based on a basic grasp of functional anatomy and fundamental biomechanics. Equally, the nature of progression is driven fundamentally by the most common traditional pattern of building structure to underpin strength, followed by power and speed.

In addition to a general periodised model of activity, progression is the consideration of programming designed to tackle the relative strengths and

	Hip function (End goal – Power)	**Knee/Ankle function (End goal – stiffness)**
Structural development	Nordic hamstring, RDL, Bulgarian split squat, single leg deadlift	Eccentric (>1RM load) single leg calf raise, eccentric SL leg press, squats
Maximal Strength	Deadlift, hip thrust	Squat
Rate of force development	Isometric hip thrust, knee flexed good morning, isometric hip thrust, starts from crouch	Weightlifting jerks, clean, snatch (power catch), explosive step up, starts from crouch
Power	Hang clean, hang snatch, heavy sledge accelerations (20-30% speed loss)	Weightlifting, squat jump, band/chain squats, heavy sledge accelerations (20-30% speed loss)
Reactivity/Eccentric control/Preactivation	Hops and bounds (distance focus), run drills e.g. straight leg pull and B skip patterns, lights sledge sprints (<10% speed loss)	Tuck jump, bilateral high hurdle hops, run drills, e.g. A skip based patterns, lights sledge sprints (<10% speed loss)

Figure 9. Activity selection focussed towards athlete weak points

weaknesses highlighted through the ratios discussed above. An example template of appropriate exercise selection is provided in *Figure 9*. It is worthwhile to note that these examples do not make substantial consideration of transverse and frontal plane control issues, nor specifically of any injury prevention focus as these are beyond the scope of this article.

Conclusions

Athletes' physical performance is a function of their learned motor pattern and their ability to cope with physical limitations such as range or access to force. Improvement in speed can be delivered through coaching strategies directed at both of these issues. However, efficiency of programming is likely to be substantially enhanced by considering the mechanical constraints of the sport situation and therein better understanding the likely nature of adaptation necessary to enhance athletes' abilities to cope with these restrictions. This requires not only more detailed consideration of the mechanical constraints of the task, but also the current adaptation status of the athlete, to allow more directed application of training stimuli. Just getting stronger will almost certainly enhance performance to some extent, but attempts to remove the specific limiting abilities that are constraining force production in the task at hand is likely to have a much more productive

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UKSCA 7th Annual Meeting

2011 Call for Scientific/Applied Case Abstracts

The 7th UKSCA Annual Meeting is to be held at Stirling Management Centre, Stirling University, Scotland, and once again promises to be the leading Strength and Conditioning event in the United Kingdom in 2011. Yet again the Association has managed to secure some of the world's top scientists and coach practitioners to disseminate their knowledge, experiences, and skills to all those who attend this most informative and enjoyable event. However, do not miss your chance to contribute to this exciting conference! Once again in 2011, we hope that the scientific/applied-case poster section will draw upon the growing success of previous years, show casing the outstanding work of our members, and again prove to be a valuable opportunity for individuals to present their work to colleagues and peers.

The UKSCA are now accepting submissions for Scientific and Applied Case Abstracts for the poster section at the 2011 meeting. We strongly encourage all members – beginning investigators and established investigators alike – to submit poster abstracts which they feel will add value and be of interest to all those who attend the conference. Posters will be displayed throughout the conference proceedings, with awards offered to the most outstanding submissions.

Submit an abstract electronically to ***duncan.french@northumbria.ac.uk***. The deadline for abstract submissions is June 3rd, 2011. Abstracts should not exceed 400 words in length, and should be presented with the sections: Purpose, Methods, Results, and Conclusions. Abstracts are considered from all scientific and research fields, in addition to any practical applied case study examples from the field of coaching and sports performance.

The first author of the poster is considered the primary author, and must make every effort to present the abstract at the meeting. One person may be the primary author on a maximum of two abstracts. Only in exceptional circumstances will posters be accepted without the lead author present at the conference.

Those who submit abstracts will be notified regarding acceptance/rejection in advance of the event. Abstracts accepted will be informed of appropriate formatting requirements. For questions concerning any aspects of abstract submission, please email ***duncan.french@northumbria.ac.uk***.


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Programming for Speed

Nick Cooper BSc, ASCC

The ability to enhance an athlete's speed is a fundamental component of strength and conditioning practice. A common feature across a number of sports that we frequently see is athletes who plateau in their speed development. Typically, the ensuing outcome is a call for 'speed gurus' to be brought in to provide an immediate fix and enlighten those with limited previous knowledge or experience to the 'secrets' of speed development. This is often followed by the breakdown of a simple philosophy of sound practice and a multi factorial consideration for athletic development.

Good strength and conditioning practice should ensure all physical characteristics required to support improved performance are developed in a considered and progressive manner and effectively 'dove tailed' into sport specific technical and tactical training. Often when a 'speed guru' delivers specific training sessions, it is carried out without due consideration to the current development of a group of athletes or an understanding of the relevance to the sport in question. The technical model of acceleration and top speed running for a 100m sprinter accelerating from a static, crouched position in starting blocks, may not necessarily translate to a football player accelerating from a moving, upright position, although many fundamental training ideas may still be relevant.

This article will present some of the key considerations for the development of acceleration and linear running speed and offer rationales for key decisions that can be applied across a range of sports. It will assume an athlete is experienced in following considered strength and conditioning programmes and has reached an appropriate level in both movement skill and tolerance to load, in a range of general strength and power exercises.

Given that top running speeds generally occur between 30m to 50m, in non linear sports such as football, rugby or hockey, it could be argued that acceleration is more important than achieving top speed. An athlete's ability to produce maximal force (muscular and ground reaction), in a short period of time relative to their body weight will determine their ability to accelerate. If we consider some of the common attributes demonstrated by elite level sprinters, (male 10.5 seconds for 100 metres, >4.0seconds static 30m, 2.8seconds flying 30m / female 11.5 seconds for 100 metres, >4.3seconds static 30m, 3.1s flying 30m), we see a number of key features. These include: an emphasis on ground contact time with no reduction in flight time or time taken to reposition the swing leg, an improved relative force production, dynamic eccentric muscle actions, an ability to tolerate greater vertical ground reaction forces and to generate hip flexor and extensor force through greater range, all of which supports our theoretical understanding of acceleration.

Strength training for speed can be split into two distinct categories:

1. General preparatory exercises
2. Specific preparatory exercises

General preparatory exercises support the development of speed by building robustness and an ability to tolerate repeated rapid, high force movements and by expressing movement patterns and muscle actions similar to those shown in running.

Typically the general preparatory exercises would involve concentric/eccentric muscle actions in movements utilising triple extension of the ankle, knee and hip. These movements would generally be high power type exercises and are intentionally not running specific. Examples of which are shown in *Table 1.*

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Category	Exercise	Sets	Reps
Olympic lift variation from hang position or blocks	Hang clean, hang snatch, jerk from blocks, clean from blocks	4-6	3-5
Dynamic bilateral lower body	Explosive squats, loaded jump squats, band squats	4-6	3-5
Dynamic unilateral lower body	Explosive step ups, loaded hops, split squat jumps, band step ups, loaded single leg landings	4-6	3-5

Table 1.

Exercise Category	Exercise	Sets	Reps
Posterior chain	RDL, nordic curls, deadlift variations from floor or blocks	3-5	8-12
Trunk, hip and hamstring	Hip lift variations, airplanes, single leg RDL, single leg deadlift, single leg squat variations	3-5	10-20
Lower limb	Sand walking or dragging variations, calf raise, loaded isometric calf, ankle hops, eccentric calf	3-5	20-30

Table 2.

Exercise Category	Exercise	Sets	Reps
Technical acceleration	Drive runs, block starts, 3 point starts, falling starts	1-2	4-6
Resisted sprinting	Sled pulls, towed accelerations	1-2	4-6
Plyometric	Bounds, hops	1-2	4-10

Table 3.

Olympic lift variations offer the athlete an opportunity to generate high force production in relative short time durations and to develop the ability to transfer force effectively through the body. The ability to express force throughout the triple extension of ankle, knee and hip relates closely to the movement patterns found in the ankle, knee and hip when accelerating and running. Greater load is tolerated due to the exercise being bilateral.

Dynamic bi-lateral lower body exercises are an effective method of developing force for many of the reasons previously expressed when referring to the Olympic lift variations. The obvious difference is that on most occasions, loads greater than those tolerated during Olympic lifting movements can be applied. In addition to the increased load, a greater eccentric component is present in the dynamic bilateral lower body exercises and the deep knee angle generated during squatting movements corresponds to the position of the knee during the acceleration phase of sprinting.

Dynamic unilateral lower body exercises offer the athlete an opportunity to express ankle, knee and hip extension force in a single leg stance. Glute and hip complex stability is encouraged on the stance leg, while hip extension is achieved with contralateral hip flexion.

A comprehensive menu of exercises to develop a capacity to tolerate force and volume are included to encourage robustness and ensure the athlete's body is simply 'fit for purpose'. Examples of which are shown in *Table 2.*

The exercises suggested build a general capacity around specific joints and muscle groups. Posterior chain exercises are performed with a set and rep range that develops a capacity for high volume-load enabling the athlete to repeatedly produce high levels of hip extension force while managing a resistance to fatigue.

Trunk, hip and hamstring exercises are also programmed for high volume-load. This is to ensure the athlete's body is prepared and able to stabilise appropriately through lumbar spine and hip during repeated high force single stance landings. A resistance to fatigue is required to ensure correct posture is maintained and the effective transfer of force through the body can be achieved.

Lower limb conditioning is implemented to provide stiffness through the ankle and foot and high force capacity through the calf and soleus complex. Heavy eccentric and isometric calf loading is preparation for the high impulse nature of acceleration and high speed running.

Specific preparatory exercises support the development of speed because, in their very nature, the exercises relate closely to the specific movement patterns and high neuro muscular coordination and loading seen in acceleration running and top speed running. Examples of which are shown in *Table 3.*

Plyometric exercises are often used by strength and conditioning coaches, but that is not always the case for technical acceleration drills or resisted sprinting. These types of exercises are more commonly left to technical track coaches as they form the basis for developing acceleration mechanics from a block start. For a strength and conditioning coach who is programming for speed development, it is important to recognise the force application benefits of performing sprinting specific exercises, rather than just seeing them as technical running drills. Exercise selection that is based on a more global view of movement will

Exercise Category	Exercise	Sets	Reps
Walking drills	Walking A, walking B, dynamic ankling, dynamic A drill variations	10-20	10-20
Skipping / Hopping drills	Skipping A, skipping B, straight leg hip extension skips	10-20	10-20
Running drills	Running A, Running B, straight leg run variations, cyclic run variations	10-20	10-20

Table 4.

Distance	Reps	Recovery	Approximate % Max Velocity
20m-40m drive runs Flying 30m	4-10	2mins–5mins	70–100%
60m-100m tempo	4-10	Full	60-80%
150m-200m tempo	3-6	2mins–5mins	50-70%

Table 5.

enable the strength coach to move away from more traditional forms of strength training and chasing maximal numbers and instead, put the focus on the application of strength, rather than simply more easily measurable gym based strength.

Two questions immediately come to mind when considering the potential impact of conventional strength and conditioning on speed development.

1. Can adaptations and responses to heavy concentric barbell lifting effectively transfer to acceleration and top speed running given that voluntary force production doesn’t directly relate to the dynamic impact loading of muscles during running?
2. Why would we concentrate on concentric barbell lifting when plyometric training methods are most commonly used in developing dynamic force ability?

Forward locomotion is a product of the ground reaction force equalling and opposing the force generated by an athlete, and causing acceleration of the athlete’s mass. If acceleration = force/mass, then an athlete’s ability to generate high force relative to body weight will influence their acceleration capability. Concentric barbell exercises provide the body with muscular and neural adaptations required to develop power, while plyometric training methods focus more on improving the rate of force development. This offers further rationale for designing a concurrent training programme where all characteristics are developed together as opposed to a more traditional periodisation model, which would have an athlete complete a phase of strength development in preparation for a power development before then focusing on the development of speed. This model significantly limits the time an athlete has to learn the skill of top speed running and to adapt to the specific forces generated during acceleration and sprinting.

Running training for speed development can also be split into two categories.

1. Technical running
2. Tempo running

Technical running sessions would range from simple walking, skipping and running drills to full speed and over speed running. Distance and velocity should be limited initially to ensure that proper foot contact and body positions are executed. If we consider acceleration and top speed running to be a skill that must be learned, then in the same way we understand the importance of learning correct Olympic lifting or squatting technique, we soon realise that two main factors that limit development are a degradation of technique due to fatigue and a degradation of technique due to an inability to tolerate the relative high forces involved with speed. Examples of technical running exercises are shown in *Table 4.*

The types of drills suggested follow a basic model of progression from walking to skipping to running. The complexity of drills in each category is progressed when a high skill level in more rudimentary drills has been consistently demonstrated. It is sensible to implement the three categories together but relative volume of each should be considered to fit with the progression model. Relative volume is high to ensure adequate repetition of a learned skill is achieved, and to build muscular capacity or resistance to fatigue in running specific movement patterns. Some element of technical running drills should feature daily in the training programme to maximise skill development.

There are two primary reasons for including tempo type running sessions in speed development programmes:

1. To achieve high foot contact volume – for tissue conditioning and simply repetition of a learned skill
2. Technical development – to improve both mechanical (foot placement, knee angle, lumbar/pelvic control) and coordination (balance, rhythm, consistency, ground contact time) qualities

These types of running sessions follow a short to long model in relation to volume. Technical execution is key to successful development, and so velocity and distance is limited accordingly. When short distance intensity has progressed, and approximately 80-90% of maximum velocity is achieved consistently, with no change in the technical running model, then the rep distances can progress. Examples of tempo running sessions are shown in *Table 5.*

It would be logical to attempt to complete running specific sessions on a track, but this is not necessary for all sessions. There is sound rationale for completing these sessions on grass given the objective is primarily to develop a technical model that allows the athlete to effectively transfer high relative force. While acknowledging overly soft or wet grass would not be conducive to technical running sessions, and perhaps add an unnecessary injury risk, soft dry ground can offer some increases in joint stiffness as well as limiting the potential stresses involved with repeated high volume impact loading on harder surfaces. Small volumes of track running should be scheduled to ensure the athlete is able to rehearse motor programmes learned through technical and tempo running sessions with reduced ground contact times. Technical running sessions on a track once every 7-10 days, and tempo running sessions on a track once every 21-28 days should also be sufficient to reduce the risk of injury for athletes transferring surfaces at given times of the year.

In conclusion, speed is a skill and at an elite level is a difficult physical characteristic to develop. The best traditional concentric biased strength programme, when run in isolation, is unlikely to support the development of speed. It seems logical to look for ideas from intelligent sprint training programmes to better understand speed development. The most effective methods involve multifactorial programmes that consider the developmental physical characteristics required to optimise speed development. Two case study examples of real life programme segments indicate some of the programming content described above *in situ*. Whilst this isn't meant to indicate longer term progression, it gives a feel of how components of training might be pieced around one another. Importantly, there are no secrets, tricks or gurus here. The long term sustainable development of speed comes from a sound training philosophy, considered programme design and effective coaching.

CASE STUDY 1 - Male 200m athlete, Senior Great Britain International

NOVEMBER

DAY	AM	PM
Monday	**Track warm up** 4 x 100m strides Lateral cross over step, Band crab walk, Walking lunge, Walking RDL, Spiderman crawl, Walking A with calf raise, Skipping A, Straight leg run, Belgique drill, Low heel/high heel/step over acceleration drill Speed 30m drive runs (6-10) 3-6	**Strength** Clean from blocks Squat RDL+ Single leg hip lift 20m Sled pulls (4-6 +10kg)
Tuesday	**Track warm up – as Monday** **Speed** 30m rolling start (4-6) 100m tempo (10)	**Strength** Bench press + Incline press Pull up + Reverse fly Isometric calf
Wednesday	**Track warm up – as Monday** **Speed – as Monday**	**Strength** Lower limb conditioning – sand drills, low impact hops
Thursday	**Track warm up – as Monday** **Speed** 90m 30m hard/30m easy/30m hard 200m tempo (4-6)	**Strength** Hang snatch Deadlift Band step up
Friday	**Track warm up – as Monday** **Speed – as Monday** **Strength** Bent over row + face pull Push press + press up Isometric calf	
Saturday	**Track warm up – as Monday** **Speed** 90m – 30m hard/30m easy/30m hard Strength Rack pull Box jump, hops for distance, run bounds Hills	
Sunday	**Track warm up – as Monday**	

MAY

DAY	AM	PM
Monday	**Track warm up – as November** **Speed** 30m drive runs (6-10)	**Strength** Hang clean Band step up 20m Sled pulls (4-6 +10kg)
Tuesday	**Track warm up – as Monday** **Speed** 120m, 140m, 160m, 180m, 200m tempo (sub 21s 200m)	**Strength** Isometric calf Lower limb conditioning
Wednesday	**Track warm up – as Monday** **Speed** 90m hard/easy/hard	**Strength** Band squat Step up jump
Thursday	**Track warm up – as Monday** **Speed** 150m tempo (4 – sub 15s 150m)	
Friday	**Track warm up – as Monday** **Speed** 30m resisted acceleration runs (4-6)	
Saturday	**Track warm up – as Monday** **Speed** 90m hard/easy/hard **Strength** Run bounds	
Sunday	**Track warm up – as Monday**	

CASE STUDY 2 - Professional Rugby League – Week 5 pre season

DAY	AM	PM
Monday	**Strength – upper body** Pull up D/bell row Prone fly **Rugby skills**	**Strength – lower body** Back squat Snatch grip RDL Glute bridge
Tuesday	**Regeneration – pool, bike** **Hand-Eye & coordination training**	
Wednesday	**Speed** Skipping A, Skipping B, Running A Straight leg acceleration Low heel/high heel/step over acceleration drill Falling 20m (4-6), 20m Drive run (4-6) **Rugby skills** **Strength – upper body** Bench Dips Single arm row	**Rugby skills**
Thursday	**Regeneration – bike, pool**	
Friday	**Strength – upper body** Bent over row D/bell pull over Chins **Rugby skills**	**Strength – lower body** High box step up Glute/Ham raise Speed 20m Sled pulls (4-6)
Saturday	**Speed – position specific** Skipping A Skipping B Running A Straight leg acceleration 15m easy / side step / 15m hard (4) 10m back pedal / up-down / turn 10m acceleration (3) 1 on 1 semi opposed – 5x15m grid (3)	
Sunday		

Acceleration: Theory and Practice

Jared Deacon BSc, BSc, MSc, P.G.C.E., ASCC

Introduction

One of the most commonly proposed determinants of success in many sports is speed – or more precisely – speed of acceleration.[1] Speed can be expressed in many forms, but speed of whole body movement in the form of acceleration from a slower speed to a faster speed is the primary focus of this article. In sprinting, acceleration and maximum velocity are determinants of sprint running performance[2] and it is clear that each phase of the sprint demands a specific training approach[3,4] and this is in both the physical and technical nature of acceleration capabilities. Sprinting in a straight line from starting blocks is the purest form of this acceleration, and is the sporting event in which acceleration is rehearsed to the highest levels in terms of both the physical and technical components of acceleration. This article intends to provide both a theoretical background to understanding the nature of acceleration, as well as a practical guide with exercises and techniques to assist in improving acceleration. The author will also demonstrate the importance of acceleration in relation to maximum velocity and the concept of 'speed reserve'.

Acceleration – What it is and what it looks like

In its purest form, as demonstrated in sprint events, acceleration comprises two distinct segments on the way to maximum velocity – the 'drive phase' and 'transition phase'. The drive phase lasts only 6–8 steps (approx 10m) and is primarily determined by the angles of the shin at ground contact. Athletes using starting blocks or starting from a crouched position should have the aim of driving out of this position and achieving a 45° angle with the whole body at first foot contact, and maintaining the 45° angle as they push into the second step. The shin angle increases by approx 6° per step over the course of the phase and once the shin angles reach 90°, the drive phase has ended and the athletes enter the transition phase which can last from 10–30m and possibly beyond in some cases.

In the early stages of acceleration, foot contact with the ground should happen behind the centre of mass. There is also a relatively long ground contact time as the athlete tries to generate velocity. The duration of ground contact in each step decreases for every step in the build up to maximum velocity, while stride length increases throughout this phase. The ground contact behind the centre of mass means that the drive action is a pushing action with relatively minimal braking (eccentric) forces (12.9%), compared to an incorrect technique during acceleration or in comparison to the larger (43%) braking component at maximum velocity.[4,5] A high contra-lateral knee drive and increased range of motion of the arms assist in maintaining balance during the longer ground contact times in the initial acceleration phase, as well as assisting in the forward and upward projection of the body.

Along with the shin angles, another key factor to successful drive phase mechanics is the lack of heel lift of the recovery leg. It is important to keep the heel of the recovery leg low to the ground and in a more direct and forward driven motion, as opposed to a cyclical action. Maximum velocity mechanics have a 'cyclic' action, while drive phase and acceleration mechanics have a more 'piston' like action which is characterised by the lower heel recovery and higher knee drive relative to the torso. A final factor is that the ankle joint should be stiff and unyielding at ground contact in this phase allowing a powerful drive from the hip, which is able to rotate about the knee joint without the knee joint collapsing and decreasing the angle between the shin and the floor.

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In the authors' experience, athletes have a tendency to make one or a combination of the following errors in the acceleration mechanics:

1. Heel recovery coming too high, too soon. Heel recovery should gradually become higher and higher over the course of the drive phase and not lift high under the hips in the first few steps.
2. Athletes stand up or 'pop up' too quickly. This occurs when the shin angles are more vertical and have increased too quickly with the athlete stepping in front of their centre of mass producing a higher vertical component (braking force), and pushing them into an upright position prematurely.
3. If the foot lands in front of the centre of mass, there is also a tendency to allow the ankle to collapse, which will add to the increased vertical forces.
4. Athletes keep their head down to 'drive' for longer. When an athlete keeps their head down rather than maintaining postural and spinal alignment, they are giving themselves the feeling of maintaining a drive while actually just running with their head down!

With all this in mind – what sort of speed should an athlete be able to reach in the first 6–8 strides? The IAAF Biomechanics project at the 2009 Berlin World Championships reveals that Usain Bolt took 7 steps to reach approx 12m into the race. At 10m he had reached 73% of his maximum velocity and approx 80% by 15m. The transition lasts through to about 16-18 steps or when the torso will be fully upright and about 95% of maximum velocity will have been achieved. For Usain Bolt this was at 35m into the race, with maximum velocity being reached at the 60m mark.

Usain Bolt - Beijing 9.58sec World Record Velocity Analysis:

- 10m – 73% max vel
- 20m – 85% max vel
- 30m – 93% max vel
- 40m – 96% max vel

In a time-data analysis by the author on 100m runners of different abilities, it has been noted that the faster athletes (sub 10sec), will spend a higher relative percentage of time in the first 10m/20m/30m and 40m of the 100m race as compared to slower athletes. This then highlights the principle of the fastest athletes (over 100m), will take longer to accelerate and thus will reach a higher maximum velocity because of this. The data bears out that the faster athletes, while spending longer in acceleration, will consequently spend relatively less time in top speed with this top speed being significantly faster than those capable of slower speeds. This adds up to the fastest athletes accelerating faster, for longer and reaching higher top speeds.

Practical Application

As has been demonstrated in the race analysis, the acceleration phase is of utmost importance to all athletes and even Bolt, who has the highest maximum velocity, is able to hit over 90% of maximum within 30m. Although often overlooked in speed development, the learning and rehearsal of the mechanics of the drive phase should be something that time and attention is given to, yet most running drills will rehearse and work on aspects of maximum velocity mechanics with high heel recovery and a more cyclic running action. The drive phase of a sprint should be executed at maximum effort on all occasions and the intensity (% of maximum velocity reached) of the repetition can be manipulated by changing the distance the repetition is performed over.

There are several drills and running based exercises that work on acceleration mechanics. The classic 'high knees' or 'A' march/walk/run would be the starting point. Careful attention should be paid to the maintenance of a vertical shin on the ascent and descent, with ground contact being very close to the centre of mass. Anything in front would reinforce negative shins angles, which produce movements where the foot lands too far in front of the centre of mass. Moving this on to an angled position, wall drive drills can be performed where the athlete hits the correct positions and practices the piston like motion of the action whilst using the wall to dictate total body angle.

Both of the aforementioned drills are useful and teach some basic patterning. However, neither produces the forces required to move the body in the desired manner. The importance of strength factors in a drive phase has been well documented[2,6] and drills alone will not make the desired levels of improvement in an athlete if the physical factors are not present. These physical factors can be worked upon in a variety of different ways and can be sub divided into:

- Starting positions
- Drive phase resistance exercises
- Explosive power exercises

Starting Positions

Starting position will dictate the amount of force required to overcome inertia and move the body from its resting state. We normally see athletes racing from starting blocks, but in training, 1,000's of repetitions are performed utilising other starting positions at various times of the year in order to develop the physical and technical skills required for successful starts from blocks. In each of the starting positions described and demonstrated, the key factors the coach is looking for are the same:

- 45 degree drive out on first step
- Feet contact behind centre of mass
- Low heel recovery
- Stiff ankle at ground contact
- Arm action should be 'long' and powerful over the first few strides

Falling starts *(Figure 1)* can be used from very early in the training year. Here, the use of gravity assists in getting the athlete into the right position by literally falling into the run. This is a top down approach and allows the drive phase to occur in a physically less demanding way by overcoming inertia through the use of gravity – falling. Arms are held to the front of the body, which assists in the falling forward and allows a powerful backward swing of the arm with the driving forwards of the opposite knee.

Standing starts *(Figure 2)* are a more static starting position than a falling start and have a longer foot stance position. They utilise more of a coiled spring approach and use the flexed position to extend powerfully away from the start. They have a more balanced contra-lateral arm position which drives forwards with the opposite knee as opposed to the falling start where the arm action is primarily a

Figure 1. Falling Starts.

Figure 2. Standing Starts.

Figure 3. Kneeling Starts.

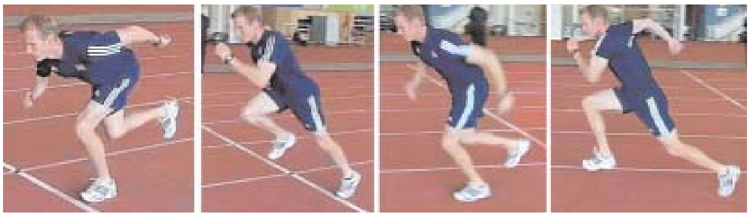

Figure 4. Hop drives.

Figure 5. 3 Point Starts.

Figure 6. Reverse Lunge into Step Up.

Figure 7. Cable Drives.

backwards driving action. These would be introduced quite early in the training year and can be done with either leg forwards.

Kneeling starts *(Figure 3)* are in a more physically demanding position and engage through the glute and upper hamstring of the front leg. They require a powerful first push forwards and give the feeling of a delay between effort and action. Normally sprinters will feel very fast getting away from the start, but with the kneeling start, the delay in getting the first foot down to the ground feels somewhat unnatural and as athletes gain experience and learn how to drive the hip forward, this time delay decreases significantly in both perception and in actuality. Kneeling starts can be introduced slightly later in the training year once the initial phase of training has been done. As they are physically more demanding, it would make sense to have worked on technical elements and strength elements before the demands of such a start are placed on the body. It is also good practice to change the front leg regularly within a session to ensure balanced development in terms of skill and strength in both limbs.

Hop drives *(Figure 4)* are a more advanced method of drive practice and are a physically and technically demanding exercise. The athlete starts on one leg with foot flat on the floor. Hops forward then steps out into a sprint. It is important to hold the balance and posture throughout and actively drive the foot into the floor to be able to move off effectively. This sort of activity would only be used once the basic mechanics of acceleration are in place, as well as the strength and control through performing other related exercises on the track and in the gym.

Three point starts *(Figure 5)* are a well used option and have variations in the exact technique employed by various coaches. This type of start should reflect the block start position very closely in the foot positioning, knee angles and hand position in relation to the shoulder. This is both a technically and physically demanding position to get right as it is so close to the actual block start position.

Drive Phase Resistance Exercises

The discussion on the use and relative merits of every posterior chain, strength and/or power based exercise in the gym which might have positive contribution to the drive phase is beyond the scope of this article, but a few key exercises which can be used in addition to the popular cleans, deadlifts, and squats are discussed and demonstrated here. It is acknowledged that sprint performance can be improved through strength training and it is generally accepted that for optimum transfer to dynamic movement the characteristics of the resistance training stimulus should be specific to the activity in terms of muscles used, muscle action type, loading characteristics and range of movement.[2,6] There does not appear to be any consensus on the appropriate method of resistance training to utilise when training to enhance acceleration, and no clear method of resistance training has been shown to enhance acceleration in comparison to other methods. Since explosive concentric muscle actions dominate sprint starts, it seems logical that similar resistance training movements might be suitable for testing and training these neuromuscular qualities.[7] The reader should be aware that some of the technical considerations may be of less importance in many sports outside of athletics, as athletes in other sports have to accelerate from lying prone or a crouch, from moving sideways or backwards for example.[4]

Barbell based gym exercises which might be employed to assist in the development of unilateral strength around the hip and knee are reverse lunges, forward lunge walks and step ups. These may also be combined to make small complexes of exercises *(Figure 6)*. Reverse lunges allow for optimal activation of the working hip to control the descent and then pull the hip upward and forwards in the ascent. This replicates the demand of the foot being static on the floor and the knee acting as a hinge joint with the hip and knee extensors pushing the body towards a fully extended position. This same patterning is observed in forward lunge walks. The swing of the recovery leg should be low and acting as a recovery leg would in the drive phase. These actions can be adapted to progress towards a higher heel recovery as would be observed in top speed running mechanics. Step ups *(Figure 7)*, have a wide variety of differing techniques, but the basic step up replicates a walking high knee drill and although a more vertical position is required, the basic unilateral motion is similar in action to drive phase mechanics.

Resistance Exercises – Sprint Based

There are a variety of methods used to assist in adding resistance to the acceleration itself. It is important to do maximal efforts with all the acceleration activities to ensure that the correct timing, patterning and mechanics are demonstrated. Traditionally, coaches use brief unresisted/free runs of maximum effort as a training stimulus to improve sprint performance[2] but towing weights is one of the most popular means of improving acceleration speed, and sleds are commonly used in a variety of sports to develop acceleration speed.[2,8,9] However, despite widespread use, there is limited information and research on the effects of towing a resistance on sprinting speed. The wide-ranging differences in current practice indicate the need for more research in this area.[8,10,11] Research indicates that sprint performance improves with strength training[12] and it is suggested that improvements in sprinting performances are directly related to movement and velocity specificity.[13] Additionally, it has been reported that strength may be transferred more specifically using similar modes of contraction.[14] Therefore, coaches have used sprint-specific strength based exercise in the form of resisted running to integrate strength and velocity components into a sprint-like running action. It has been documented that there is an increase in force development of the muscles of the hip and knee during resisted sprints, which may be achieved through greater recruitment of muscle fibres and/or greater neural activation[1] although further research is required in this area.

One particular investigation[15] examined the effects of resisted and assisted training methods on 20, 40 and 60 metre sprint performances. It was found that using resisted methods made some significant improvements in 20 and 60 metre times, but that other methods also made improvements in the various sprint tests. The group which used a combined training programme, using both resisted and assisted methods of training made an overall significant (p=<0.05) improvement. Although the mechanisms behind these changes were not examined, the authors suggested that the sled resistance training increased force production to generate speed and that further research to examine the adaptations that take place with resisted towing to discover the mechanisms behind improved sprint performance.

Resisted towing in the form of sleds has been used for many years,[4,8,9,11] and, although there are a limited number of investigations on the subject, it has been proven to be successful in assisting the development of the acceleration phase from a speed perspective. Current views on the effectiveness of sled pulling are derived primarily from subjective and empirical observation of coaches.[2] The improvement in acceleration capabilities may be caused by greater recruitment of muscle fibres and/or greater neural activation.[2,9] The '10% rule' is often one that has been mentioned by coaches as the mechanical changes that occur with more than a 10% reduction in speed have been deemed undesirable. The 10% rule is not scientifically substantiated but rather based on practical observations[16] and the coach must make the judgement on each individual about how they are managing the resistance placed on the sled.[17] This 10% rule can be misinterpreted quite easily and many coaches have used 10% of body weight as resistance on the sled. This would not make sense as a sled versus a tyre versus grass versus track versus wet surfaces versus dry surfaces would all provide a different resistance. The simplest way is to have the athlete time themselves at the end of their warm up over the distance the sled will be pulled. Then add 10% to that time and this is their target. Place a weight on the sled, which will allow them to achieve this time. This weight can then be adjusted for any resistance in any conditions to give the same outcome.

Hill sprints provide an obvious means of acceleration development as the angle of the ground is raised, so the angle of the body changes to be more like an acceleration posture. Athletes who have issues with holding a mechanically correct position can use hill sprints to naturally get them into the right position to drive assuming the right degree of incline to achieve this is chosen. It has been reported that uphill running, while shortening stride length and increasing ground contact time, will increase the stress placed on the hip extensor groups as the athlete attempts to maximise stride length, therefore increasing this component on a flat surface.[9] Stairs can provide a similar stimulus, however, finding suitable places to get a reasonable run in a straight line can be difficult. Stairs additionally assist the athlete in maintaining a dorsiflexed position due to an increased tendency to keep the foot cocked in preparation for ground contact when running up stairs to avoid the toe catching the steps. Stairs also encourage a more direct running action as described in the acceleration mechanics part of this article, where there is less cyclical action and more piston-like drive.

Another pulling resistance, which can be used in isolation to assist in developing some specific strength is using cable pulleys for cable drives *(Figure 7)*. The set up is important to ensure that the athlete is in the right position to push and extend. The set up demonstrated is safe and effective in achieving the right body alignment and positions, while being able to

Figure 8. Trolley Pushes.

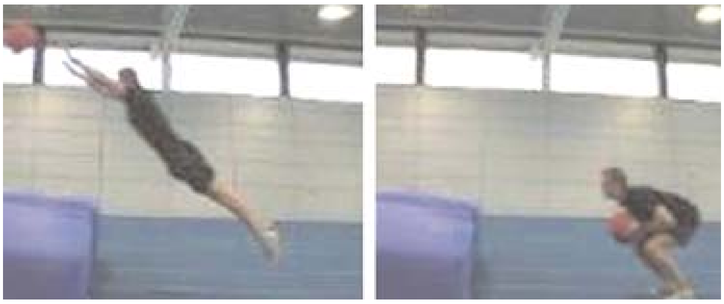

Figure 9. Med Ball Dive – landing on high jump bed.

Figure 10. Med Ball Jump and Dive - double footed jump then a dive onto high jump bed.

Figure 11. Med Ball Split Dive – starting in split stance and diving onto high jump bed.

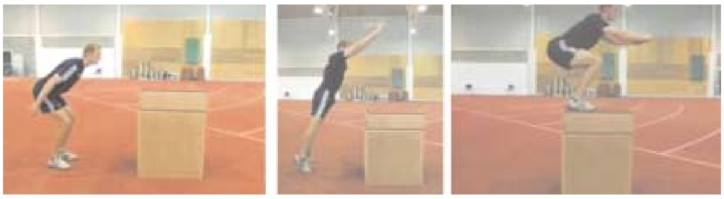

Figure 12. High Box Jump.

Figure 13. Box to Bed Jump

load up a significant amount of weight. The ankle should stay rigid and the knee angle remains static as the hips and body are drawn over the stance leg knee. This could be coupled with a resistance on the lower leg of the recovery leg to work through the position with a load.

Finally, one innovation which has proven useful to the author, is the use of a hurdles trolley for short pushing activities *(Figure 8)*.[2] The trolley can be loaded with varying number of hurdles to set the resistance level, as well as the coach being able to add or assist during the activity while guiding the trolley. This allows the athlete to get into a correct position and hold that position with correct technique of the lower limbs.

Resistance Exercises – Plyometric Based

The drive phase is not plyometric in the strictest sense due to the relatively small eccentric component over the first few steps. Therefore it is primarily a concentric explosive activity because ground contact times are longer in the drive phase and are less reactive in nature. There are several exercises which can mirror and develop this. The medicine ball and concentric jump-based exercises demonstrated in *Figures 9–14* show some simple means by which to develop this type of explosive power. They are also very safe means and athletes find these activities a fun challenge and add something a little different to the training programme.

Speed Reserve

As previously mentioned, the ability to develop velocity in as short a time as possible may be of most importance to performance in many sporting activities, but in many activities maximum velocity is not always attained and repeated short sprints are more common.[4] Furthermore, many sports require sprinting ability over very short distances and often without a change of direction.[7] For example, it is documented that it is uncommon for rugby players in any position to sprint further than 20m in any single incident in a game.[18,19] Most time for field sports would therefore be spent in drive phase, and transition phase would play a lesser role with maximum velocity in theory, playing an even lesser role again. This theory would seem logical, but the concept of speed reserve is an often unnoticed, yet key concept, in many sports and events. It is the difference between the speed capability of the athlete and what they require at any one time. For example, a 400m athlete who has very quick 200m speed will be able to run the first part of the race at a relatively slower and easier speed than athletes with slower 200m speeds. This would then leave the speedier athlete in a strong position to win the race by having more speed available to them. Applying this principle to team sports, it has been reported that between 60–80% of maximum speed is normally required. Increasing maximal speed would allow an increase in sub maximal speed capabilities *(Figure 15)*. Greater absolute speeds would increase the speed reserve for sub maximal activities. This improvement will make the athlete more efficient and enable them to sustain these speeds throughout their specific sports.

Figure 14. Box to Box to Bed Jumps

Conclusions

Acceleration is a specific skill, which has both technical and physical elements requiring a concentrated programme of development in order to be successful. Although many sports do not require the higher level of technical proficiency of a track sprinter, the ability to generate the required forces in the right direction is still a requirement in order to make use of this ability in a game situation. Following some simple rules, guidelines, ideas and concepts outlined within this article, athletes from all sports will be able to improve their acceleration capabilities and add to their competition skills and abilities.

Resources and References

For athletics coaching resources go to Ucoach website www.uka.org.uk/coaching

Loren Seagrave:
http://coaching.uka.org.uk/audio/loren-seagrave-interview-sprint-mechanics/from-filter/

England Athletics Coaching Conference Handouts:
http://coaching.uka.org.uk/document/england-athletics-2009-national-coaching-conference-handouts/from-filter/

Charlie Francis: various video and written resource available at www.charliefrancis.com

Dan Pfaff – Canadian Athletics Coaching Centre resource video.

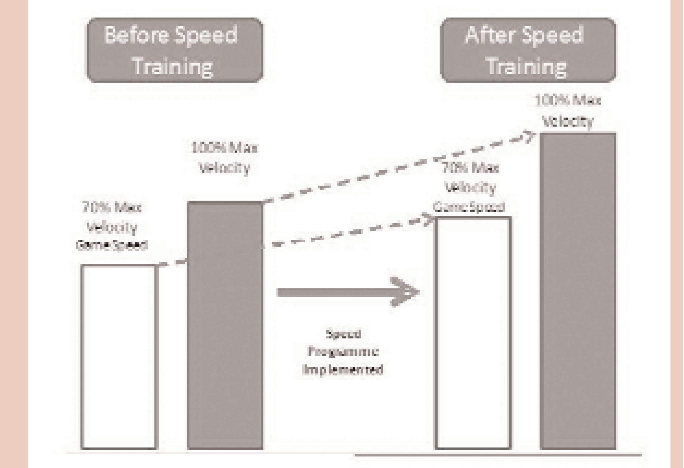

Figure 15 - Enhancing speed reserve by increasing top speed (after & adapted from C. Francis).

Conference Notes

USA T&F Conference, Orlando, Dec 2009.

England Athletics Coaching Conference, Sheffield, Dec 2009.

Loren Seagrave Workshop, Loughborough, Feb 2009

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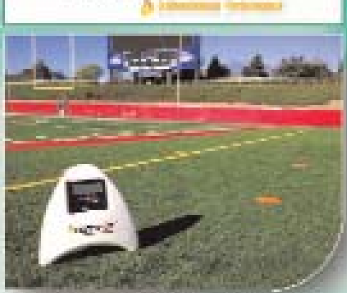

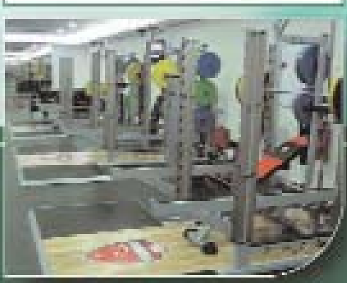

A Biomechanical Comparison of Accelerative and Maximum Velocity Sprinting: Specific Strength Training Considerations

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Introduction

Numerous biomechanical research studies have been conducted in both accelerative (e.g. [45,46,47,48,49,84]) and maximum velocity sprinting (e.g.[5,16,57,69,96,97]). Whilst there clearly exists a relative wealth of biomechanical data regarding these phases of sprinting, the differences between them are seldom discussed. Although accelerative and maximum velocity sprinting have not been directly assessed within a single cohort of athletes, general similarities such as the triple extension (proximal-to-distal hip, knee, ankle sequencing) can clearly be identified from the aforementioned research. However, both subtle and gross differences can also be identified between accelerative and maximum velocity sprinting from existing literature. These include differences in the basic temporal and kinematic factors such as step length, step frequency and flight and contact times, the magnitude and direction of the forces generated against the ground during stance, and the kinematic and kinetic patterns exhibited by the ankle, knee and hip joints.

From a practitioner's point of view, different methods of training can be utilised to either increase the rate of acceleration or the ability to attain a higher maximum velocity. An understanding of the relevant biomechanical differences between accelerative and maximum velocity sprinting would allow the strength and conditioning coach to select appropriate exercises during specific training periods that best replicate both the observable kinematics, as well as the causative kinetics at each joint. A greater understanding of these two phases could potentially allow the coach to focus directly on improving one phase, or to concurrently improve both to the greatest possible extent without negatively influencing one or other of them. The aim of this article is therefore to identify and discuss some of the key temporal, kinematic and kinetic differences between

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Table 1. Contact and flight times published in previous sprinting research from various distances/steps within a sprint.

Stage of sprint		Source*	Mean contact time (s)	Combined stage mean for contact time (s)	Mean flight time (s)	Combined stage mean for flight time (s)
Step number	Distance (to nearest m)					
1	-	[73]	0.220	0.198	0.050	0.027
	-	[84]	0.200		0.045	
	1	[4]	0.196		0.063	
	1	[19]	0.177		0.050	
2	-	[73]	0.180	0.173	0.060	0.061
	-	[84]	0.173		0.058	
	2	[19]	0.159		0.082	
	2	[4]	0.179		0.043	
3	-	[84]	0.159	0.153	0.074	0.072
	3	[19]	0.136		0.082	
	3	[4]	0.164		0.060	
4	-	[84]	0.135	0.139	0.081	0.083
	5	[19]	0.131		0.099	
	5	[4]	0.152		0.069	
7	10	[19]	0.120	0.120	0.101	0.101
10	15	[19]	0.110	0.110	0.115	0.115
-	16	[45]	0.119	0.119	0.114	0.114
-	46	[4]	0.111	0.111	0.113	0.113
Max velocity after preferred acceleration distance		[55]	0.094	0.094	0.126	0.126
-	125	[60]	0.111	0.113	0.126	0.126

** [73] = 20 field sport athletes, [84] = 1 male sprinter with a PB of 10.80 s, [4] = 8 US National level sprinters, [19] = 1 male sprinters with a PB of 10.15 s, [45] = 28 male recreational athletes, [55] = 10 male sprinters with a mean PB of 10.91 s, [60] = 1984 200 m Olympic Champion.*

accelerative and maximum velocity sprint running from published literature, and to consider the implications these variations may have when constructing a S&C programme to develop the different phases of linear sprint running. While there is evidence to suggest that the upper limbs play a part in sprint running performance, [41,42] their contribution is largely a response to that of the lower limbs [7,39,59,60,73] and will not be focussed on in this article.

Ground contact times

Previously published data shows that as a sprint progresses, ground contact times tend to decrease *(Table 1)*. Data from international level sprinters[4] shows clear differences between mean contact times during the first four steps (0.196, 0.179, 0.164 and 0.152 s), and those at maximum velocity (0.111 s). Salo, Keranen and Viitasalo[84] also observed contact times to decrease during the first four steps (0.200, 0.173, 0.159 and 0.135 s), and Čoh and Tomazin[19] confirmed that these continue to decrease over the first 10 steps *(Table 1)*. Aside from the research of Atwater,[4] there exists limited data from individual athletes during both acceleration and maximum velocity. However, Atwater's[4] data is comparable to those observed by researchers investigating early-acceleration, mid-acceleration or maximum velocity in isolation *(Table 1)*, reinforcing the notion that contact times show a gradual decrease as an athlete continues to accelerate up to maximum velocity. Therefore, such temporal differences may clearly be an important consideration to the S&C coach when selecting specific exercises to develop the different phases of a sprint.

Acceleration

During the acceleration phase, ground contact times typically range between 0.12 and 0.20 s *(Table 1)*, with the early and late stages of acceleration at the higher and lower end of this range, respectively. Longer ground contact times clearly allow an athlete more time to produce force. This allows greater impulse to be produced – (impulse is the product of force and time, and directly determines an athlete's change in velocity), and would thus appear advantageous for performance. However, the ultimate aim of any sprint is to cover a specific horizontal distance in the shortest time possible and thus it may not be favourable to achieve increases in impulse through simply increasing contact time. Better sprinters have been found to minimise contact times, allowing the stance phase to be terminated prior to full extension of the leg joints and thus making recovery as efficient as possible during the swing phase.[61] Whilst this ability may be related to greater strength in these faster sprinters, it would still appear that for any given sprinter, greater joint extension towards the end of the stance phase, where force production will be low, is not beneficial due to the poor configuration of the muscles surrounding these joints for producing force.[51] Further research is required to investigate this issue since it may be possible that an optimal contact time exists during acceleration: one which is sufficiently long to allow athletes to produce large forces, without being so long that contact times are extended beyond the time during which large forces can be produced.

Maximum velocity

Ground contact times at maximum velocity have typically been found to range between 0.09 and 0.12 s.[4,55,60] They are seemingly related to maximum velocity sprint performance, as research has shown that between sprinters, a reduced contact time is associated with greater horizontal velocity.[4,60,96] Weyand, Sternlight, Bellizi and Wright[96] found that in subjects of different sprinting abilities, those who reached higher maximum velocities on a level treadmill spent less time in contact with the ground than those who reached lower maximum velocities, which is confirmed by findings from earlier studies.[4,59] Weyand *et al*.[96] also showed that both faster and slower subjects (maximum velocity range = 6.2 to 11.1 m/s) required a flight time of approximately 0.13 s to be able to adequately reposition the legs for the next step. The differences in maximum stride frequency (range = 1.8 - 2.4 Hz) between fast and slow runners, resulted entirely from the contact portion of the stride being shorter in faster runners. Potential limits to the study were that participants were classed as "physically active" and would not appear to be representative of more elite level athletes, and data was collected on a treadmill which may differ from overground running.[31,82] However, despite these potential limitations, reducing ground contact times at maximum velocity is likely to be key for athletes at all levels to increase maximum velocity sprint performance. This is reinforced by the data of Mann and Herman[60] *(Table 1)* which shows flight times for elite athletes to be the same as those "physically active" subjects used in the Weyand *et al.*[96] study. The S&C coach therefore ought to seek appropriate ways to enable an athlete to minimise ground contact times at maximum velocity without hindering their performance. How shorter ground contact times are achieved is a challenge of causality to the S&C coach and throws up the following question: does less contact time allow an athlete to sprint faster or is a shorter stance phase a function of sprinting fast? An understanding of this issue will affect the strategies adopted to reduce ground contact times during maximum velocity, and will be revisited in subsequent sections in this article.

Ground reaction forces

Although ground contact time is clearly an important performance variable, it is also paramount that athletes generate large forces during these ground contacts to produce sufficient impulse to overcome inertia and gravity, and thus achieve high levels of performance. However, the magnitude and direction in which these forces are applied appear to differ as a sprint progresses. Since forces are ultimately the underlying cause of movement, be it in sprinting or any other form of locomotion, a greater awareness of how these forces are produced will enable the S&C coach to have a much better understanding of accelerative and maximum velocity sprinting, and thus be more informed regarding exercise selection for training.

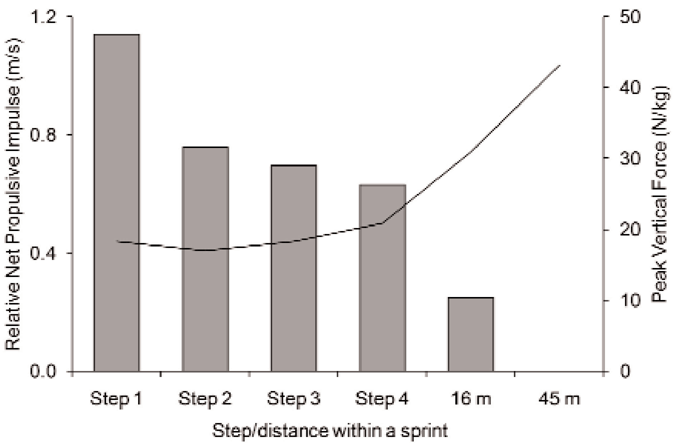


Figure 1. Relative net horizontal propulsive impulse (bars) and peak vertical force production (line) during steps 1 to 4,[84] at the 16 m[47] and 45 m[70] marks within a sprint.

Acceleration

Data from selected research studies (Figure 1) demonstrate that as the net horizontal impulses decrease throughout the acceleration phase towards maximum velocity, the peak vertical forces increase. Horizontal impulse production (relative to bodyweight) has been shown to predict 61% of the variance in sprint velocity in 36 participants from a variety of sports during the mid-acceleration (16 m) phase of a maximal effort sprint.[47] In contrast, vertical impulse production at the 16 m mark was found to account for only 17% of the variance in sprint velocity. Caution must be given when interpreting this data, as direct causation cannot be assumed since sprint velocity at 16 m is a product of sprint performance over that entire distance, whereas the ground reaction forces at 16 m are those of a single stance phase. However, Hunter, Marshall and McNair[47] speculate that during the acceleration phase of a sprint, the most favourable impulse profile is one in which sufficient vertical impulse is generated to overcome gravity and create a flight time long enough for repositioning of the lower limbs, whilst all other strength reserves are applied horizontally in order to maximise acceleration.

In addition to the progressive changes in the demand for increased vertical force as the acceleration phase progresses, the effects of horizontal braking forces become greater throughout this phase. Horizontal braking impulses have been shown to increase threefold from -1.5 Ns in the first step of a maximal effort sprint from blocks, (equivalent to a 0.02 m/s reduction in velocity for the subject studied), to -4.8 Ns (-0.06 m/s) in the fourth step.[84] By the 16 m mark (approximately step 10-11), mean braking impulses have been found to reach -7.2 Ns (-0.10 m/s).[47] Although these findings are not directly comparable, they suggest that braking impulses continue to progressively increase as a sprint progresses. During the initial steps, this appears to be largely due to an increase in the peak horizontal braking forces generated. Salo *et al.*[84] observed mean peak braking forces of -215, -348, -421 and -672 N in steps one to four, whilst the absolute mean braking phase durations were 0.012 (6.0% of total stance), 0.014 (8.1%), 0.012 (7.5%) and 0.013 s (9.6%). However, as the acceleration phase continues to progress, the duration of the braking phase increases and by the time maximum velocity is reached it has been found to last for 0.048 s (44%) of the stance phase.[69]

In addition to these increases in the amount of deceleration experienced during early stance, there also exists a gradual reduction in the subsequent increase in velocity (due to positive horizontal impulse) achieved during the remainder of the stance phase as the acceleration phase progresses. Salo *et al.*[84] found propulsive impulses to decrease from 93.5 Ns (+1.18 m/s) to 49.1 Ns (+0.62 m/s) between steps one and four of a maximum effort sprint. By the 16 m mark, propulsive impulses were found by Hunter *et al.*[47] to have reduced to 25.2 Ns (+0.35 m/s). The overall net propulsive horizontal impulses, (positive propulsive minus negative braking), therefore progressively decrease throughout the acceleration phase as a result of an increase in the negative braking impulses, as well as a decrease in the positive propulsive impulses. Once the positive propulsive impulse equals the negative braking ground impulse (and the small braking impulse due to air resistance), the athlete is thus sprinting at constant (i.e. maximum) velocity.

Maximum velocity

Since the velocity of the centre of mass does not change between successive steps once maximum velocity is reached and maintained, (provided enough horizontal force is applied to the ground to overcome the effects of air resistance and horizontal braking forces), the rest of the applied force is directed vertically to overcome the effects of gravity in order to maintain maximum velocity.[96] It would therefore appear that the desired ground reaction force orientation changes from more horizontal to vertical as a sprint progresses, and that the magnitude of the horizontal braking force gradually increases *(Figure 1)*. In the study by Weyand *et al.*[96] it was found that the participants able to reach higher speeds were able to express higher peak vertical forces (relative to body mass). This enabled them to develop the necessary vertical impulse to overcome the effects of gravity and thus 'rebound' off the ground more quickly, clearly relating to the shorter ground contact times discussed previously. Weyand *et al.*[96] therefore suggested that by applying greater vertical forces during maximum velocity sprinting, faster runners are able to achieve the effective impulses and flight times necessary to reposition their swing legs with shorter contact times. This reduction in ground contact times due to the greater vertical forces applied by faster runners results in increased stride frequencies without a concurrent decrease in stride length.[96] It would therefore appear that increasing lower body strength and the rate at which it is produced would be an appropriate strategy to decrease ground contact times during maximum velocity sprinting, whereas simply instructing an athlete to reduce their ground contact time would most likely result in the sacrifice of force production and stride length, and ultimately sprint performance.

Table 2. Mean touchdown distances from various distance/steps within a sprint.

Stage of sprint	Source*	Touchdown distance** (cm)
Step 1	[68]	-13
Step 2	[68]	-4
Step 3	[68]	+5
16 m	[45]	+25
50 m	[3]	+40

** [68] = 25 male sprinters with PBs ranging from 10.20 s to 11.80 s, [45] = 28 male recreational athletes, [3] = 14 male sprinters with a mean PB of 10.83 s.*

*** Negative values represent the CM ahead of the stance foot.*

Kinematics at touchdown

Whilst considering the horizontal and vertical force components separately is important since it can clearly aid the understanding of sprinting, they are part of a single ground reaction force vector and thus cannot be independently altered. The direction in which the resultant force vector acts is largely dependent on body position and the muscles being activated.[54] Different lower limb joint angles and trunk orientations at touchdown will affect the horizontal distance between the centre of mass and toe at touchdown, a variable that has been termed touchdown distance.[47] Differences in body configuration at touchdown and thus throughout the stance phase could clearly be of consequence to exercise selection for the different sprint phases. Since the majority of the energy needed to reposition the limbs during the swing phase appears to be provided by passive mechanisms of energy transfer rather than muscular power,[60,96,97] the kinematic factors relating to the stance phase will form the primary discussion in this section.

Acceleration

During all steps within a sprint, the ankle initially dorsiflexes after touchdown, before plantarflexing for the remainder of stance.[6,48,50] In the first step of a sprint, this transition from dorsiflexion to plantarflexion has been found to occur at approximately 30% of stance,[6] whilst by mid-acceleration (14 m) it occurs at around mid-stance.[50] The knee and hip joints typically extend from touchdown onwards during both early and mid-acceleration,[6,48,50] and for some athletes the knee starts to flex just prior to toe-off.[6,48,50] One interesting observation during accelerative sprinting is that the centre of mass must be rotated forward about the stance foot prior to rapid extension of the stance leg.[48] If the leg was to extend at the point of touchdown, the centre of mass would be directed in a more vertical direction and, as already highlighted, the aim during acceleration is to propel the centre of mass horizontally. Therefore, at the beginning of the stance phase it is this rotation that contributes to forward motion, whereas later in stance, rapid extension of the leg joints facilitates further forward acceleration, since the athlete is in a more favourable position for directing their leg extension force horizontally.

It is possible to reduce this need to rotate the centre of mass in front of the stance foot by repositioning the foot further back relative to the centre of mass at the point of ground contact, thus achieving a greater negative touchdown distance (i.e. the CM further ahead of the foot). Touchdown distance has been found to gradually increase as a sprint progresses (i.e. the CM becomes progressively further behind the foot at touchdown; *Table 2*), and has previously been related to the magnitude of the braking impulse generated during stance in accelerative sprinting (16 m), with foot placement further in front of the body related to higher braking impulses.[47] It appears that keeping the foot behind the CM at touchdown during early acceleration, (and restricting how far in front it is placed during mid-acceleration), may help to facilitate performance, although it is possible that this may only be true to an extent since placing the foot too far behind the CM during early acceleration could leave the leg in a less favourable position for producing force, thus leading to lower levels of performance.[6]

Maximum velocity

During maximum velocity the ankle and knee joint angles typically reduce for the first 60% of the stance phase, whereas the hip joint continues to extend throughout the entire phase,[5] similar to its movement during acceleration. During maximum velocity, the foot touches down in front of the centre of mass (positive touchdown distance), with values of up to 40 cm reported *(Table 2)*.[3] In attempts to reduce ground contact times and horizontal braking impulse while maximising propulsive forces, coaches commonly use 'paw back' drills to bring the foot further back relative to the centre of mass. However, simply minimising large touchdown distances could potentially just result in a decreased stride length unless an athlete is strong enough to achieve the vertical force production required during the ground contact phase. Consequently, when looking to reduce the extent to which an athlete's foot is forward of their centre of mass upon touchdown, the S&C coach should determine whether strength or technique factors are limiting the athlete's ability to do so without sacrificing stride length and overall velocity.

Joint kinetics

The kinematics at touchdown, and during stance, provide an accurate description of the movement patterns used during sprinting. However, knowledge of the underlying kinetics are required for a more complete understanding of the movement. These kinetics are calculated using inverse dynamics analyses, which allow the *resultant* joint movements and powers to be determined (i.e. the net effect of all muscles crossing that joint). Phases of power generation and power dissipation can therefore be identified for the flexor and extensor muscle groups crossing each joint. For example, whilst a joint may be extending throughout stance, the muscles surrounding that joint may not be acting to extend that joint, but are actually exhibiting a power dissipating (net eccentric) flexor movement, to slow the rate of extension, as is the case at the hip prior to toe-off. Although it is acknowledged that individual muscle characteristics are unknown, the terms *net concentric* and *net eccentric* will be used when referring to these respective phases of power generation and dissipation about different joints throughout this article. Identifying the basic differences in the kinetic patterns associated with the muscle activity surrounding the hip, knee and ankle during different phases of sprinting can therefore allow the S&C coach to better select exercises specific to the relevant joint kinetics required for each phase.

Ankle

The muscles surrounding the ankle joint create a plantarflexor movement throughout the entire stance phase. Following foot strike, this resultant joint movement helps to reduce the negative vertical velocity of the body through power dissipation (net eccentric contraction) about the ankle for approximately 30% of stance during early acceleration,[6,48] 50% during mid-acceleration[50] and 60% at maximum velocity.[5] Once this has been achieved, and the dorsiflexion has ceased, the plantarflexor movement then generates power (net concentric contraction) to extend the ankle joint and help propel the body into the subsequent flight phase. During early-acceleration, the total energy absorbed due to power dissipation at the ankle joint during early stance is less than the subsequent work done due to power generation by almost a factor of 3.[6] By mid-acceleration (14 m) these appear to be roughly equal (i.e. a factor of 1),[50] whereas during maximum velocity this factor has been found to drop to around 0.6,[5] with the ankle plantarflexors dissipating more energy than they are generating (i.e. doing more net eccentric than concentric work). There is therefore clearly a larger power generating (net concentric) emphasis at the ankle joint during early-acceleration compared to maximum velocity. This may be due to the reduced horizontal braking and vertical impact ground reaction force peaks during early-acceleration, as well as the increased time available to generate force, although additional research is required to investigate this further.

Knee

During early-acceleration, the knee typically continues to extend upon touchdown, although this rate of extension is sometimes slowed by the presence of the horizontal braking forces.[6] These forces are commonly associated with the presence of a net flexor movement at the knee joint in the first few milliseconds of stance during early-acceleration,[6,48] after which an extensor movement dominates for the remainder of the stance phase. Slightly more variable knee joint movement patterns have been observed during mid-acceleration[46,50] and maximum velocity,[5,62] although there is typically a knee flexor movement of greater magnitude during early stance as the phases of a sprint progress, (likely due to the increasing influence of the braking forces). Due to these differences, the knee joint appears to be considerably more involved in net concentric activity during the earlier stages of acceleration, whereas as a sprint progresses the knee musculature has been suggested to adopt a more compensatory role.[5] In all stages of a sprint, the muscles surrounding the knee joint appear to switch to flexor dominance prior to toe-off in an apparent attempt to terminate ground contact, and also due to the muscle sequencing involved in the biarticular transfer of power distally down the leg.[34]

Hip

Although the hip joint has typically been shown to extend throughout the entire stance phase during all accelerative and maximum velocity phases of a sprint,[5,6,46,48,50,62] the resultant joint movements around the hip are variable across the literature. In all phases, a net extensor movement is present at the hip at touchdown, and the magnitude of this has been identified as being important to sprint performance at maximum velocity.[62] By toe-off, this movement has

Table 3. Key biomechanical differences in stance phase characteristics between acceleration and maximum velocity.

Variables	Acceleration	Maximum velocity
Ground contact times	Longer	Shorter
Ground reaction forces	Greater emphasis on horizontal	Greater emphasis on vertical
Joint kinetics	Greater emphasis on net concentric power generation (particularly at the ankle and knee)	Greater emphasis on net eccentric power dissipation (particularly at the ankle and knee)

changed to flexor dominance in order to reduce the rate of extension at the hip joint, but the time at which the dominance switches from extensor to flexor appears not to be dependent on the phase of a sprint, having previously been observed at around 70% of stance in the first two steps of a sprint,[6,48] ~50% at the 14 m mark;50 and both ~60% and ~80% during maximum velocity (at 60 m).[5,46] Whilst this could be influenced by the accuracy with which this data can be determined using current inverse dynamics analyses, (and the propagation of errors as the analysis progresses up the leg), it may be due to individual ability and differences in technique between the studied athletes. For example, hip extensor dominant athletes capable of producing more powerful contractions may require an earlier switch to flexor dominance in order to prevent the duration of the stance phase increasing.

The overall patterns observed in the joint kinetics are logical, given the demands of sprinting, as greater power generation is required towards the start of the run to rapidly create velocity from an initial stationary position. With the exception of the kinetic activity at the hip, it would seem that there is a shift in emphasis from this power generating (net concentric) to power dissipating (net eccentric) activity as a sprint progresses. Eccentric work may, therefore, become increasingly important during mid-late acceleration and maximum velocity sprinting due to the larger peak vertical and horizontal braking forces experienced.

Strength training recommendations

The kinetic and kinematic differences identified between accelerative and maximum velocity sprinting in this article (summarised in *Table 3*), suggest that if a S&C coach wishes to maximise the transfer of training effects to a specific phase of sprint performance, appropriate exercise selection is important. There are numerous strength training exercises which may be suitable to develop both phases of sprinting, some of which are highlighted in *Table 4*. Based upon Bondarchuk's[10] theories of training transfer, exercises for improving sprint speed can be classified in a hierarchy according to the degree to which they satisfy the principles of dynamic correspondence[87,95] for the skills of accelerating and sprinting at maximum velocity.

General preparatory exercises

General preparatory exercises (GPE) such as those shown in *Table 4* produce high forces against the ground (predominantly bilaterally) and are primarily used to develop neuromuscular adaptations such as motor unit recruitment and firing frequency.[36,52,71,72,75,86,98] These exercises are related to the ability to produce force through a triple extension (hips, knees and ankles) movement pattern.[12,24,26,38,41,99,102] Based upon this principle, it has been postulated that high force strength exercises, such as squats and deadlifts, and high force, high velocity explosive exercises, such as cleans and snatches, may induce neural adaptations which enable the athlete to recruit larger motor units more effectively for the similar movement patterns observed in sprinting.[14,35,67,77,99]

Clearly a wealth of information exists on these exercises and their associated benefits. It is beyond the scope of this article to provide a technical coaching model and rationale for each of these exercises, so readers are referred to other literature (e.g.[11,22,232,76,80,88,100,103,104,105]). Furthermore, as GPE do not necessarily

Table 4. Sample strength training exercises which could be utilised for the development of acceleration and maximum velocity sprinting during different phases of a training year.[10]

Phase		Acceleration	Max. Velocity
↑ Specificity	Specialised Developmental	Resisted sprinting Short hill sprints	Weighted vest sprints Speed bounding
	Specialised Preparatory	High load sled towing Standing long jump Med ball dive throws	Hurdle jumps Depth/drop jumps Overhead med ball throw
		Jerks Barbell squat jumps Explosive step-ups	
	General Preparatory	Clean and Snatch Lunge and split squat Squat and Deadlift (and stiff-legged)	

closely replicate the kinematics of the skill being trained and therefore do not meet the principles of dynamic correspondence to a high degree, they are not the primary focus of this article. It is not until the specific preparatory periods of training that a S&C coach ought to select exercises bearing greater resemblance to sprinting to help direct the strength increases gained from GPE towards the patterns required. Due to a lack of evidence to support the use of some of the more specific exercises discussed in this article, it is important to note that the exercise selection guidelines for the different sprint phases given in *Table 4* for the specialised and preparatory developmental phases are intuitive suggestions, based on the previously discussed biomechanical comparisons to provide some examples of how such differences could be accommodated in training. More research is required to investigate the transfer of training of such exercises to performance in the different sprint phases, and to assess the extent to which these exercises satisfy the principles of dynamic correspondence. The aim of the remainder of this article is therefore to provide a rationale for utilising these exercises during the specific preparatory period of a sprint training programme.

Specialised preparatory exercises

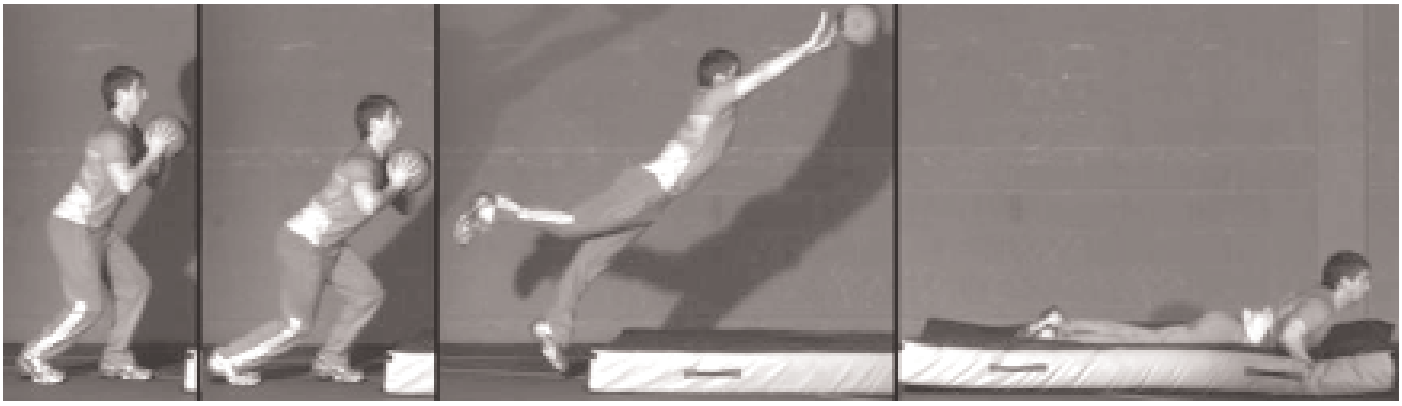
While typical multi-joint lower-limb strength training exercises such as the squat are deemed appropriate for the development of strength during a general preparation phase, more specific preparation periods containing specialised preparatory exercises (SPE) should cater for the phase of sprinting being addressed.[28,32,53,81,107] During specific training periods, it could be speculated that the strength exercises selected should have contact times close to, and forces comparable to or higher than, those in sprinting. Additionally, the above comparison of differences between phases would suggest that the exercises selected should also reflect the different directional force requirements between acceleration and maximum velocity. However, it is largely differences in body position, (e.g. a larger positive touchdown distance – centre of mass initially much further forward relative to the foot at touchdown during acceleration), that allow an athlete to redirect their force production relative to the ground (i.e. globally), rather than a modification to the way the body operates within its local frame in terms of force production (i.e. a proximal-to-distal hip-knee-ankle triple extension is clearly evident in all phases[5,48,50]). This suggests that attempts to match an exercise to the directional force production requirements should take place through a change in body position, so similar forces are generated from a closed kinetic chain pattern of movement.

The relatively short ground contact times during both acceleration and maximum velocity pose a challenge to the athlete. It has been shown that the temporal response to the development and transmission of muscular force in vivo to a single electrical impulse in human knee and ankle extensors in young adult males far exceeds the time available when running,[37] highlighting that it would be impossible to reach maximum force production during the stance phase. For this reason, it would appear that strategies to increase rate of force development should supersede those implemented to increase maximum strength during this phase of training.

Plyometric exercises are widely used by coaches as a means by which to increase the rate that force can be produced through an enhanced utilisation of the stretch shortening cycle (SSC),[13,93] as occurs in all stance phases of a sprint about the ankle.[5,8,50] The duration of contact will reflect the type of SSC function taking place. Schmidtbleicher[86] suggests that the SSC can be classified as fast if the contact times are less than 0.25 s and angular displacements of the hips, knees and ankles are small, whereas a slow SSC comprises longer contact times and larger angular displacements. Although the understanding of the SSC mechanisms remains incomplete, different adaptations are likely to result from fast and slow SSC[9] and thus training with slow SSC may not be suited to activities that involve a fast SSC and vice versa. The ground contact times during acceleration and maximum velocity *(Table 1)* imply that a fast SSC occurs in both. However, there are clearly differences in contact time as a sprint progresses, and simply classifying all contacts into the same 'fast SSC' category may be misleading, as contact times during early acceleration can be around double those observed during maximum velocity (e.g.[4], *Table 1*). Where possible, exercises with contact times at the shorter end of the 'fast SSC' continuum should be selected for maximum velocity and the longer end for acceleration, although in reality there may be few plyometric exercises where the ground contact times are less than 0.16 s.[101] However, the importance of force production and the rate at which it is developed must be accounted for, as it appears that faster sprinters are able to achieve higher velocities due to their ability to produce greater force in less time, rather than simply spending less time in stance. Further research is clearly required to assess the direct transfer from plyometric exercises with different sprint-specific contact times to the different phases of sprinting. It is acknowledged that greater forces are produced during a number of plyometric exercises than in sprinting.[70] As a result, in exercises such as bounding and hopping where ground contact times are longer than those during sprinting, one could speculate that they are still likely to have a positive transfer effect due to the higher levels of force production and the similar leg extension patterns adopted. However, the greater the disparity between ground contact times in the sprint phase being developed and the plyometric exercises used, the less specific the exercise (and potentially the SSC used) will become. Furthermore, although a greater lower-limb eccentric demand during stance has been identified when sprinting at maximum velocity,[5] a SSC occurs at the ankle during all phases of sprinting. Thus, plyometric exercises would clearly be appropriate during acceleration as well as maximum velocity, and previous research has observed improved acceleration performance (over 40 m) following a plyometric intervention.[83]

The SPE listed as suitable to all sprint phases within *Table 4* appear to provide a transition from GPE to more specific SPE and may be useful in the local rather than global reference frame of force production. Whilst there is limited research regarding some of these exercises, they do not correspond dynamically to a great extent to one phase or another, but are suggested to have mechanical similarities to both phases of a sprint so can be classified as special preparatory exercises for developing sprinting performance. Exercises performed under loads, which have a slow SSC component and relatively low eccentric actions such as a jerk exercise or a barbell

Figure 2. Medicine ball dive throw.



squat jump may seem more suited to improving an acceleration phase of sprinting. However, as these exercises produce high vertical forces[33,44] it could also be argued they are also suitable for improving maximum velocity sprint speed.

The exercises suggested for the development of acceleration *(Table 4)* place an emphasis on the development of explosive concentric strength, previously identified as important during this phase. The medicine ball dive throw *(Figure 2)* incorporates the forward rotation of the centre of mass about the stance foot prior to leg extension, as identified during accelerative sprinting, to augment the horizontal production of force. Standing with feet in a staggered position with a medicine ball held to the chest, the athlete extends explosively at the ankle, knee and hip whilst 'diving' forward and projecting his or her body into the air, launching the medicine ball in a largely horizontal direction for maximum distance. For safety, a crash mat should be used for landing as illustrated in *Figure 2*. It is also advisable for athletes new to this exercise to practice the technique and executing a safe landing without any load before progressing to the full dive throw movement.

The standing long jump *(Figure 3)* would seem to be well suited to acceleration due to its low eccentric and high concentric demands, and the requirement for the athlete to move their centre of mass forward of their base of support prior to jumping, helping to direct their leg extension forces (associated with the triple extension) more horizontally. Performing the exercise off one leg and hopping for distance will make the activity more specific to an acceleration phase *(Figure 4)*.

High-load sled towing has been proposed to be a form of training that bridges the gap between general strength training and specialised developmental track-based conditioning.[49] This training method encourages an increased forward lean, as observed during acceleration as a result of the large horizontal ground reaction force production, as well as a unilateral triple extension pattern. The guidelines for loading of weighted sled towing, which appear later in this article, should be followed when resisted sprinting is purely being utilised as a special developmental exercise (SDE). The suggestion that training with weighted sleds and vests may elicit long-term alterations in sprinting technique, which adversely affect sprint performance, is purely speculation and unsubstantiated in the research literature. Resisted sprint techniques using higher loads are likely to alter sprint kinematics acutely,[25,57,64,72] however higher loads may provide more general strength adaptations which will assist with the transfer of training from GPE. The influence of sprinting with loads higher than those currently suggested in the literature requires further research.

A major consideration for the S&C coach in regard to the type of exercises selected during maximum velocity specific training are the increased braking forces evident as a sprint progresses from early acceleration towards maximum velocity. The explosive power generating (net concentric) action of muscles about the knee and ankle during acceleration make way for greater eccentric strength demands, which becomes

Figure 3. Standing long jump.

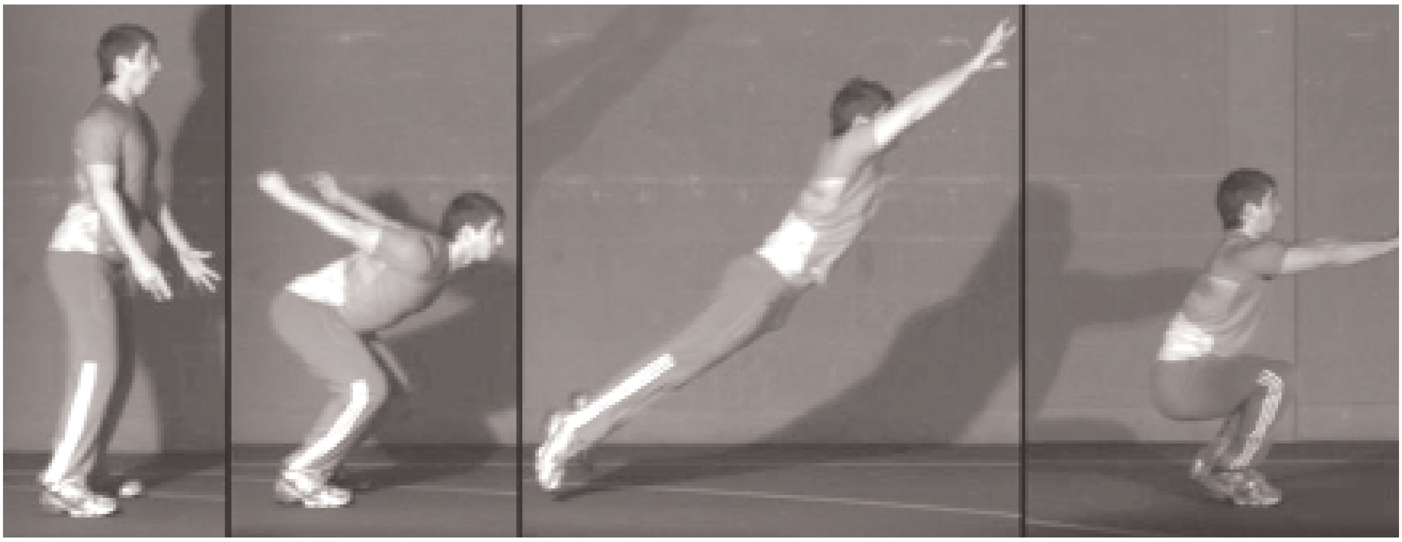
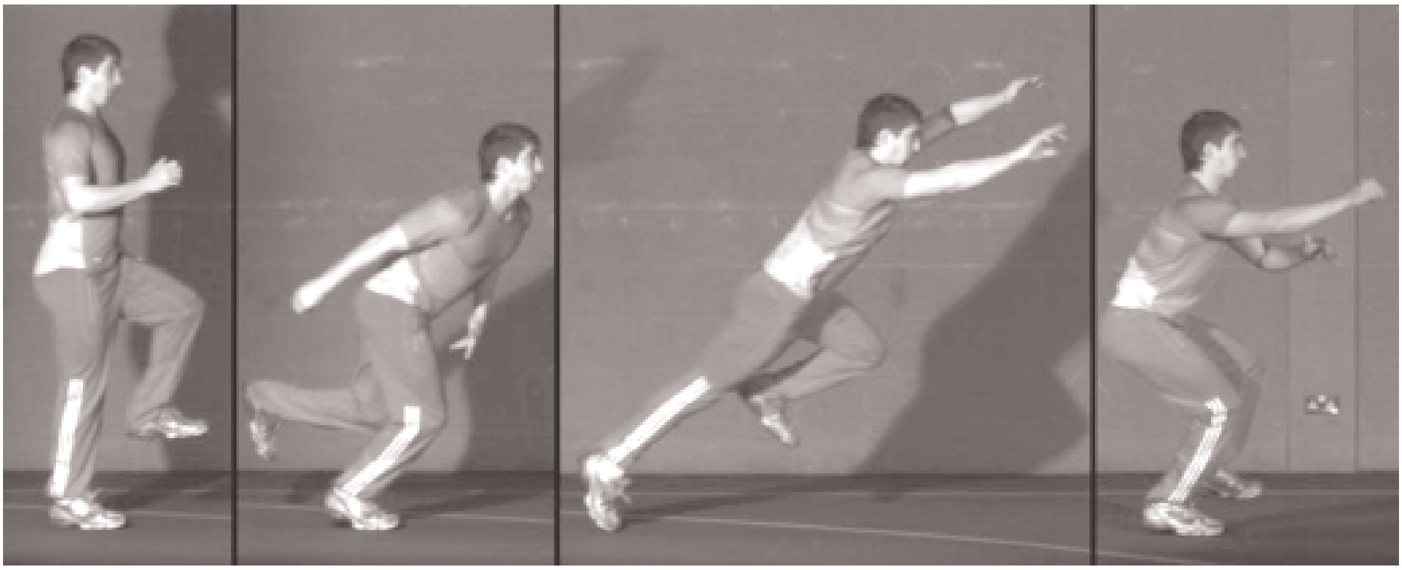


Figure 4. Single leg standing long jump.



increasingly important as velocity increases. This is due to the increased negative vertical velocity which an athlete must reverse upon contact, as evident by the increased power dissipation (net eccentric work) observed about the ankle and knee joints as a sprint progresses. The exercises suggested in *Table 4* for the development of maximum velocity sprint running are typically characterised by vertical force production, smaller displacements at the ankle, knee and hip and a greater emphasis on power dissipation (eccentric strength) requirements when compared to acceleration.

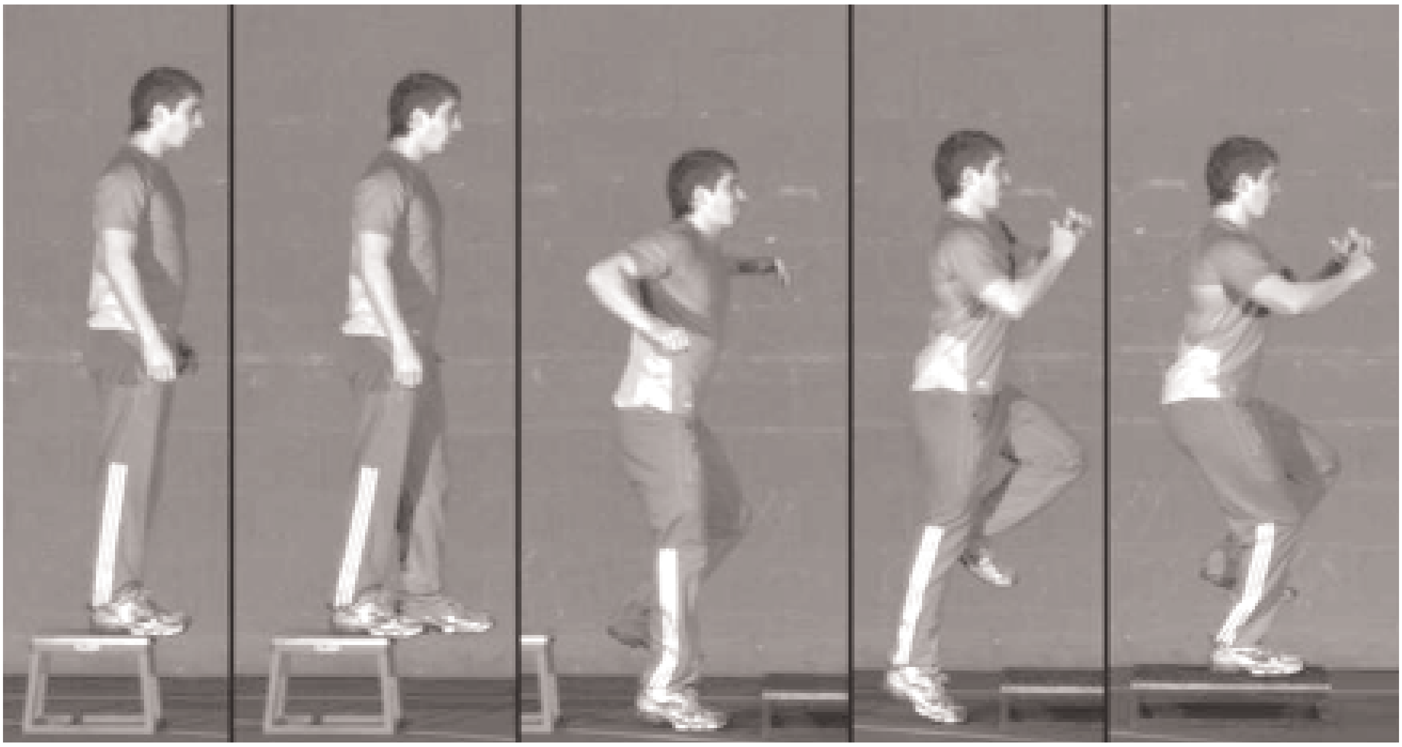
Vertical depth/drop jumps *(Figure 5)* require large vertical forces[9] to be produced and emphasise a short SSC, thus appear to be well suited to maximum velocity sprint running. Traditionally, the depth jump is performed bilaterally, which reduces the specificity of this exercise to sprinting. Single leg depth jumps are not often advocated due to the excessive force exerted unilaterally and long contact times. However, with a suitably low box height and reduced ground contact times, single leg depth jumps may be an appropriate method of training for maximum velocity for more advanced athletes *(Figure 6)*.

Based upon typical flight times of 0.125 s in maximum velocity sprinting *(Table 1)* and simple equations of projectile motion, the vertical velocity of the centre of mass at touchdown would be achieved from a box height of 2 cm. This suggests that depth jumps from considerably greater heights actually place a much greater initial demand on the body to overcome the downward velocity when compared to early stance during maximum velocity sprinting. Whilst a box height of 2 cm is not necessarily a recommended box height, it indicates that the ground reaction forces exhibited when the foot strikes the ground during maximum velocity sprinting are produced by more active means (due largely to hip extension) than the forces observed during a depth jump. For these reasons, hurdle rebound jumps *(Figure 7)* may be more appropriate to maximum velocity sprinting than depth jumps. Hurdle rebound jumps have a high eccentric loading phase and require considerable force production during ground contact. On the downward phase the athlete has to actively 'strike' downwards quickly in order to apply force to the floor in time to bring legs back up quickly enough to clear the succeeding hurdle. Hurdle rebound jumps may be more favourable than a box rebound jump as the athlete is often in a flexed position when jumping from the box and so full extension is not present on every other repetition.

The overhead medicine ball throw *(Figure 8)* is another exercise requiring largely concentric vertical force

Figure 5. Vertical depth/drop jumps.

Figure 6. Single leg vertical depth/drop jumps.



production through a triple extension pattern that may provide a link between GPE and max velocity sprinting.[10,66,90] Little research has been conducted into the optimal weight to utilise for medicine ball overhead throwing. Loads of around 7% of body mass have shown moderate correlations with peak power output, as measured with a CMJ[66] with lighter loads, (3kg) showing a much higher correlation.[90] It should be noted that these results are likely to be influenced by several factors including the anthropometric dimensions of the athlete, strength levels and degree of skill.[66] Heavier medicine balls (8-15kg) are likely to bring about adaptations which are more general in nature, so when used as a SPE the load of the medicine ball should be light enough (5-7kg) to allow a more rapid and explosive execution of the movement to improve the transfer of training to maximum velocity sprinting.

There are numerous exercises specific to either phase or appropriate for both phases, and therefore it is important to note that the exercises proposed thus far are suggestions based on the previously discussed biomechanical differences. However, discussion of these exercises clearly highlights the importance of considering the different demands within a sprint due to the different phases.

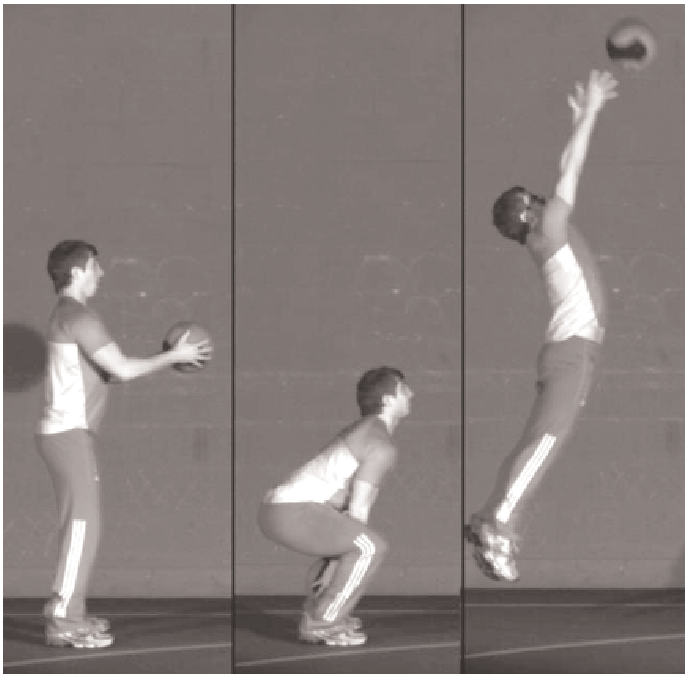
Specialised developmental exercises

SDE involve overloading the actual skill being trained by replicating the movement pattern and in doing so, make it possible to more effectively and selectively improve an element of the skill being targeted.[10] Any SDE should be used alongside, and in conjunction with, further execution of the actual skill being trained, usually within the same session, to reduce any potential for negative transfer of learning. A S&C coach has a limited number of exercises at their disposal when selecting SDE. Exercises which overload a mechanical element of a sprint phase should be selected, with assisted and resisted sprinting and various plyometric bounding exercises suggested in the literature for improving sprint performance.[2,21,28,29,30,58,79,89,91,101,106]

Many different resisted and assisted sprint training methods have been investigated with the aim of improving the acceleration phase of sprinting.[1,28,58,79,89,91,106] Sled towing is one specialised developmental exercise for sprinting, purported to lead to greater levels of adaptation by recruiting more muscle fibres through increasing the load on the leg extensors.[17,29] It is well established that resisted sled

Figure 7. Hurdle rebound jumps.

Figure 8. Overhead medicine ball throw.



towing causes alterations to acceleration phase kinematics,[58,65,74] by acutely increasing stance time and angles at the trunk and hip resulting in an increased contact time during the first step of a sprint start[25,65] and inducing a more horizontal position during an acceleration phase.[58,74] Although sled towing sprint training is believed to increase lower-limb strength, there are concerns that the effects may not transfer to acceleration performance due to negative influences on acceleration kinematics.[49,58] As a result, several studies have sought to determine the optimal load to minimise kinematic alterations to technique but maximise long term benefits to acceleration performance.[1,58,65,89] If sled load is too light, stimulus to the neuromuscular system will be insufficient resulting in little change in sprint performance through this means,[89] but if resistance is too high, acceleration kinematics may be altered,[65] reducing the specificity of the exercise and the transfer of training effect. Data indicates that a load which represents 10% of body mass appears to have no negative effect upon kinematic variables associated with an acceleration phase,[1,65,74] whereas loads greater than this begin to adversely affect technique.[65] Other authors have suggested loads of 5-10% body mass[74] and up to 32% body mass[58] may improve sprint performance. Similarly, it has been suggested that acceleration velocity should be decreased by no greater than 10% as a result of towing a load.[49] Previous authors[58,89] have proposed an equation to calculate the optimal load required for sprint training with a sled:

$$\%\ \text{body mass} = (-1.96 \times \%\ \text{velocity}) + 188.99$$

This is where % velocity represents the required training velocity as a percentage of maximum velocity (e.g. 90% of maximum). Although these recommendations offer some insight into the optimal load for sled towing, further research is required. There have been relatively few intervention studies that have examined the effects of sled towing upon sprint performance,[17,39,86,90,102] with results showing acceleration velocity appears to improve as a result of sled towing sprint training compared to non-resisted sprint training but with maximum velocity remaining unaltered.[18,40,94,106] Other studies have found a period of sled towing training to be no more effective at improving acceleration than non resisted sprint training.[89]

Utilising weighted vests whilst sprinting has been suggested as a means of special developmental training to improve maximum velocity sprint speed.[2,18,25,85] Few studies have investigated the effect of weighted vest sprinting upon changes in sprint kinematics[2,25] and sprint performance after a period of training wearing additional load,[18] with suggestions in the literature for prescription of training mainly anecdotal.[28,29] Increases in eccentric loading at ground contact causing higher braking forces and longer contact times have been shown to induce changes to sprint kinematics when vest loads are >15% of the athletes body mass.[2,25] However, there is currently no evidence that short exposures to loads heavier than this whilst sprinting causes alterations to sprinting kinematics long-term.

Both uphill and downhill running have been suggested to improve sprint performance.[20,27,79] Research is lacking on biomechanical alterations to sprint technique as a result of a gradient change, however it has been shown that sprinting up a 3° slope decreases velocity (3%), decreases step length (5%) and increases trunk flexion, effectively placing an athlete into a similar position to that observed during an acceleration pattern of sprinting.[56,78] Authors have suggested that hill incline should be of a gradient that does not compromise running form,[27] although clearly this is open for interpretation. Guidelines for uphill sprinting in the literature are largely anecdotal[27,78,79] but it is recommended that slopes do not exceed 3°. The chronic effects of this SDE compared to sprinting on a flat surface have yet to be investigated.

Bounding exercises have been shown to produce similar force-time characteristics to that of maximum velocity sprinting[70,101] and are performed unilaterally in a cyclical manner whilst generating high forces, which are observed by large hang/flight times when compared to sprinting at maximum velocity. For these reasons, bounding exercises would appear to meet the principles of dynamic correspondence with respect to maximum velocity sprinting. The sprint or speed bound exercise referred to in *Table 4* is simply an exaggerated sprint with an emphasis on completing the required distance as quickly as possible.[101] The distance covered with each 'step' is therefore less than, and the stride frequency is greater than, in traditional bounding, where height and distance are maximised without necessarily an emphasis on completing the required distance or number of steps as quickly as possible.

Minimal research exists comparing the biomechanical factors of unilateral based plyometric exercises to sprinting (e.g.[70,101]) or their transfer to sprint performance (e.g.[64,83]) with most studies in this area investigating bilateral plyometric exercises and their association with vertical jumping (e.g.[63,92]). With this in mind, the S&C coach should logically select plyometric-based SDE based on the relevant research available and the related discussion points highlighted in this article.

Conclusion

In conclusion, there are clear biomechanical differences during the stance phase of acceleration and maximum velocity sprint running. Longer ground contact times exist during acceleration, with a greater requirement for explosive concentric strength, directed more horizontally. Shorter ground contact times exist during maximum velocity, with a greater requirement for reactive eccentric strength, and vertically directed forces. These relatively clear discrepancies can help inform the S&C coach in selecting exercises to improve either phase in isolation. Less clear, however, is the approach a S&C coach should take when looking to improve both speed qualities concurrently. Without a sound understanding of the biomechanical parameters involved in linear sprint running, a S&C coach may, at best, limit an athlete's horizontal velocity during acceleration and maximum velocity and, at worst, hinder their performance in either phase. More research is needed to ascertain the effects of different training modalities on the different phases of linear sprint running and whether training for one will have a detrimental effect on the other.

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The Application of Weightlifting to Sprinting

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Introduction and problem statement

Weightlifting and its derivatives are commonly used tools to enhance sprint performance. Coaches have placed high importance on the lifts due to their explosiveness and spatial-temporal similarity with sprinting, particularly the triple extension of the hip, knee and ankle joint.[6] Scientists have found that using weightlifting derivatives produces more favourable adaptations to enhance sprint performance than power lifting style training.[15] Nonetheless, debate exists as to whether weightlifting derivatives do actually overload the biomechanical components of sprinting and whether you "need to clean" to be a fast sprinter.

The purpose of this paper is to explore the nature of adaptations seen following the use of weightlifting derivatives and their relevance (or irrelevance!) to sprinting. This paper will address the issue by exploring the mechanical and physiological demands of sprinting before deconstructing the biomechanical demands of weightlifting. The relevance of weightlifting to sprinting will then be discussed. It is beyond the scope of this article to review the vast amount of literature on the physiological adaptations of weightlifting and high force training. However, the mechanisms of adaptation to weightlifting training are important considerations, as they will dictate the frequency, volume and intensity of work to be performed in order to facilitate positive adaptations for sprint performance.

Anatomical, physiological and mechanical limitations to sprint performance

By understanding the physical limitations to sprinting, an appropriate strength and conditioning programme may be developed to improve the physical characteristics which are limiting an athlete's sprint performance.

Anatomical

When comparing the relationship between mass and speed across a variety of animals and humans, (including sprint and distance runners), it was found that relative muscle mass was positively related to movement speed.[25] From an anatomical perspective, faster animals have more fat free muscle mass.

Concentric muscle action velocity in vivo is related to muscle fascicle length, as longer muscle fascicles reduce muscle contraction time.[23] These findings have relevance to sprinting as Kumagai *et al*.,[22] found that 100m sprint performance was related to the vastus lateralis muscle fascicle length. Put simply, faster sprinters had longer muscle fascicles.

When assessed in an isolated environment, Kubo *et al*.,[20] found that there were no differences in the stiffness characteristics of the achilles tendon between sprinters and controls. In running, Kuitunen *et al*.,[21] found (using an inverse dynamics analysis), that although ankle stiffness remained constant with increasing running velocity, faster runners adopted consistently greater ankle stiffness than slower runners. Kubo *et al*.,[20] also found that the vastus lateralis tendons of sprinters had greater elastic properties than controls. Indeed when assessed in running, knee stiffness did increase with running speed.[21] This evidence does point to structural issues like achilles tendon stiffness as dominant in determining ankle stiffness and also possibly a limiting factor to brevity of ground contact. As

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we use the knee to moderate leg stiffness across a range of speeds, our fixed ankle stiffness represents a top end limit. If the stiffening properties of the achilles tendon were increased and the elastic properties of the knee were improved, it would be possible to reduce contact time and maintain centre of mass height with larger impulses during ground contact and subsequently improve sprint performance.

Although it appears that animals with greater fat free muscle mass are faster than those with less, extra muscle mass is useless unless the knee and ankle tendons have the compliance to act as a stiff spring to prevent the negative vertical displacement of the centre of mass. Additionally, longer muscle fascicles are required to facilitate greater contraction velocities under higher forces. From an anatomical perspective, training must be undertaken to maximise the relationship between muscle mass and tendon stiffness, whilst increasing muscle fascicle length. There is evidence to suggest that activities which produce an eccentric high force and velocity overload may achieve these aims.[23]

Mechanical

Hunter *et al*.,[16] used a multiple linear regression on selected biomechanical variables to determine which ones account for most of the variance in the acceleration phase of sprint performance. The authors found that 57% of the variance in sprint performance was explained by relative propulsive impulse whilst relative braking impulse explained a further 7%. This research has supported the work of Weyand *et al*.,[24] who showed that athletes who were able to maximise their impulse within the shortest ground contact time possible were able to perform longer strides at maximum velocity. During acceleration, it seems that the amount of impulse relates directly to the horizontal velocity of the athlete. Hunter *et al*.,[16] furthered their work to show that there was a relationship between large mean hip extension velocity during ground contact and propulsive impulse. This is of interest because Bezodis *et al*.,[2] and Johnson & Buckley[19] have both reported large peak hip power during ground contact. In fact, peak hip power occurs as the foot is under the hip, immediately prior to the hip flexors being eccentrically loaded to facilitate a high velocity hip flexion.[2;26] Jacobs & van Ingen Schenau[18] have shown that with jumping movements, power is most effectively transferred in a proximal to distal fashion. The proximal to distal sequencing of hip, knee and ankle extension (once the large hip power has been produced), may facilitate a greater transfer of power to the ankle plantar flexors, (which exhibit large concentric power[2]), and then to the ground during the stance phase of sprinting.[16] In coaching terms, this is referred to as the triple extension.

Although maximising propulsive impulses is fundamental to sprint performance, it appears that minimising braking impulses, and reducing the negative vertical displacement of the centre of mass, may all contribute to reducing ground contact times.[4;17] In order to minimise braking impulses, the horizontal velocity of the foot prior to touch down should be reduced, as should the horizontal distance between the foot and the centre of mass at touchdown. Practically, this requires using an active foot contact. The mechanical consequences of this are that the knee and ankle joint can maximise the stiffness qualities of the tendon during ground contact.[9;21] This research has shown the interesting relationship between tendon architecture and mechanical function of an athlete sprinting.

To improve sprint performance, training must be undertaken which increases the power of the hip extensors whilst the knee and ankle extend in a proximal to distal fashion and the foot is in contact with the floor and under the hip.

Physiological

A review of the mechanical limitations to sprinting have revealed that large amounts of muscle force are required in short periods of time in order to both reduce the negative vertical displacement of the centre of mass, and to increase propulsive impulses. From a physiological perspective, it may be considered that maximal force expression and rate of force development limit sprint performance. The limitations to maximal force expression include muscle cross sectional area, rate coding and levels of muscle activation.[9] The limits to rate of force development include muscle fascicle length, rate of cross bridge cycling, doublet discharge rate and rate of muscle activation.[9] Training to increase maximal force expression requires heavy strength training. Whilst rate of force development can be improved in relatively weak athletes by increasing maximal force expression,[5] increasing rate of force development requires light to moderate load, high velocity resistance training, which can include plyometrics and weightlifting derivatives. It is important to note that adaptations to power training are load specific.[5]

Biomechanical demands of weightlifting

The purpose of this section is to discuss the biomechanical demands and nature of the pull phase of the clean and snatch. By understanding the biomechanical demands of weightlifting, it will be possible to identify whether weightlifting is a relevant modality to improve sprint performance.

Baumann *et al*.,[1] reported that when elite athletes snatch, maximum hip, knee and ankle angle occurred within 0.04s of each other at the end of the second pull. Additionally, maximum vertical velocity of the barbell occurred immediately prior to maximum extension of each joint angle, and within 0.05s of the end of the second pull. Peak angular velocities at the knee were greater during the second pull than the first, providing a potential reason for increased barbell velocity and power during the second pull when compared to the first.[10] This is important, as it shows that elite athletes employ a pattern of maximal triple extension to maximise barbell velocity and power.

Hip extension angular velocity was also greater than peak knee extension angular velocity, indicating that in order to achieve greater barbell velocity during the second pull the hips had to extend at a very high rate.[1] It is important to note that although the hips extend at a very high rate, no relationships have been found between angular kinematics and peak barbell velocity,[3] or successful and unsuccessful lifts.[13] Nonetheless, the greatest power production during both the clean and the snatch occurs during the second pull, when the hips and knees are undertaking a pattern of triple extension and extending at their maximum rate.[1;10]

Enoka[8] reported that during the clean, the athletes employed their hip extensors concentrically to

Table 1: A table to show the relevance of weightlifting to sprinting based on the limiting factors of sprinting and the biomechanical requirements of weightlifting.

Requirement for Successful Sprinting	Relationship to Limiting Factor	Weightlifting Application
Large hip extension angular velocity[17]	Large propulsive impulse[17;24]	Peak hip extension angular velocity coincidental with peak barbell velocity[3] in order to produce large propulsive impulse[12]
Large hip extension power[2;19]	Large propulsive impulse[17’25]	Large propulsive impulse generated by hip extension power[1;8;12]
Proximal to distal extension pattern of the hip, knee and ankle under the centre of mass[16;17]	Maximise propulsive vertical impulse[17;24]	Proximal to distal extension pattern of the hip, knee and ankle under the centre of mass[1;7;8] in order to maximise propulsive impulse[12]
Knee stiffness[16;19]	Increase spring stiffness and reduce contact time[4;21;26]	Power catch (no evidence) or pattern of eccentric and concentric loading of knee extensors during transition[1;8]
Ankle stiffness[16]	Increase spring stiffness and reduce contact time[4;26]	Power catch (no evidence) or pattern of eccentric and concentric loading of ankle plantar flexors during transition[8]

maximise hip extension velocity. Baumann *et al*.,[1] did note a strong correlation (r=0.95) between peak hip extensor movement and system mass, indicating that performance was related to the torque production of the hip extensors.

The contribution of the knee flexors and extensors was a little more complicated, although it remained constant throughout the sample of athletes, regardless of skill or load. As reported in other investigations, the knees underwent a pattern of extension, flexion and extension which signifies the double knee bend.[1;7] During the first pull, the knee extensors were loaded concentrically prior to an eccentric loading of the knee flexors in preparation for the double knee bend. During the double knee bend, the load shifted to the knee extensors eccentrically prior to a large concentric action of the knee extensors in the second pull. Essentially, during the knee bend the athletes were utilising the stretch shortening properties of the knee extensors to maximise concentric knee extensor power.[7]

Interestingly, the relationship between system mass and peak knee extensor movement (r=0.61) and peak knee flexor movement (r=0.57) was much weaker, and indicated that the pattern of knee motion was much more related to differences in technique rather than performance.[1] This has supported the work of Enoka,[8] who showed that whilst timings of knee muscle power changed with load, magnitude did not. In practice, a skilful and well-timed double knee bend maximises performance and the ability of the hip extensors to produce large amounts of power.[7;8]

Interestingly Enoka[8] reported that the ankle plantar flexors were loaded concentrically, eccentrically and then concentrically during the double knee bend. This has shown that using a double knee bend may be advantageous for developing the eccentric loading capabilities of the ankle plantar flexors.

The results of these investigations reveal that employing the double knee bend in weightlifting, facilitates an eccentric-concentric coupling action of the knee extensors and ankle plantar flexors which may hold relevance to sprinting. Additionally, the large power production of the hip extensors at the end of the triple extension maximises weightlifting performance and may facilitate favourable adaptations for sprint performance.

Relevance of weightlifting to sprinting

It is worth reiterating that the relevance of a training exercise is determined by whether it will elicit specific adaptations, which improve the factors that limit the individual athlete's performance. If it is considered that sprinting is limited by an athlete's ability to maximise propulsive impulse in a short ground contact time,[17;24;26] then weightlifting exercises may be relevant as they produce large propulsive impulses.[12]

In order to produce large propulsive impulses in sprinting, the hip extensors are required to produce large concentric power during ground contact.[2;16] Indeed, in both the snatch and the clean, performance is limited by hip extension power during the second pull.[1]

During sprinting it appears that power is transferred to the ankle in a proximal to distal fashion (triple extension), which is similar to the transfer of energy from the athlete to the bar during the pull phase in weightlifting.[2;11;16] Whilst sprinting, the height of the centre of mass is maintained and ground contact time is reduced by the large eccentric loading capabilities of the ankle plantar flexors and knee extensors, and the subsequent stiffening characteristics of the knee and ankle joint.[16;20;21]

In order to reduce ground contact time, the stiffening characteristics of the ankle and knee joint need to be improved. Although there is no evidence that any phase of the pull or catch in weightlifting overloads this, there is a high rate of eccentric to concentric loading of the ankle and knee extensors during the double knee bend. By employing a well-timed double knee bend technique during weightlifting or a shallow catch during a power clean or power snatch, the stiffening characteristics of ankle and knee joints may be improved.

In *Table 1* the limiting factors of sprint performance have been presented and the relevance of weightlifting for particular limiting factors has been identified. It is hoped that this could serve as a useful needs analysis of sprinting and act as a justification for the inclusion or exclusion of weightlifting exercises for sprint performance.

Practical applications

Weightlifting is a skill which must be coached appropriately.[8] If the technical execution of an exercise is poor, the relevance of the exercise to sprint performance may be lost. Certain phases of the pull phase in weightlifting overload the musculoskeletal system in a way which is relevant to the factors that limit sprint performance. For example, the snatch is a faster lift and produces more power,[10] so heavy snatches or snatch pulls may be relevant when overloading the power production characteristics of hip extension. Equally, more absolute load can be lifted with a clean, and hip movement increases with load,[1] so heavy cleans or clean pulls may be more appropriate when attempting to facilitate higher force adaptations at the hip extensors. Variations of lifts such as pulls from boxes and lifts from hang can be used to overload the hip extensors without the athlete having to lift from the floor. This may reduce the total stress of the exercise, whilst maintaining sufficient specific stress to facilitate high force and power adaptations at the hip extensors. These might be used in season or during a heavy competitive schedule. Using a power catch may overload the knee extensors and plantar flexors in a manner which is relevant to sprinting, (i.e. eccentric loading in order to maintain the height of the centre of mass). The largest limiting factor for the biomechanical relevance of weightlifting to sprinting is the fact that sprinting takes place with one leg on the floor at a time whilst weightlifting requires two. A simple solution may be to lift from one leg or catch in a split position. However, these should be used with caution, as firstly, it is vital that the athlete is technically proficient at weightlifting and secondly, lifting from one leg may reduce the overall force applied and power produced by the athlete, and may not be a significant enough stress to facilitate the adaptive process.

It is important to recognise that, although weightlifting exercises can be used to overload certain characteristics of sprint performance, they are not the only means of training which will improve sprint performance. When selecting an exercise to improve sprint performance it is important to understand the limiting factors of sprinting, the specific limits of an athlete or group of athletes and what adaptations are likely to occur as a result of using a particular exercise. In order for strength and conditioning coaches to be more informed with their exercise selection, the biomechanical demands of a greater number of exercises must be analysed by researchers.

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Michael Afilaka interview

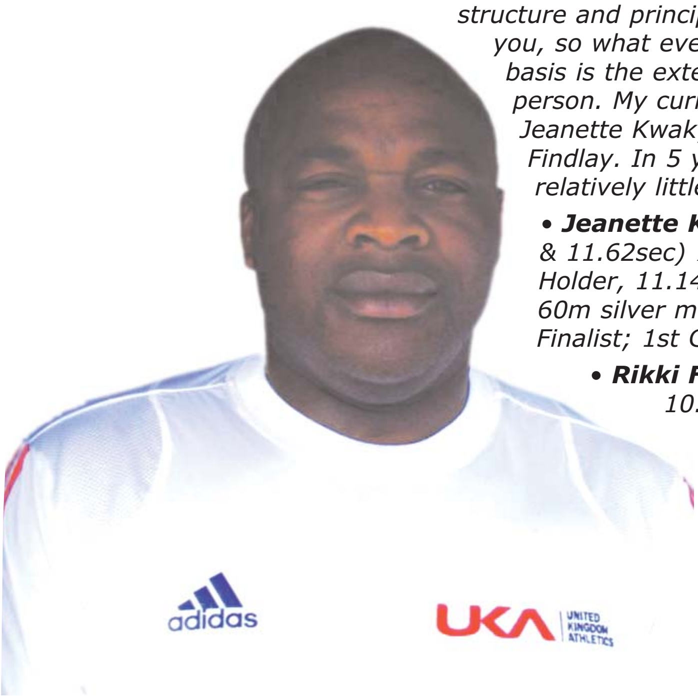
What was your athletic background prior to coaching and how do you think this has informed your coaching philosophy?

I retired in 2000 from athletics, having competed for about 10 years in track. Over the 200m I was ranked as a top 10 British sprinter a couple of times, made the AAA's final, won the Scottish champs, BUSA (indoor & out) and anchored Britain to a 4x100m silver at the World Universiade in 1995. I became very inquisitive and passionate about getting faster and the different training methods in the sport. I never wanted to coach though. My search for knowledge took me to great coaches like John Smith, Dan Pfaff, Tom Tellez and recently Lance Bramann and Michael Holloway. A lot of my beliefs and practice is built on science, solid technique and a clear understanding of loading, progression, regeneration and recovery. As an athlete and a coach I also worked and learnt from British coaches including Ted King; Ron Roddan, who coached me from 1994-97; Lloyd Cowan; the late John Bailey and Mike Smith to name a few. I have learnt different things from different people and arrived at my own philosophy.

What athlete success have you had and how far do you credit the role of the coach in their achievements?

Firstly, I think the role of a coach is very important. I started in coaching by running monthly regional camps and weekly talent programmes in the Midlands between 2002 and 2004. I did not start my own coaching group until winter 2004. I am BIG on discipline, planning and a sound structure around what I do and I try and extend this to my athletes. The great UCLA Basketball coach John Wooden once said, (& I completely agree with him), "if all we do as coaches is make our kids great basketball players then we have failed as coaches." That is the embodiment of MY coaching fundamental: making athletes responsible; making them understand and respect themselves, their sports and the TEAM that is helping them get to where they are going to. If you keep on learning and developing as a person, then you can apply yourself to most things using the same structure and principles that the sport has taught you, so what every coach sees on a daily basis is the extension of the athlete as a person. My current athletes include, Jeanette Kwakye, Ashleigh Nelson and Mark Findlay. In 5 years of coaching I have had relatively little success:

- **Jeanette Kwakye:** (Joined me at 7.50 & 11.62sec) 7.08sec 60m British Record Holder, 11.14sec -100m - World indoor 60m silver medalist, Olympic Games 100m Finalist; 1st GB woman finalist since '84.
- **Rikki Fifton:** (Joined at 20.91 & 10.52sec) (2004 -2011) - Former European U-23 200m medalist, 2008 Olympian, Former No1 European 200m ranked, 100- 10.16sec, 200m- 20.46sec
- **Angelita Broadbelt Blake:** 110H – (2008-2010)



Michael Afilaka MSc, BA(Hons). Michael is regarded as one of the leading British sprint and hurdle coaches and has worked with a number of elite athletes both on the track and in other sports. He is currently working for UKA as a senior performance coach based at Lee Valley Athletic Centre in London, where he works with world class elite and development athletes and is in charge of the Great Britiain 4x100/4x400m junior women's programme.

improved from 14.2 to 13.20 sec, progressed in the 2 years from 28th in the UK to 1st for pure hurdlers (Jessica Ennis was ranked 1st overall).

In between 2005-2007, I also coached some national level athletes, (all of whom have moved on): Leon Baptist (200m -20.80sec, 100m -10.3sec), James Ellington (100m -10.3sec), Sarah Claxton (12.93sec), Gemma Bennett (14.10 to 13.17sec) among others.

For me all these results were achieved coaching on a part time basis in the evening like most coaches when I was back from work. I did not coach FULL time until Oct 2009.

What value do you place on general strength qualities in the progressive development of speed potential?

General strength is important in all I do. My starting point is that weights/strength training is a means to an end, not the end in itself i.e. it is not the main activity but it helps us execute our activity better. So getting the athlete strong enough to carry out the particular activity at the required and the highest level is very important in my programme. For example, if an athlete can't pull to the top in clear lift, then they can't fully extend and would not be able to fully extend out of the block on their first few strides. In that case we step back and address the obvious lack of body part strength that we need for that particular movement, rather than be obsessed with how much they can't lift. I work very closely with Raph Brandon (National EIS S&C lead), who understands our weekly and yearly plan. I feel his understanding of what we do is important, so both the strength and track training can be integrated at the highest level. We produce programmes individual to the athletes, but also one that is incorporated into other aspects of our training e.g. Speed session, plyo's, throws, multi jumps etc.

From day 1 our max strength regime goes together with our speed development sessions, which in the early GPP phase is twice a week. We also divide the strength programme across the year - weights work, what we call S&C (this we refer to as muscles robustness/muscles integrity work) e.g. muscle activation work, development of weak hip flexors. Some of this includes slow movements, movements under tension, posture and isolationist development.

What performance value do you see to purely technical improvements in athletes?

With regard to running and movements, my overall philosophy is 'until an athlete makes the fundamental technical changes then they can't improve'. So when you see an athlete with BAD technique, it's a combination of what they are doing and what their body would allow them to do, so they might not be not strong in certain areas or be body aware in their movement pattern. If it's the latter, I spend a vast amount of time teaching and changing what I need them to do. For example, acceleration - we will cue, video work (via biomechanics - to improve flight time, contact time), via different drills over a long period of time so they can master the skills (start in October).

What strategies do you implement to monitor and/or control fatigue in speed focussed athletes, considering so much of their weekly programme is explosive in nature?

This is quite simple. The athlete needs to develop their CNS battery doing work that is 95%+ intensity. The moment there is an obvious change in the movement of the athlete regarding the particular objective of the session (e.g. speed session) and quality drops, I stop the session. I use film (during sessions), watch fatigued movement, sessions before and after (density of sessions weekly and cycle) and a lot of therapy during the week. Some of my women sprinters have specific kinesiology/physical tests that we do to determine what they can handle for the day. We track figures of our past good scores to decide if certain sessions are done and also I take a lot of consideration from the impact a woman's menstrual cycle has on the kind of work we are doing as the joints, SIJ and the general oestrogen level are down so we plan for that as well. Yes we want to develop speed but a lot of speed work is SUB MAX in nature in the course of the yearly speed programme as the body cannot run fast all year round in training.

What are the biggest problems you see in the coaching of speed in the UK?

Picture fruits on a tree being the highest point of that tree. The roots, trunk, branches and leaves would be at a lower level. Your main activity or event always sits at the fruit level, which is the activity in itself. Now if you relate each element of the work we do to the structure of the tree from the bottom (root) up, circuit training would be at the roots level as it's too far from the 'fruit', bounding would be slightly upper in the chain, blocks starts might be the leaves as it's closer to the activity.....Max Velocity would be the fruit as it's closest in nature and intensity to the event. So the simple answer to your question is that a lot of coaches stay too far away from the activity in the preparation phase and leave it to the last minute to do the quality work- speed in this case. They spend a vast amount of time 'building a base' or 'getting fit'. Most of the time the 'fitness' is not related to the activity; it takes the body more than 2 weeks to get speed. In fact you might argue that it's the hardest component to achieve out of all the energy pathways and it's the focal point for most of the energy systems e.g. speed endurance. One of the other problems we have especially from junior to senior athletes is that we don't make a lot of technical, fundamental or strength changes as they grow up. Another issue is coaches that do too much too soon with the speed instead of building it in gradually through the periods/cycle/year, while also managing it with regards to other work components.

If you had a key fundamental lesson you have learned in your years of coaching speed athletes, what would it be?

For speed lesson, maximum absolute speed can't be achieved unless the athlete moves correctly, on the ground and in the air. I have learnt to manage my speed component through the year, while incorporating extensive learning and technical changes. As I said above, it's about CNS stimulation and development to cope with that particular event. Generally, I have an open mind, respect your peers and understand how they get their results. Be a little more patient in the early days and most importantly, NEVER stop learning and caring about your athlete. It's a joint relationship that requires both parties input for it to work, the key is for each party to know where their boundary lies and own it, master it.


A


B


C


D

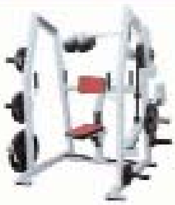

E


F


Dual Stack Functional Trainer
at the Sports Institute of Wales


Belt Squat


8 Post Modular Power Rack


4 Way Neck


Selectorised Shoulder Press


Adjustable Plyometric Box