ADVANCED FITNESS TRAINING

for elite sports performance

A SPECIAL REPORT FROM

PEAK PERFORMANCE

The research newsletter on stamina, strength and fitness

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CONTENTS

FROM THE EDITOR

Advanced fitness training for elite sports performance

Once upon a time, simply playing and practicing your sport was considered more than adequate for developing sport performance. However, the sports science revolution of the last 20 years has changed all that. In 2010, whatever your sport or the level you compete at, maximising your sport fitness is absolutely essential for achieving your true potential.

In this special report, we look at the latest breakthroughs that are (or should be!) revolutionising the way sportsmen and women train for sport. These latest findings explain how you can build more power, more strength, more speed and more endurance so that you can perform faster, stronger and longer!

The report also contains the latest thinking about how you can structure your training in the longer-term in order to maximum your fitness gains and speed your recovery. It also tackles the perennial conundrum of how you can build strength and endurance simultaneously – an essential requirement for most sportsmen and women.

There's more good news too; by implementing these new training guidelines, you'll be able to achieve your fitness goals more efficiently and with reduced injury risk. This in turn means less time spent building your sport fitness and more time for developing your sports-specific skills!

Whatever your sport, sport fitness is absolutely critical, so if you're really serious about achieving your maximum potential, take advantage of this latest sport fitness science to get ahead of the pack!

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Plan for your future with real world periodisation

At a glance

- The importance of planning for optimal sport performance is outlined;
- The difference between linear and non-linear periodisation is clarified;
- The need for tapering is explained together with 'specificity of periodisation'

Organising training, periodisation and tapering to ensure fitness is improved year on year and that peaking is correctly timed is one of the most challenging aspects of coaching. Richard Godfrey looks at what the latest science has to say and demystifies the jargon along the way

In recent years, the concept of periodisation (the planned organisation of training) has become increasingly jargonised and hence often difficult to comprehend, particularly the difference between linear and non-linear models and when to use them. In this article, we'll attempt to simplify things and hopefully provide a clearer understanding to enhance the construction of your training plan in the short, medium and longer-term.

Back to basics

Any good sport fitness programme must have the following training principles at its heart:

- Progressive overload – the need to regularly increase the magnitude of any training stimulus;
- Specificity – recognises the fact that the body adapts in a way that is specific to the nature of the stimulus imposed [1]. For

example, to run faster, you need to train at a faster pace *etc*;
- Reversibility – also known as detraining, recognises that reduction in the magnitude of a given stimulus results in a decrease in conditioning for that particular parameter.

In recognising the need for specificity and the need to avoid detraining (reversibility), Matveyev, a Russian physical culture expert, devised 'periodisation' in the 1960s as a method of organising training in order to enhance the likelihood of a good training outcome [2]. He proposed that if a specific stimulus is not presented to the body on a regular basis then that aspect of conditioning will be diminished or lost. Research has since shown that without an appropriate stimulus, a good level of fitness can be lost in two to six weeks [3-6].

Traditional periodisation

Traditional periodisation starts with identifying a number of discrete competitions over the year that the athlete is required to peak for. Organisation of the annual training programme starts with those important competitions and works backwards. From a physiological perspective, it is not possible to improve the level of conditioning in several areas at one time. Training is therefore planned so that at certain times of year the emphasis is on improving one parameter while other areas are simply maintained.

Periodisation is usually partitioned into 'duration categories' to allow the prescription of training from a broad to more precise focus. To accomplish this there are three training cycles:
- A microcycle of one to 14 days;
- A mesocycle of two weeks to six months;
- A macrocycle of one to four years.

Hence the broad focus is macro, the more detailed is meso and fine detail is micro.

In any year there are four phases of training: the conditioning (or preparation) phase, the transition phase, the pre-competitive/ taper phase and the competitive phase. For summer sports such as 5000m running and javelin, the major conditioning phase occurs in the winter. For winter sports such as cross-country skiing and ski jumping, it occurs in the summer. Regardless of the actual time of year therefore, the off-season is the time when base endurance is the major focus for endurance sports and strength training is the major focus for strength and power sports. Of course in some sports, the demand is for a combination of endurance and power (*eg* rowing) so a simultaneous combination of endurance and resistance training is required (*see articles 3 and 4 elsewhere in this report*).

The transition between periods of major training emphasis should be seamless. So, in the transition phase there is an increase in one training type and a decrease in another. Taking 5000m and 10,000m running as an example, base endurance work occurs predominantly in the winter. Around mid-January, one session per week of base endurance work would be dropped in favour of a tempo/lactate threshold (LT) session, *ie* working at between 65-85% of maximal heart rate (where exactly within this range is appropriate will be individual-specific and depends on current level of conditioning). During the next four to six weeks there is a gradual decrease in the volume of base endurance work and an increase in the amount of threshold work. In this way a seamless transition occurs between periods of predominant focus.

'In linear periodisation, the primary aim is preparation for competition'

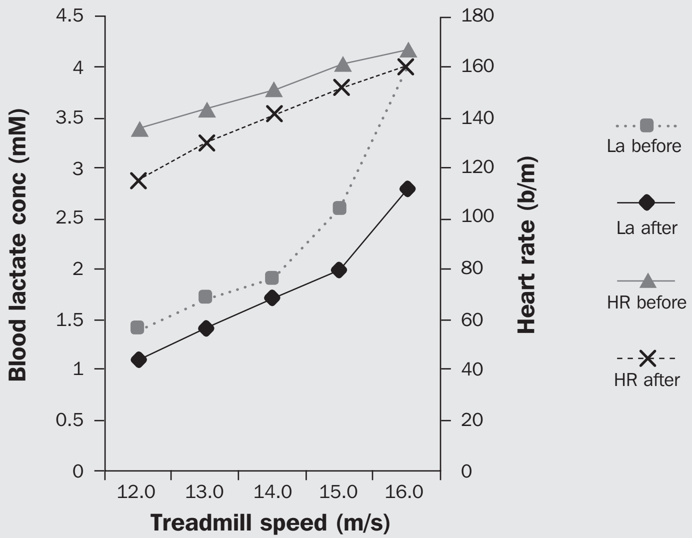
Table 1 at the bottom of the page shows an example of a periodised year for a 400m swimmer. This is an annual linear periodised programme with six to eight competitions in a season lasting 16 weeks (LT = lactate threshold training).

For winter sports, using cross-country skiing as an example,

Table 1: Periodised year for a 400m swimmer

Preparation		Transition	Pre-competition		Transition	Competition Season	Transition
Base endurance	LT	LT/Speed	Speed	Taper	Taper	Main competition training	Active rest
14 wks	8-10 wks	3 wks	2 wks	2 wks	1-3 wks	1 competition every 14 days for 16 wks	4 wks

Figure1: The physiological effects of LT/tempo training after 8-12 weeks



base endurance work occurs in the summer. This usually involves roller skiing, running and cycling, utilising base endurance training such as 30 minutes to two hours of continuous or interval work at 50-70% of maximum heart rate.

Likewise, the transition phase between the preparation (conditioning) phase and pre-competitive phase involves a decrease in the base endurance work and a gradual increase in the volume of tempo/LT work.

This increase in tempo/LT volume (either as increased duration per session or frequency per week or a combination of the two) continues until it becomes the largest percentage of training time. In other words tempo/LT work becomes the focus or emphasis of training at that time. The result is a rightward shift in the lactate work curve and a downward shift in the heart rate work curve. In functional terms this means the athlete is able to maintain a higher pace without fatiguing appreciably (*see figure 1*).

Other training types or stimuli are not eliminated but are used occasionally to maintain other aspects of conditioning. The key point here is that for individual endurance sports, training organisation is very similar, the only difference being the 'opposite' times of year where types of training occur between summer and winter sports.

This type of periodisation, where a limited number of discrete, specific times for peaking in the year are identified and training organised around them, is known as '*linear periodisation*'. In this model, the primary aim is preparation for competition or, more generally, improving the functional capacity (anatomy and physiology) of the individual. However, in sports where there is a long season, such as football and tennis, the time for training is reduced and the number of competitions is increased, and so a different form of periodisation with a different purpose is favoured.

Non-linear or undulating periodisation

The demand for more competitive sport to satisfy increasing audience demand and the desires of commercial sponsors has led to an increase in the length of the season in many sports and an increase in the number of competitions. This results in reduced time for applying training stimuli.

For example, in professional football, it is quite common for the quality of play generally to decrease towards the end of the season. Clearly, aspects of physiology related to 'high-intensity' performance are retained thanks to specific stimuli resulting from the game environment. However, those aspects that help to minimise fatigue and ensure good recovery are being lost because of a lack of lower intensity work, which is much more limited in the competitive situation.

Accordingly, it is common to see a decrease in aerobic capacity (VO_2max) during a long season in many sports towards the end of the season. This is a problem because a good 'aerobic base' is fundamental to allowing an athlete to handle a large training and competing load and to facilitate rapid recovery.

Steps should therefore be taken to avoid a reduction in VO_2max

'The primary aim of non-linear periodisation is the maintenance of previously hard-won physiological advances'

and this can be achieved by adding in one or two training sessions into each microcycle to maintain those aspects, which might otherwise be lost. For example, this could mean additionally including a long, slow distance session at 50-60% HRM (to maintain VO_2max) and a session of two to four minute intervals at 90% of HRM (to maintain anaerobic performance) every two weeks.

The primary aim of non-linear periodisation is the maintenance of hard-won physiological advances. Table 2 shows a simple example of a non-linear model from resistance training. Strength, strength-endurance and power are objects of desire among strength and sprint athletes and to ensure that at certain times of year all are maintained, training must encompass all of these every week.

Whether using linear, non-linear or a combination of the two models, providing scientific evidence that one model is superior to another is extremely difficult. For example when scientists examined the magnitude of strength improvements when comparing linear with daily undulating (non-linear) periodisation in 2002, they found that the non-linear model was best for strength gains (7). In 2003 another study repeated the same work, this time examining changes in local muscular endurance. No difference was found between a linear and non-linear model but there was a difference using a 'reverse linear' model, which worked best (8). In other words gradual increases in volume with gradual decreases in intensity were the most effective for increasing muscular endurance.

Tapering

Tapering (or 'peaking') is used to ensure that peak performance occurs when required. In broad terms, this involves reducing the volume of training to allow replenishment of energy stores and to facilitate recovery. Specifically, tapering requires maintenance of the intensity of exercise with a parallel reduction in the volume undertaken.

The relationship between the amount of reduction in volume and the amount of time over which that reduction takes place is critical. If the reduction occurs too fast then there will be an

Table 2: An example of a non-linear (undulating) resistance-training programme

MONDAY (strength)	
Squats	3x 3RM, 3m RI
Leg curls	3x 3RM, 3m RI
Bench press	3x 3RM, 3m RI
Seated row	3x 3RM, 3m RI
Calf raises	3x 3RM, 3m RI
WEDNESDAY (strength-endurance)	
Squat	3x 10RM, 1m RI
Knee ext	3x 10RM, 1m RI
Lower back ext	3x 10RM, 1m RI
Lat pull down	3x 10RM, 1m RI
Leg curl	3x 10RM, 1m RI
Calf raise	3x 10RM, 1m RI
Bench press	3x 10RM, 1m RI
Seated row	3x 10RM, 1m RI
Military press	3x 10RM, 1m RI
Abdominal curl	3x 10RM, 1m RI
Arm curl	3x 10RM, 1m RI
FRIDAY (power)	
Squat	3x 6 @ 12-15RM, 1m RI
Knee ext	3x 6 @ 12-15RM, 1m RI
Lower back ext	3x 6 @ 12-15RM, 1m RI
Lat pull down	3x 6 @ 12-15RM, 1m RI
Leg curl	3x 6 @ 12-15RM, 1m RI
Calf raise	3x 6 @ 12-15RM, 1m RI
Bench press	3x 6 @ 12-15RM, 1m RI
Seated row	3x 6 @ 12-15RM, 1m RI
Military press	3x 6 @ 12-15RM, 1m RI
Abdominal curl	3x 6 @ 12-15RM, 1m RI
Arm curl	3x 6 @ 12-15RM, 1m RI

NB, ‘RM’ is ‘rep max’, so 3-rep max is the heaviest weight that can be lifted just three times; ‘RI’ is rest interval; So, 3 x 3RM, 1m RI = three sets using the 3-rep max weight with one minute rest between sets

Figure 2: A combined linear/non-linear model; a linear periodised programme with 2-week detail for a non-linear competitive phase where there are 1-2 competitions per week for 16 weeks

Preparation		Trans	Pre-comp		Trans	Comp Season	Trans
Base endurance	LT	LT/Speed	Speed	Speed	Taper	***Non-linear periodised programme***	Active rest
14 wks	8-10 wks	3 wks	2 wks	2 wks	2 wks	1-2 comps per wk for 16 wks	4 wks

Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14
LSD	speed	LT	speed	easy	comp	rest	speed	LT	LSD	LT	speed	easy	comp

Note LSD = long, slow distance work, LT = lactate threshold / tempo work, Trans = transition phase, comp = competitive or competition.

insufficient stimulus to prevent detraining. If the reduction is too slow, inadequate recovery will result and performance will be sub-optimal.

Exponential tapers are generally considered best and are of two types; fast and slow decay. Exponential tapers involve a 'relative reduction' in volume – *ie* successive percentage decreases – whereas linear tapers reduce the volume by absolute amounts. A fast decaying exponential taper (larger percentage decreases), is used with very well conditioned (*ie* 'fitter') individuals or those with less available time between required peaks. A slow decay (smaller percentage decreases) is used with those who are less well conditioned (*eg* where time off due to illness or injury has been required).

In 2007, Canadian scientists carried out a meta-analysis (a study looking at the results of a number of previous studies) of the effects of tapering on performance utilising data from 27 separate research studies [9]. They concluded that 'a 2-week taper during which training volume is exponentially reduced by 41-60% seems to be the most efficient strategy to maximise performance gains'. This is an excellent and useful piece of information but it is not known whether this applies equally in well conditioned and less well conditioned individuals, partly because the level of competition in which the subjects participated was unknown. Hence, caution is required, but this is currently the best information we have and so we should 'suck it and see'.

Real-world periodisation

In the real world, with many sports increasing the amount of competition during their competitive phases, programmes emerge which are a combination of models, with a linear periodised model operating for most of the year and a non-linear model operating during the competitive phase. An example of this is given left in figure 2.

Conclusion

Periodisation is a means of organising and managing training to provide a greater likelihood of successful performance through year on year improvement and planned management of peak performance. Non-linear or undulating periodisation is increasingly used but rather than an either/or situation, it is most effective when both linear and non-linear models are adopted within the same annual cycle. This is particularly true where a sport has a long, intense competition season and, in that period, non-linear periodisation is, arguably, the only logical choice.

'Non-linear or undulating periodisation is increasingly used but rather than an either/or situation, it is most effective when both linear and non-linear models are adopted within the same annual cycle'

Achieving the correct taper has often been seen as the interface between coaching art and coaching science. Our constantly improving understanding of the efficacy of tapering is increasing the chances of optimal performance. However, much of our knowledge is still largely anecdotal and we look to the research literature to improve coach confidence and effectiveness. Where this is particularly true for periodisation, recent research evidence provides a good guide for tapering. Namely, that a two-week exponential taper during which there is a 41-60% reduction in volume seems to result in the best performance improvements.

Practical implications

- Athletes seeking increased fitness should plan their training schedules using a scheme of periodisation for best results;
- For long periods of competition, undulating periodisation plans may be more appropriate;
- The demands of the sport and fitness level of the athlete will also determine the best method of tapering.

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Building endurance: move forwards with reverse periodisation!

At a glance

- The concept of endurance in terms of energy systems in the muscles is explained;
- The conventional 'long and slow' method of building endurance is compared and contrasted with a lesser well-known method called reverse periodisation and the potential advantages and disadvantages are described;
- A practical guide to using reverse periodisation is given.

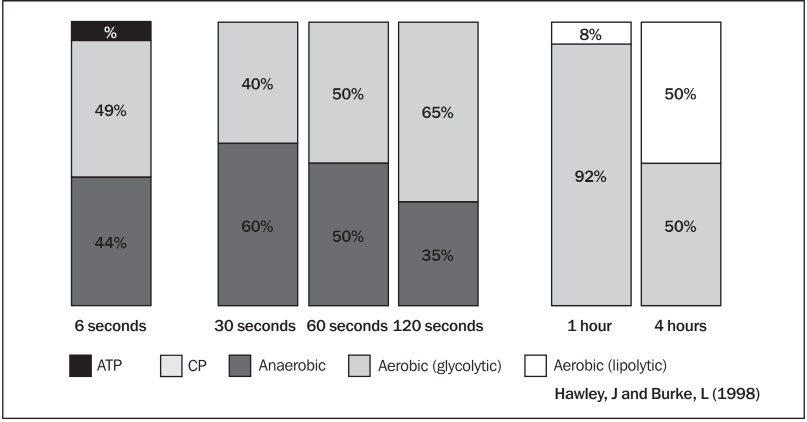
The conventional approach for endurance athletes seeking new personal bests is to build an aerobic base using large volumes of low-intensity training, then to sharpen up to build speed and competition fitness. However, according to Nick Grantham, it doesn't have to be this way because there's an alternative known as reverse periodisation…

What is endurance?

Endurance is simply the ability to resist fatigue, and fatigue in its simplest terms is the inability to sustain a given power output or speed. When the demand for energy from the working muscles is greater than the supply, you will either have to stop, or reduce the workload (*ie* slow down). The body has four ways to generate energy for the muscles so they can perform exercise. The four 'energy producing' processes are:

- ATP-CP system – uses adenosine triphospate (ATP) and creatine phosphate (CP) stored within your muscles to provide energy for short sharp bouts of exercise. This is your instant energy;

Figure 1: Energy systems and contribution during exercise



'The contribution from each energy system varies according to the intensity level of the exercise and the body's fuel supply'

- Anaerobic (lactic) system – anaerobic means 'without oxygen' and this system involves the breakdown of carbohydrate without using oxygen;
- Aerobic system (glycolytic) – this system generates power for muscle contraction from the breakdown of carbohydrate in the presence of oxygen;
- Aerobic system (lipolytic) – this system generates power for muscle contraction from the breakdown of fat in the presence of oxygen.

However, you never use exclusively one of the four systems. All exercise uses a combination, but the contribution from each system varies according to the intensity level of the exercise and the body's fuel supply (*see figure 1*).

Periodisation

The principles of periodisation, based on Eastern European ideas and methods, are the foundation of many athletic training programmes. However, surprisingly little is supported by scientific research, despite the fact that periodisation is widely used and widely written about, despite the numerous presentations on this topic, and despite the fact, based on practical observation, that it apparently works [2].

Tradition dictates that to be successful in endurance-based sports you need to complete high volumes of training. The traditional approach is to move from high volume/low-intensity work to low volume/high-intensity work. Basic periodisation also moves from general to more specific work as the competition approaches [3]. This is a popular method and is heavily featured in the classic book by Tudor Bompa (*Periodization: Theory and Methodology of Training*)[4]. But what if intensity and not volume is really the key for unlocking your endurance potential?

‘What if intensity and not volume is really the key for unlocking your endurance potential?’

A popular quotation, often attributed to Albert Einstein, is the definition of insanity as ‘doing the same thing over and over again and expecting different results’. When you read this, you probably thought, ‘Well, that’s obvious; of course you can’t expect to get a different result by simply doing the same thing over and over again’. However, I’m constantly amazed how often I see sportspeople doing exactly that.

This is not to say that classical approaches should be scrapped altogether, but in events where local muscular endurance is required, for example in swimmers, runners, cyclists, rowers and triathletes, reverse periodisation may be the better option [3]. The same can also hold true for athletes competing in team and combat sports.

Changing paradigms

Ian King, an Australian strength and conditioning coach, offered an alternative to the traditional model of endurance training in his book *Foundations of Physical Preparation*. In particular, he presented an alternative to the periodisation model, which he called ‘reverse periodisation’.

Ian King describes his approach thus: ‘The “reverse” approach is based on maintaining intensity closer to that which the competition demands (recognising that initially, the athlete’s capacity to perform this intensity will be low) then to increase the volume progressively, without sacrificing the intensity. In summary, the goal is for the athlete to learn how to

Figure 2: A traditional model for the periodisation of endurance

1. Develop an 'aerobic base'
2. Develop foundations of specific endurance (threshold work)
3. Carry out specific endurance work, together with and speed and power training
4. Taper

Aerobic endurance **Develop foundations of specific endurance** **Specific endurance**

run fast over a distance that they are capable of running fast over, then to increase that distance. The difference in approaches of these two models is essentially this: the traditional model commences with capacity (volume) and shifts towards power (intensity). The alternative model, as the name suggests, reverses this approach, commencing with power then shifting toward capacity.'[5]

Although there's a relative lack of research into the whole area of periodisation, this alternative approach makes intuitive sense, and people who made a living from coaching athletes such as Charles Poliquin and Istvan Bayli continued to contribute to its design and use. Here was a training method that could be applied across a wide range of sports, from endurance events such as swimming and running to team and combat sports.

The model for reverse periodisation can be traced back to the 'Eastern Bloc' days. In his book *Speed Trap*, track coach Charlie Francis (who clearly understood the importance of training intensity) discussed how East German sprinters began their training at top speed over short distances, before increasing the distance as the season progressed. This training methodology was not reserved purely for sprinters; it was also used by East Germany's competitive swimmers, who completed tough workouts in an endless pool[6].

Ian King's argument was that what worked with speed and power athletes could also be of benefit to any sportsperson taking part in events that require an element of endurance. Key to his rationale is the concept that speed endurance must be developed at the appropriate pace.

The revised method pretty much flipped the more traditional approach on its head. Athletes using this method bypass the 'aerobic base' work of the traditional model (*see figure 1*)and start by training specific endurance and speed/power training before moving on to threshold work and then tapering (*see figure 2*). At no point are they moving slowly for long durations. This is significant, because while the traditional approach of developing an 'aerobic base' focuses on the central adaptations of the cardiovascular system (heart and lungs), it pays scant regard to the muscles used to actually move the body! As Ian King makes clear in his text on the subject, sports conditioning is not just about endurance, and certainly not just about the heart and lungs.

The demands placed upon the musculoskeletal system at slow speeds are totally different to the demands placed upon it when working at higher intensities. It's a lot therefore to expect an athlete to spend months plodding around building an aerobic base, and then to suddenly crank up the speed and start working at higher intensities as the competition season approaches. This is because you are essentially asking the musculoskeletal system to re-programme itself to cope with the increase in training intensity, yet the development of endurance goes hand-in-hand with the functional specialisation of the skeletal muscles [7]. The reverse periodisation theory says that if you want to compete at a certain intensity, why not start at that intensity and then build the volume; not only will you get central adaptations that will go a long way to developing a great heart and lungs, you will also develop the inter- and intra-muscular coordination required to compete at the appropriate intensity.

'It's a lot to expect an athlete to spend months plodding around building an aerobic base, and then to suddenly crank up the speed and start working at higher intensities as the competition season approaches'

In practice: endurance sports

It is beyond the scope of this article to provide detailed training plans for all endurance sports (*eg* running, swimming, cycling, *etc*), but this section should provide you with some guiding

Box 1: The six training levels (L) for endurance sports

- ***Level One (endurance: 3+ hours)*** This level is pretty much where most people naturally default to. You are not going to stress the body enough to improve your aerobic fitness
- ***Level Two (aerobic capacity tempo: 45mins+)*** This level can be considered as your tempo workload and this is where you will start to make gains in your aerobic capacity
- ***Level Three (aerobic capacity – lactate threshold: 8-20mins)*** This is your lactate threshold (LT) work, where you increase the level you can work at before lactic acid builds up and stops you. LT training is one of the most important areas for training gains
- ***Level Four (maximum aerobic power – VO_2max: 3-8mins)*** This is a borderline anaerobic level where you increase your VO_2max, which helps train the body to clear lactic acid more efficiently
- ***Level Five (anaerobic capacity: 30s-3mins)*** This level is anaerobic, high intensity and where the demand for energy surpasses that which can be supplied by aerobic system. This training is often combined with Level Four training;
- ***Level Six (anaerobic power (about 10s)*** At this level you are sprinting. This is a level (extremely high intensity) that needs to be trained all year round.

principles that can be applied to any endurance sport. For the purpose of this next section it is useful to understand what intensity you should be working at and when. Box 1 (*above*) provides an outline of six training levels. This is just one system; you can work within your own training intensities as the underlying principle of developing power/intensity before capacity/volume remains the same.

A traditional plan may start off with sessions focusing on Level One (L1) work (long, steady efforts) before moving on and adding in L2/L3/L6 work, then later hitting L4 and building to L5.

If you adopt the reverse periodisation approach, you can flip things on their head. You start with L4 and L5, and then add L3. After these blocks you add L1/L2 and L6. You then cycle back to the L3/L4/L5 as a focus later in the season, either right before or right after events, or both. The idea behind reverse periodisation is that you develop your power first, and then you train yourself to maintain it. Then you add it to your normal base/tempo sessions that act as race simulations.

‘Reverse periodisation is a much more sensible approach for getting match- and fighting-fit’

Team and combat sports

The endurance fraternity have not been the only ones to adopt the traditional method of developing endurance. But just because a football match lasts 90 minutes and a rugby match lasts 80 minutes does not mean you have to be able to maintain a constant workload for those time-frames. The same also applies to boxers and other combat athletes. Just because a boxing contest may last for more than half an hour, it doesn’t mean you have to get up at 5am for a six-mile run! You fight in three-minute rounds and your workload during each round is intermittent in nature. Reverse periodisation is a much more sensible approach for getting match- and fighting-fit. Here is a suggestion for developing endurance in team and combat sports.

Table 1: An overview of the endurance sub-qualities that team and combat sport athletes need to emphasise

Sub-quality		Work	Ratio of work to recovery	Duration	Frequency	Intensity
Anaerobic	ST	10-60 secs	1:0.5-1.3	*15-30 mins	1-4 per week	Depends on the purpose of training, but for intervals 70%+ MHR
	LT	60-120 secs		*15-30 mins		
Aerobic	ST	2-6 mins		30+ mins		
	LT	6+ mins		30+ mins		

LT = long-term; ST = short-term; MHR = maximum heart rate

*Does not include warm-up or cool-down or recovery periods.

A traditional endurance plan for team/combat sport would almost certainly start off with sessions focusing on developing long-term aerobic endurance before moving on and adding in some short-term aerobic endurance. Once the base has been established, more time would be spent developing anaerobic capacity before finally working on what is arguably the most important endurance sub-quality for team and combat sport, anaerobic power.

Adopting a reverse approach, however, makes more sense. When I train my team and combat sport athletes, we start with very short, high- intensity efforts to develop anaerobic power. We then spend time on establishing anaerobic capacity before finally developing aerobic power and capacity (*see table 1*).

As we move closer to the business end of the season, we start to mix things up and add a variety of sessions that tax all of the endurance sub-qualities, in much the same way as those you would experience during a match or bout.

Conclusion

This article is not suggesting that we completely scrap the more classical approaches – simply that, if you have fallen into the trap of repeating yourself year after year, now may be a good time for a different approach. For example, if cycling or running is your thing, you'll be very aware of the short days during the winter months and the problems of trying to train outside in the dark. With a reduced 'after-work' training time available, it makes sense to train more intensely during the winter and to increase the longer rides and runs as the evenings draw out –

Practical implications

- Experienced endurance athletes with a good existing aerobic base may gain performance advantages with a reverse periodisation approach, particularly where speed is also required
- Reverse periodisation is less suitable for novice or very de-conditioned athletes and should therefore be used with caution.

exactly the approach of reverse periodisation. So maybe it's time to stop following the crowd and try something new in your training methods – after all, what have you got to lose? You may find you have plenty to gain…

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Concurrent training I: maximising strength and endurance

At a glance

- The fundamentals of metabolic pathways in endurance and strength training are outlined;
- Recent research on the roles of our genes and two key enzymes called AMPK and mTORC1 in facilitating adaptation to endurance and strength training are explained;
- Fitness training strategies are given to help athletes maximise their strength and endurance gains when performing concurrent training.

For hundreds of thousands of years, humans have evolved to be either as strong or as tireless as possible, but not both. As Keith Baar explains, however, recent science has provided clues as to how to legally move past the obstacles that evolution put in the way of developing both strength and endurance

Traditionally, the title 'World's Greatest Athlete' is bestowed upon the winner of the decathlon. The reason for this is that a champion decathlete exhibits the ultimate combination of strength and endurance. Despite this, many have argued that since these athletes would never beat a world-class specialist in any of the 10 individual events that make up the decathlon, they can't be the greatest athlete in the world. However, what makes the decathlete the single greatest athlete lies in their mastering *both* strength and endurance events.

The basic reason is that, within our bodies, the two processes of building strength and endurance are diametrically opposed: in other words, one tends to prevent the other. Therefore, to master both strength and endurance, we have to overcome limitations that have been laid down in our genes over hundreds of thousands of years.

It is not just decathletes that need to master both endurance and strength. All motor-endurance sports – for example, cycling, swimming and rowing – require both, as do many games, including rugby, basketball and ice hockey. Therefore, knowing how to optimise both strength and endurance is one of the keys to success for the modern sportsman.

While coaches have long been the leaders in developing strategies to maximise performance, a surprising number of advances in molecular exercise physiology mean that, for the first time, researchers are beginning to understand how best to train simultaneously for strength and endurance.

Enzymes and exercise training

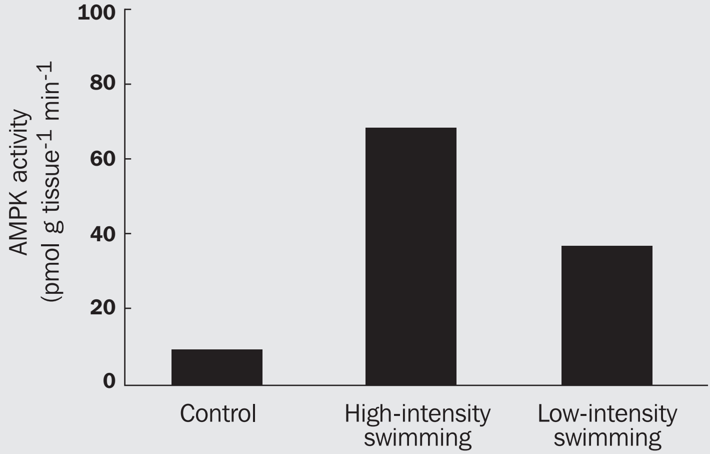
Before we can discuss how to train for strength and endurance together, it is necessary to understand a little about the basic process of how our muscles build strength and endurance. To do this, we will have to talk about two **enzymes** that play an important role in the effect of training on muscle. The first is the 'AMP-activated protein kinase' (AMPK) and the second is the mammalian 'target of rapamycin complex 1' (mTORC1).

'For the first time, researchers are beginning to understand how best to train simultaneously for strength and endurance'

AMPK and endurance – As the name suggests, adenosine monophosphate (AMP) activates AMPK. AMP is a molecule formed in muscles when large amounts of ATP are needed to power exercise. Basically, ATP is broken down into adenosine disphosphate (ADP), inorganic phosphate, and energy. It is this energy that we use to power our bodies. In order to rapidly make new ATP, two ADP molecules can be combined by an enzyme called myokinase, to produce a new ATP plus a molecule of AMP. It is this AMP that turns on AMPK during exercise.

During exercise, this enzyme increases the rate of sugar uptake and fat oxidation, allowing us to make more energy aerobically. But AMPK also has other important roles in

Figure 1: Exercise intensity and the activation of AMPK (adapted from [1])



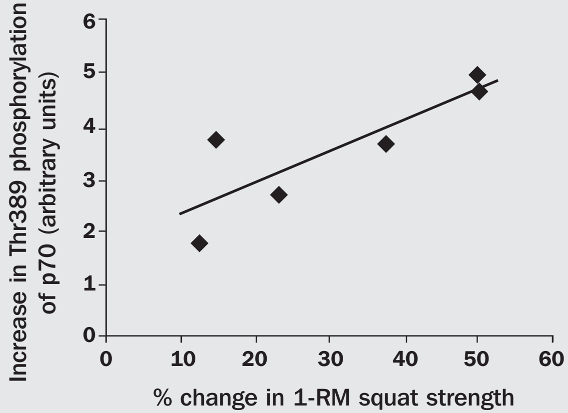
Activation of AMPK following either long-duration exercise or repeated sprint exercise. All exercise produces a metabolic stress that results in the activation of AMPK. However, high-intensity exercise results in significantly greater activation of AMPK than low-intensity exercise.

muscle. Along with the short-term increase in metabolism, AMPK is involved in the control of a number of genes that give muscles more endurance.

Using drugs and different models of muscle, molecular exercise physiologists have shown that repeatedly activating AMPK in muscle results in many of the adaptations that occur following endurance exercise. This includes the improved transport of fat and sugars into muscle, and the increase in **mitochondrial** mass, resulting in greater endurance. From these data, it is now widely believed that, within muscle, one of the primary goals of endurance training is to activate AMPK.

In an elegant study by Shin Terada, we learned that while long-duration exercise increases AMPK activity, repeated short high-intensity sprints produce a greater effect on AMPK (*see figure 1*). This tells us that, as far as muscle is concerned,

Figure 2: mTORC1 and strength gains (adapted from[2])



The correlation between mTORC1 activity (determined by the phosphorylation of S6K1) 30 minutes after a bout of resistance exercise, and the increase in strength following 14 weeks of resistance training. Note the strong correlation between mTORC1 activity and strength gains.

the best type of exercise for improving endurance is repeated high-intensity sprint exercise.

However, this does not mean that purely repeated sprint training is the best way to improve whole-body endurance performance, since a number of other tissues – including the heart, the circulatory system, and the connective tissue – must also adapt in order to translate endurance training into improved performance. But as far as muscle is concerned, the higher the intensity, the higher the AMPK activity and hence the better the subsequent endurance adaptation.

mTORC1 and strength – Unlike AMPK, mTORC1 is not activated by endurance exercise. Instead, this enzyme is turned on following resistance exercise. In fact, the activity of this enzyme is the best marker for muscle growth and strength improvement discovered to date. In every animal tested, from mice to humans, mTORC1 activity following a single bout of exercise is the best predictor of muscle hypertrophy and improved strength (*figure 2*). Not only does the activity of mTORC1 correlate with improved strength – when this enzyme is blocked by the drug **rapamycin**, muscle doesn't grow in response to a normal growth stimulus.

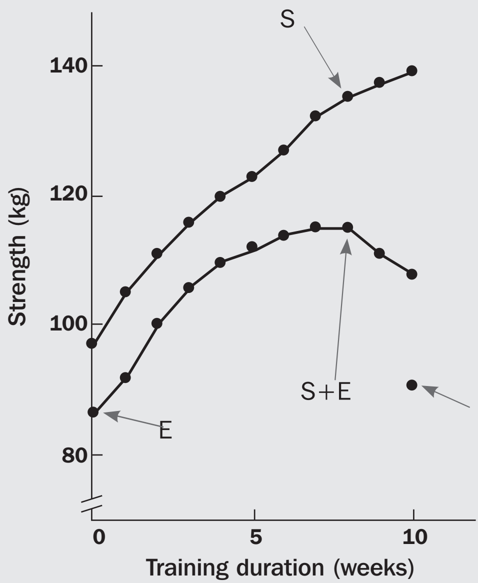
So, we know that mTORC1 is required for muscle growth and increased strength, but you are probably now wondering what it does. In order for our muscles to grow bigger and stronger, we need to increase how much protein we make within our muscles. This is where mTORC1 comes in. This enzyme controls muscle size and strength by regulating protein synthesis. Following resistance exercise, mTORC1 activity is increased and as a result there is an increase in protein synthesis that makes muscles bigger and stronger. From these data, strength coaches should have as their goal maximal activation of mTORC1 when looking to improve an athlete's strength.

Many strength coaches and athletes are already doing this unwittingly, by taking **amino acids**. The reason that this helps increase strength is that, like resistance exercise, amino acids – especially the branched-chain amino acids, such as leucine – activate mTORC1. Consequently, coordinating amino-acid supplementation and resistance exercise results in greater mTORC1 activation and therefore greater improvements in strength.

If amino acids can increase muscle size and strength, why not take supplements to maintain high amino acids at all time? The reason that this doesn't work is that mTORC1 has a self-braking mechanism. What this means is that if amino acids are sustained at high levels in the blood for too long, mTORC1 and protein synthesis are shut off. Therefore, it is the timing of the amino acids and not the total amount that is the key.

Another way to activate mTORC1 is through growth factors like insulin and insulin-like growth factor (IGF-1). Insulin and IGF-1 can both directly activate mTORC1 and indirectly activate mTORC1 by increasing the uptake of amino acids. This is why the IOC has banned insulin and IGF-1 as performance-enhancing drugs. However, diet can be used to legally increase

Figure 3: Concurrent training effect (adapted from[3])



The effect of endurance (E), strength (S) or concurrent training (S+E) on squat weight lifted. The endurance-training-only group was tested initially and following the 10-week training programme. The strength-training-only group improved their squat performance by 40%, while the strength-plus-endurance group showed only a 25% improvement in squat performance and the endurance-only group did not show a change in squat strength.

insulin, simply by adding some carbohydrate to any amino-acid supplement that an athlete takes. Coordinating this supplement with resistance exercise can increase mTORC1 activation and, as a result, strength.

The concurrent training effect

Many athletes and coaches will tell you that if you train for endurance and strength together improvements in performance are slower than if you train for one alone. This phenomenon is called the 'concurrent training effect' (*see figure 3*). It is here that molecular exercise physiologists are beginning to contribute to training efficiency.

As we have already discussed, AMPK leads to improved endurance and mTORC1 increases strength. So you might be asking: if two *different* enzymes have evolved to enhance two different aspects of fitness, why is it difficult to increase both simultaneously? The answer lies in the fact that AMPK can block the activation of mTORC1. What this means is that, in our genes, there is a block to improving both our endurance and our muscle mass and strength at the same time. This will come as no surprise to many coaches and athletes who already know that endurance training tends to prevent strength gains.

This genetic interaction almost certainly developed hundreds of thousands of years ago as we evolved to move over great distances to hunt for food. These long trips not only found the food that kept us alive, but also decreased the amount of muscle we had and, as a result, the amount of fuel we needed to consume. Today, when having enough food is not a concern, we are still fighting against the way we evolved eons ago.

Dynamics of enzyme activation

In order to overcome this genetic limitation and train for both endurance and strength, we need to understand a little more about how the two enzymes in question work. As described above, AMPK is turned on during exercise, but it is rapidly turned off when we refuel. This is because it senses the amount of glycogen in the muscle, as well as the metabolic state of the muscle. When these return to normal, AMPK turns off.

On the other hand, mTORC1 isn't turned on during exercise, but rather during the recovery phase from resistance exercise. The maximal activation of this enzyme occurs between 30 minutes and six hours, but can be maintained a full 24 hours, after a single bout of resistance exercise. The correlation between mTORC1 and strength gains occurs both at 30 minutes and six hours after training, suggesting that it is important to have mTORC1 active for a long time, in order for it to influence muscle strength.

Training for endurance and strength

From the information above, it becomes more obvious how we can maximise both endurance and strength. The key aspects of any programme aiming to do this are the timing of the exercise and the use of diet. The basic rules are:

1. Perform endurance training first and strength training last;
2. Add intensity to your endurance;
3. Take food with your weights;
4. Keep your strength sessions short;
5. Use negative repetitions.

The whys behind the rules

1. Endurance first – strength last: AMPK is rapidly turned off after exercise, but mTORC1 needs to be high for as long as possible for maximum effect – and AMPK turns off mTORC1. Therefore, if endurance exercise is performed first, early in the day, and glycogen is reloaded, then AMPK will be low later in the day (when the strength exercises are performed) and will not interfere with mTORC1. Training for strength at the end of the day (5–6pm) allows mTORC1 to be high for the rest of the evening and while the athlete is sleeping. When the athlete wakes, they will have at least 12 hours with high mTORC1, promoting muscle growth and improved strength before their next session of endurance exercise turns on AMPK and turns off the strength signal.

2. Add intensity to your endurance: AMPK is turned on by all exercise – but, since it responds to metabolic stress, the higher the intensity, the higher the metabolic stress and, therefore, the higher the AMPK activity. The best way to add high intensity is to follow a long endurance session with some high-intensity intervals. The long, slow exercise depletes muscle glycogen and this makes the high-intensity work even more of a metabolic stress than if the high intensity is performed while the athlete is fresh. This is because, as already mentioned, AMPK senses muscle glycogen levels. Therefore, depleting muscle glycogen before high-intensity exercise is optimal for activating AMPK and improving muscle endurance.

3. Take food with your weights: Diet is the most overlooked aspect of training and, when training for both endurance and strength, diet becomes even more important. Eating a high-carbohydrate meal or snack an hour after your endurance training will help to turn off AMPK and replenish muscle glycogen. Taking a drink or snack that delivers 6-8g of protein before strength training helps deliver amino acids to the working muscles. Since blood flow is increased to these muscles, they will see more amino acids than the non-working muscles and this, together with the activation of mTORC1 by the strength training, will result in maximal strength gains. Also, adding a protein- and carbohydrate-rich meal soon after completing training (around one hour) will increase insulin and amino acids in the muscle, thus supporting the training session.

'In our genes, there is a block to improving both our endurance and our muscle mass and strength at the same time. This will come as no surprise to many coaches and athletes who already know that endurance training tends to prevent strength gains'

4. Keep your strength sessions short: Make sure that your strength exercises don't last more than 60 seconds. Six to eight reps, performed properly, minimises the metabolic stress of the exercise. Energy for less than 60 seconds can be supplied from muscle stores. Stored ATP, **phosphocreatine** and glucose can provide all of the energy required to work hard for less than a minute. This keeps the metabolic stress of the exercise low, minimising AMPK activity and therefore maximising mTORC1. Taking twice the active time (*ie*, resting for around two minutes between sets) to recover those stores will also help keep the metabolic stress low.

5. Use negatives: Negatives (slow, lengthening contractions) put the maximal load on the muscle for the minimal metabolic cost. Muscle is around 1.8 times stronger when lengthening under load than when contracting. More importantly, muscle consumes much less ATP during lengthening contractions than it does during shortening contractions. This means that the body needs less ATP to lower a weight than to lift it. Besides that, we can handle a heavier weight with lengthening contractions. The result is more weight and less ATP used, and this translates into more mTORC1 activity and stronger muscles.

Summary

Most modern sports and games put a huge emphasis on developing both strength and endurance. For almost 30 years, we have known that training for both is not as efficient as training for either one individually. As molecular exercise physiologists, we are beginning to understand why this is, and that we can use diet and intensity of exercise to create training programmes that will simultaneously improve both strength and endurance. However, even when applying the rules proposed here, the genetic limitations mean that training for both strength and endurance will never be as effective as training for either individually. As a result, those of us who study concurrent training will continue to marvel at the great decathletes and always consider them the 'World's Greatest Athlete'!

Practical implications

- Because there's a degree of conflict in the biochemical processes underlying strength and endurance improvements, athletes should plan their strength and endurance training sessions according to the guidelines set out above;
- *Athletes should also remember that the role of diet is also critical for optimising simultaneous strength and endurance gains, particularly the timing of protein and carbohydrate intake.

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Concurrent training II: an update on concurrent training

At a glance

- The concept of concurrent training is introduced and previous research is discussed;
- New research demonstrating the benefits of concurrent training is presented and practical advice given for those wishing to try it as part of their own training routine.

Many sports require high levels of upper and lower body strength, muscular endurance and flexibility, yet the prevailing wisdom is that you can't train all these aspects of fitness simultaneously. However, according to James Marshall, new research suggests that concurrent training can deliver the goods

Prevailing wisdom says that by training on one area you automatically interfere with the development of another. In this article, we'll look at recent research from the University of California that shows how a method of training can improve all these factors at once [1,2].

Many sports require explosive actions to be performed in quick succession with limited or no recovery time. This scenario may then be repeated, for example over 5-30 seconds of a tennis rally, 1-2 minute periods of play in a rugby match, or 2-5 minute rounds in combat sports, and then carried on over the duration of the match.

Box 1: Endurance and strength

Strength is usually improved by coordination of the motor units within the muscle, the rate of firing of motor neurons within the muscle spindles and an increase in cross sectional area of the muscle. Endurance is improved by the ability to take up more oxygen (VO_2max) through central processes such as an increase in stroke volume (blood volume pumped with each heartbeat) as well as at the cellular level through an increase in capillarisation (the network of tiny blood vessels that supply working muscles) and the number and size of mitochondria (energy producing factories) within the cell. Endurance training on its own has not been shown to improve strength training and strength training on its own has not been shown to improve oxygen uptake.

'Concurrent training is a very time-efficient method of training, allowing a lot of activity in different formats to be performed in a short space of time'

Explosive movements require a strength base, while throwing, striking and hitting actions also require strength. Players who are leaner have less weight to carry around and so (all other things being equal) experience less fatigue. Players who have a greater VO_2max (maximum oxygen uptake capacity) can recover more quickly between these repeated bouts of work.

Rarely does a sportsman or woman use either strength or endurance in isolation; if you become stronger, but can't do as much overall work because you have poor endurance, you will be less effective. Conversely if you run around and get to a lot of positions but can't then execute effectively because you're too weak, that's no good either!

Given the above, it makes sense that fitness training for a particular sport should (at least some of the time) reflect the demands of that sport and that means working on endurance, strength, and muscular endurance at the same time. **Concurrent training** is the integration of aerobic type work and resistance type work in the same session. This is a very time-efficient method of training, allowing a lot of activity in different formats to be performed in a short space of time.

Coaches have known this for a long time; go to most combat sport gyms and you will see fighters working on bags, followed by circuit type exercises, followed by sparring or combinations of all three. Rugby League players often play small games, which require running around, followed by some partner resistance work or tackling bags or getting up and down off the floor, followed by more games.

However, some research has shown that trying to work on strength and endurance concurrently can interfere with muscle power or strength adaptations (3). This is also commonly stated in physiology textbooks and so sports science undergraduates are taught this, too (4). This leads to a situation where coaches who are training athletes see results, but sports scientists who are measuring physiological parameters come up with different answers from the coaches.

Whether you think the coach or scientist is right can depend on the research that you look at. The nature of research and publishing normally means that you have to look at one specific area, test it, apply a training principle and then retest it. In order to eliminate all other variables, researchers often limit their study to one specific area, and study that in detail (*see box 2*). Unfortunately this approach doesn't always transfer to the real world because the body (and the athlete) may not respond the same way to events and stimuli in isolation. Most athletes have to work on technical and tactical aspects of their sport for most of the year. Many of these sessions will be having at least some conditioning effect, so one aspect of training cannot be isolated.

'Rarely does a sportsman or woman use strength or endurance in isolation'

Overtraining

Another possible reason why some studies have found concurrent training ineffective is that they were conducted without following periodised plans, which may have led to overtraining. The study by Hickson consisted of ten weeks' continuous progressive exercise, with strength lessening in the last two weeks (9). If an athlete starts a programme with residual fatigue, he or she will not be able to adapt to an increase in stimulus and instead suffer a drop in performance, or a plateau.

Meanwhile, some studies looking at concurrent training and which showed interference (ie concurrent training ineffective) used untrained subjects [10,11]. The studies that have shown no interference and improved both endurance and strength have used well trained subjects [12,13,14]. It may well be, therefore, that untrained subjects do not have the capability to adapt to the combined training load.

Also, a lot of the research has looked at concurrent training where strength and endurance work were performed in different sessions in the same week or where basic concepts of periodisation weren't applied. One of the first studies looking at concurrent training was by Hickson, back in 1980[9]. The study used three groups of subjects:

- An endurance group, who alternated between interval training using six 5-minute sets with 2 minutes' rest on a cycle ergometer three days a week, and a running programme of 30 minutes in week one, 35 minutes in week 2 and 40 minutes thereafter;
- A strength group who trained three days a week on five sets of 5 parallel squats, with three sets of 5 reps on knee extensions and knee flexions; and two days a week on three sets of 5 reps on leg press and three sets of 20 reps on calf raises, with additional deadlifts and sit ups;
- A combined group who did both training protocols with a 2-hour rest between the endurance and strength sessions.

The results were as follows:

- The endurance group improved their endurance with no change in strength;
- The strength group improved their strength with no change in endurance;
- The combined group improved their endurance as much as the endurance-only group and also, for the first seven weeks, their strength. The strength gains leveled off, however, between the 7th and 8th weeks and then decreased during the 9th and 10th weeks of training.

This last result is not surprising; the subjects had not done any

Box 2: Concurrent training – effective or ineffective?

There are a number of reasons why some previous studies have shown concurrent training to be ineffective. Among these are:

Protein interference: After strength training, protein synthesis is essential in order to repair and rebuild the muscle. Endurance training has been shown to reduce the rate of protein synthesis in the hours after exercise, so combining the two incorrectly could limit the strength gains [5];

Neural interference: More a hypothesis than proven, the theory is that endurance training weakens the ability to produce explosive strength by reducing the rate of firing of the motor units within muscles[6];

Glycogen depletion: Both endurance and resistance training result in the depletion of glycogen stores (glycogen is the muscles' premium fuel grade fuel for high-intensity exercise). Performing two-a-day sessions or daily sessions may not allow enough time for muscle carbohydrate stores to be replenished adequately. Low glycogen levels have been shown to reduce the intra-cell signaling after resistance exercise, which may inhibit strength adaptations [7];

Changes in muscle fibre type: Intense endurance training can cause a reduction in the number of Type II fibres within the muscle, and also the rate of firing of those muscles [8]. And it's the type II fibres that respond most to hypertrophy stimuli and increase strength gains. If there are fewer of these fibres, and those that are left do not fire as quickly, then strength gains are potentially lessened.

training for months prior to the study and it's likely they adapted for seven weeks and then predictably got tired. If the study had stopped at eight weeks, the combined group would have shown gains in both strength and endurance. After ten weeks of continuous training, it's possible that the subjects were overreaching (*see box 2*), especially at the loads and intensities set. Yet this study is often cited as 'proof' that concurrent training limits strength adaptations.

Researchers in California recognised these problems and designed two comprehensive studies that utilised concurrent training within the same session and measured several performance outcomes [1,2]. The first study used 28 female soccer and volleyball college athletes as subjects and measured the following:

- **1 repetition maximum** (1RM) of three lower body and five upper body exercises;
- Muscular endurance of the legs using leg press and upper body on five different exercises;
- Body fat percentage and fat free mass;
- Upper and lower body flexibility.

The second study used the same female athletes and also 20 male athletes and measured **systolic and diastolic blood pressure** and VO_2max on a graded treadmill running test. Both studies were conducted over 11 weeks with the subjects training three times a week for an hour and 50 minutes each session. The subjects were split into two groups who performed the following:

Serial training group

- Aerobic warm up - five minutes;
- Alternating sets of resistance exercise with brief rest periods – 60 minutes;
- Aerobic exercise – 30 minutes;
- Range of motion cool down – 15 minutes;

Integral training group

- Aerobic warm up – 20 minutes;
- Alternating sets of resistance exercise with brief aerobic **cardioacceleration** – 75 minutes;
- Range of motion cool down – 15 minutes.

In the resistance section of the workout, both groups did three sets of 8-12 repetitions of nine different exercises, starting with

Table 1: percentage change in tests between beginning and end of study

	Serial	Integrated
1 RM Upper body	19%	17.8%
1 RM Lower body	17.2%	23.3%
Muscular endurance legs	18.2%	27.8%
Muscular endurance upper body	9.6%	5.2%
Body fat percentage	-1.1%	-5.7%
Fat free mass	1.8%	3.3%
Lower body flexibility	6.5%	8.4%
Diastolic blood pressure	-14%	-12.6%
Systolic blood pressure	-8.7%	-13.2%
VO_2max	18.9%	22.9%

a load of 50%1RM. The difference was that in the serial group the heart rate was deliberately kept low (107.9bpm) by sitting down between sets whereas the integrated group performed 30-60 seconds of vigorous aerobic exercise (usually treadmill running) to elevate their heart rate (151.1bpm) between sets. The serial group performed their aerobic exercise after their resistance training. Both groups did exactly the same amount of work; it was just the sequencing of the exercises that was different. Both groups then finished their workout with 15 minutes of range of motion exercises.

There were three hypotheses in this study:
1. Serial training is as effective as training in either strength or endurance alone, producing similar gains;
2. Integrated training produces training effects that are greater than single mode training alone;
3. Integrated training produces greater training effects than serial concurrent training.

The results (*see table 1*) showed that all three hypotheses were correct (the authors did not have control groups who performed the single mode of exercise alone; instead they compared their results with those produced from other studies that did only use single modes of exercise). The two main points here are that there was no apparent interference effect from combining strength and endurance training; and that simply changing the sequencing of exercises can have a very big impact on results. In fact, apart from the upper body strength and muscular endurance, all parameters measured in the study were improved more in the integrated than serial group.

‘Researchers have suggested that in integrated training there is actually a synergy between strength and resistance training, and the results seem to support this’

Explanation

The authors of the Californian study above suggested that in integrated training there is actually a synergy between strength and resistance training, and the results seem to support this. It could be that by elevating the heart rate and increasing blood flow to the muscles prior to strength training, the movement of hormones such as insulin and nutrient delivery to muscles is enhanced, leading to greater recovery and adaptation. This same mechanism also assists in delivery of oxygen and removal of waste products, which would assist local muscular endurance.

Integrated training may also help the heart (which is of course a muscle itself) become stronger and more efficient by repeatedly challenging the vascular pump within the heart and by increasing muscle perfusion within the cardiac muscle. This repeated stimulus may be a better way of working the heart muscle than a single block of aerobic work after the resistance training.

In practice

Taking information from one study and trying to apply it wholesale isn’t always wise. For starters, an hour and 50 minutes (as used above) is a long time to work out. In my experience an hour is pretty much the longest you can train while still maintaining intensity and concentration. Also, the subjects in this study were not playing any sport at the time, which means they didn’t have to do technical/tactical sessions, play matches or to nurse the bumps and bruises associated with competition!

Having said that, there are some important take-home points. Firstly, the sequencing of the exercises does seem to have a major impact on the results, even when the same amount of work is performed, and integrated training appears more effective than serial training. This means preceding weight-training sets with a brief period of 30-60 seconds of aerobic work throughout the session.

Secondly, the concept of hard/easy days isn't new and allows recovery of glycogen and adequate protein synthesis to take place. This could be the key difference between this study and others (which did not provide adequate recovery for their subjects) that showed an interference effect, and should be a principle in your training, too.

Thirdly, studies that have shown an interference effect have been conducted on untrained subjects, so if you are new to training, or returning from injury, it may be best to separate the two modes of training first – *ie* perform serial rather than integrated training. However, if you are well conditioned, then integrated sessions could be for you, as long as you allow adequate recovery between your sessions.

Practical implications

- For well conditioned athletes, concurrent training may well be as effective as conventional training; this could be especially useful when time for training is limited;
- Because concurrent training is physically demanding, athletes should always ensure adequate recovery when employing this type of strength/endurance regime.

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Effective endurance training: why Goldilocks was wrong!

At a glance

This article:
- Takes a fresh look at the conventional approach to tempo training in the light of new research;
- Explains why a train low, train high approach can lead to increased performance;
- Provides practical training recommendations.

In recent years, the 'middle way' has been a popular mantra of politicians. However, as Joe Beer explains, when it comes to training intensity in endurance sports such as cycling and triathlon, the middle way is most definitely not the most effective route to elite levels of fitness

Professional elite athletes know how to train because they have access to the best coaches and a because of the Darwinian process that 'kills off' bad methods and keeps good ones thriving! However, until very recently, the amateurs have never had access to the facilities and coaching backup of elite performers, so more often than not they have tended to source information from the best athletes they know locally and/or the group ethos prevailing in their particular training group or environment. The problem with this approach is that the 'sheep mentality' of merely doing what everyone else does is not especially effective. And let's be honest, sheep don't win many athletic medals!

Peaks in the clouds

Athletes used to look to the top of the sports mountain, shrouded in the clouds of greatness, and wonder what went on up there. Take, for example, the secret regimes of the 1980s 'doctors' behind the Iron Curtain, possessed of the ability to increase team performances in track, field and cycling. Nowadays, we have greatly increased transparency with more and more data from individuals, teams and countries, and from journals and interviews. From 4km cycling powerhouses [(1)] to elite junior rowers [(2)], as well as many others, data is published for all to see. Thankfully, we can now see that the gains are less about pharmacology and more about the analysis of training, outcomes and lessons learned.

'Data suggest that the 'Goldilocks' approach to training (not too hard, not too easy) is detrimental for optimum performance, resulting in a no man's land of not much progress'

For example, the prologue ride of cyclist Bradley Wiggins in the 2009 Tour De France was online within days so that cycling fans could swoon over the his super-human effort – an average power output of 442 watts. Wiggins also published blood test data to counter any suspicion that he must have been on 'something special' to get fourth place overall. However, that's a separate article entirely about champion genetics, weight loss and superb equipment choices.

Fortunately, this new openness gives sports scientists, coaches and amateur athletes the chance to see how the best actually train, and most importantly for you, it allows a trickle down of certain 'golden nuggets' of information from upon high. Think of it in the same way that steering wheel control paddles trickled down from rallying and F1 racing to your family car.

So it was fascinating when data were presented in the *International Journal of Sports Physiology and Performance* on 36 elite junior rowers' actual training data[(2)]. These data have rocked the training methods of some and given the thumbs up to what others are already doing. What they suggest in a nutshell is that the 'Goldilocks' approach to training (not too hard, not too easy) is detrimental for optimum performance, resulting in a no man's land of not much progress.

Table 1: Blood lactate, heart rates and training 'zones'

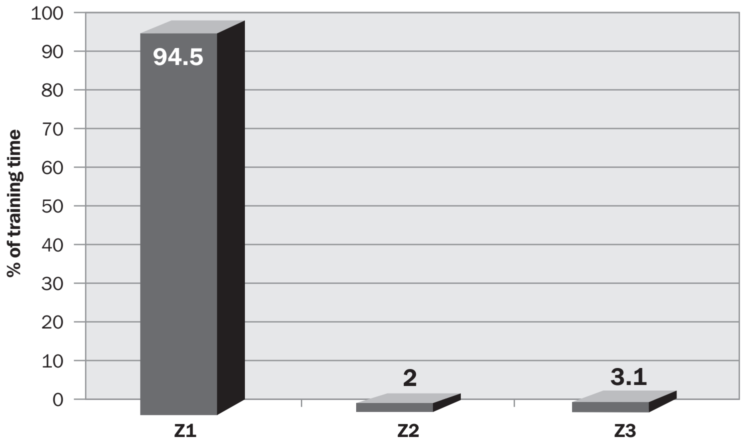
Zone	Description	Lactate/hr points
Z1	Extensive endurance compensation training	Lactate level below 2mmol/L heart rate less than 80% of maximum 'low lactate base training'
Z2	Intensive endurance	Lactate 2-4 mmol/L 80-85% HRmax 'no man's land'
Z3	High-intensity endurance Race specific velocity-endurance	Lactate >4mmol/L above threshold Velocity training to induce lactate accumulation, ie 'high intensity intervals'

Standing on the shoulders of giants

Researchers in Germany have looked at the training and competition data of elite rowers with national, world and Olympic rowing performance capabilities. Over a 37-week period, training was quantified methodically using heart rate monitoring, assessment of lactate threshold points (the point at which fatiguing lactate begins to accumulate rapidly in the blood) and performance outcomes. The rowers (14 of whom went onto Olympic finals), were lab tested to find critical points of blood lactate concentration in order to define certain training zones. These are shown below:

While you probably won't have a blood lactate tester to hand, it's quite easy to get a feel for the 2 and 4mmol/L levels. Below 2mmol/L of lactate, there's no burning sensation and heart rates are around 60-75% of maximum. Between 2 and 4mmol/L, blood lactate builds and declines, never quite bringing you to your knees but you definitely get a sense of a 'workout'. Above 4mmol/L, (sometimes referred to as the 'lactate or anaerobic threshold'),

Figure 1: Percentage of training time performed in Zone 1 for elite rowers (2)



Data show that the elite rowers averaged more than 90% of their rowing training volume to Zone 1 base training although they still committed some time to high intensity work.

exercise feels very hard, and in fact rowing data suggests that 6-8mmol/L is often reached in training by elite rowers. This high-intensity effort is such that once under way, you hope it ends very quickly! Typically, it involves from around 40 seconds to 8 minutes of maximal effort (2).

When the researchers analysed the 37-week data, their findings were very interesting. One of the most important of these was that internationally successful junior rowers performed 95% of all specific rowing training at a heart rate corresponding to a blood lactate concentration under 2mmol/L (*see figure 1*).

Within the average 12-14 hours of training per week the athletes logged over the scrutinised period, this meant six hours of actual rowing in Zone 1 (Z1). Two to three hours were spent resistance training, two hours doing alternative steady state aerobic training, and one hour doing warm-up/flexibility work. Given that this data covered the competition period, it is extremely important to note that the athletes did just 30 minutes a week of very high intensity work.

The real world

Many endurance athletes do events that, in the real world, typically last from 15 to 20 minutes and upward. These include 5K road races, 10-mile time trials and sprint triathlons. Few actually compete in events as short as the rowers tested, though anyone in an event lasting over 40 seconds is really an endurance athlete. Many people are now entering ultra-endurance triathlons such as the Ironman where finish times are 9 to 17 hours. Similarly, sportive cycle events lasting 4 to 10 hours are attracting record numbers. How should these athletes train?

From earlier work on rowers [3], the importance of training below the anaerobic threshold has been steadily gaining attention; and anaerobic thresholds are increasingly being used as a diagnostic tool rather than a training method. In short, the anaerobic threshold is not the Mecca of training effort; it's merely one of the many ways used to measure an improvement or decline in fitness capability. Trying to train at threshold is not the way to train: you are working too hard to be easy and too easy to be properly hard!

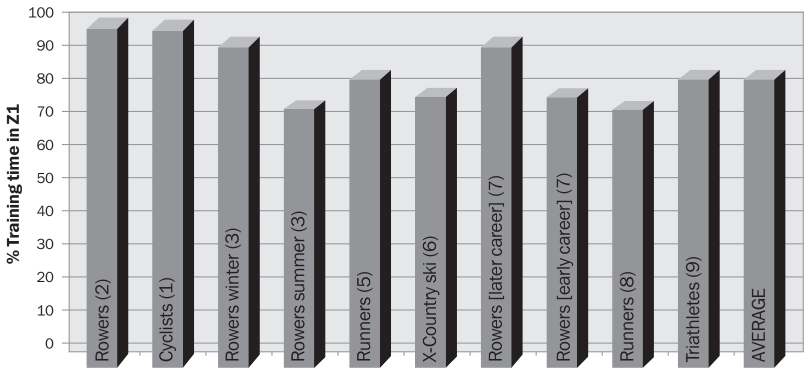
As respected cycling journalist and coach Fred Matheny put it almost 15 years ago in an article in *Bicycling*: 'NML (no man's land) workouts provide a kinaesthetic sense of working hard but expose the rider to too much stress per unit gain. Instead most base training should be guilt-producingly easy, and the top end, high-intensity-training (HIT) should be very mentally hard, not sort of hard' [4].

'Most base training should be guilt producingly easy, and the top end, high-intensity training should be very mentally hard, not sort of hard'

Rowing quality sessions

Lets look at what the rowers in this study did for quality [3]. Over the study period, they averaged just 2-3% of their time performing very high intensity efforts. In distance terms they did 73km in the tempo zone (Z2) but just over 3200km in Z1. Although 2000m rowing requires just 6-7 minutes of maximal effort, they still focused on 'very easy' or 'very hard'.

Figure 2: Percentage of training time performed in Zone 1 by elite athletes across various sports (taken from different studies) (1-3, 5-9)



Data show that national to Olympic standards elites average more than 80% of their training volume in Zone 1 base training, despite training for events ranging from 4 minutes to 2 hours. Despite high-tech training tools, top performances still require a fair amount of training time in the bank; there's no get-fit-quick solution. *Numbers in brackets refers to study reference number

Examples of these high-intensity sessions included:

- 2-3 x 3-10 mins @ 90% HRmax – 10-20 mins recovery between;
- 2-8 x 40-120 sec @ maximal effort – 5-15 mins recovery between.

In order to be ready for this very high level of effort, you need to ensure you've done your base sessions in a controlled manner. The priority is being ready to do the hard work, not making endurance sessions harder than they need to be. Far too many athletes try to push the base and then fail to go really hard for their HIT training.

Why does train low, train high work?

How is it that large amounts of low-intensity work can develop base conditioning, aid recovery from HIT sessions yet not turn an athlete into a 'plodder', churning out 'junk miles'? Well, first off if you do your base work in the 60-80% HRmax zone, you will get as fit and efficient as your genetics will allow for that particular training mode.

However, you can't turn base work into quality – it can be good quality technical work and it can be good quality tempo of movement, but it can't be harder than the Z1 upper threshold. If you train in Z1 consistently, allow recovery and have no major health issues, your body will reach around 90% of its potential – no tempo work, no HIT and relatively little effort. Although you may feel guilty, easy training can get you 9/10ths of the way to your peak potential!

You can train excessively in the tempo 'no man's land' zone for years. But while it gives you a buzz from your workouts and gets reasonable performances, the inputs verses the outputs never match up. For example, if you train over 15 hours per week but include more than 25% of your training in Z2 'no man's land', you'll fail to get better despite logging more time than others who do mostly Z1 and are improving. Remember the phrase 'guilt-producingly easy' for more than 90% of your week, especially if you've been someone who has always trained too hard up until now. Figure 2 shows how elite athletes across a range of sports spend most of their time in zone 1.

For many athletes, the 'train low, train high' mantra requires a mindset change, forcing them to think about things differently. Perceptions such as 'base is easy now', 'I can relax knowing I don't have to keep up with other people' or 'It's now more enjoyable but also more effective', are typical when people finally get what the elites already know.

'For many athletes, the 'train low, train high' mantra requires a mindset change, forcing them to think about things differently'

Summary

Whatever endurance athlete type you are, train low, train high can work for you. This does not mean 'go easy, we don't want to push ourselves do we?' Inclusion of the very high intensity (Z3) work is absolutely critical. However, for long-term success, you need to construct your training so that the body can evolve in a very patient way. Many athletes, even with the best coaching, only see on average a 2 to 8% improvement in a given year, especially those who've got several racing seasons under their belts already. If you've been struggling in no man's land and not making much progress, try using train low, train high approach and set realistic improvements of say 5% (not 10 or 15%) faster for the coming year. And if you remember the valuable three golden nuggets above, better times are ahead.

Practical implications

- Athletes should carefully examine how they allocate the proportions of their time spent at different intensities of training;
- The evidence suggests that the bulk of endurance training should be conducted at an easy tempo with some time set aside for very intense sessions; athletes should not fall into the guilt trap by trying to train too hard during the easy sessions.

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Heart rate training for fitness – don't be a slave to the rhythm!

At a glance

- Evidence is presented for the suitability or otherwise of using heart rate monitors to predict VO_2max, measure exercise intensity, determine training zones and monitor overtraining;
- The importance of lactate measurement for assessing optimum training intensities is emphasised;
- Examples are given where use of perceived exertion and other methods may be more suitable than using HRMs.

Athletes have used heart rate training to develop aerobic fitness successfully for years. However, slavish adherence to heart rate training zones won't allow an athlete to reach his or her true potential. Gary O'Donovan and Romain Denis discuss the strengths and limitations of heart rate monitoring and heart rate training

For centuries, heart rate monitoring consisted of placing an ear or a stethoscope on the chest. The heart's electrical activity was first recorded in the 19th century and American biophysicist Norman Holter invented a portable device for recording the heart's activity in 1961. The Holter monitor can record the heart's electrical activity for 24 hours or more, but it is too large for recording heart rate during exercise. Watch-like heart rate monitors were first developed in the 1980s, and since then most endurance athletes have used heart rate training[1]. It is claimed that today's heart rate monitors can perform all sorts of wonders, from predicting maximal oxygen uptake to detecting overtraining; in this article we'll examine the validity of these claims.

Prediction of VO_2max

Strengths Some heart rate monitors can be used to predict VO_2max (maximal oxygen uptake). For example, it has been shown that the Polar S810 heart rate monitor can accurately predict VO_2max, which is a strong predictor of endurance performance and the best measure of health-related fitness. In different tests, most participants' estimated VO_2max scores were within 5ml/kg/min of their directly measured scores(2). The S810 is also highly reliable, yielding consistent results test after test(1). What's more, S810-predicted VO_2max was favourably associated with cholesterol and blood pressure in a study of 3,820 men and women aged 25-64 years(3).

'It is noteworthy that the heart rate monitor penalises the "fat fit" by expressing VO_2max relative to body weight'

Limitations In the example above, the Polar S810 predicts VO_2max from age, height, weight, gender, self-reported physical activity level, and resting heart rate measurements. Strict adherence to testing procedures is required because, as the manufacturer acknowledges, a number of factors influence resting heart function, including noise, temperature, time of day, diet, alcohol, smoking, exercise, and pharmacological stimulants. Be aware also that self-reported physical activity level is prone to error.

It is also noteworthy that the heart rate monitor penalises the 'fat fit' by expressing VO_2max relative to body weight. When we directly measure maximal oxygen uptake in our lab, we express the results relative to body weight and independent of body weight (millilitres of oxygen per kilogram of body weight per minute and litres of oxygen per minute, respectively). In our lab, for example, we might determine that a 110-kg middle-aged man has a VO_2max of 4 litres per minute, which is excellent compared to an untrained man of the same age. When this value is expressed relative to body weight, the same individual has a VO_2max of 36ml/kg/min, which is no better than an untrained man of the same age. Unfortunately, VO_2max is rarely expressed independent of weight outside of the laboratory.

Progress monitoring

Strengths A reduction in heart rate for a given intensity is usually indicative of an improvement in fitness. In our experience, previously inactive individuals and those returning from a period of injury are often delighted to see a reduction in heart rate for a given intensity after only four weeks of aerobic training.

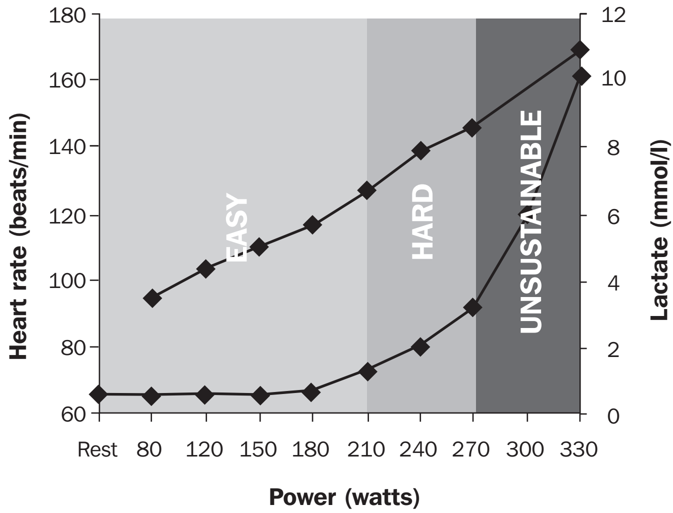
Limitations A number of factors other than a change in fitness might explain why heart rates can differ from one test to another; for example: natural biological variation is such that heart rate can vary by 2-4 beats/min from one day to the next; dehydration can increase heart rate by up to 7.5%; heat and humidity can increase heart rate by around 10 beats/min; and, altitude can increase heart rate by 10-20%, even with acclimatisation[4]. Trained individuals are unlikely to experience discernible reductions in submaximal heart rates and improvements in fitness are best identified from changes in the blood lactate response to exercise (*see 'determining training zones' below*).

Measuring exercise intensity

Strengths In normal individuals, there is a linear relationship between heart rate and intensity during incremental exercise[5]. Therefore, exercise intensity can readily be expressed as a percentage of predicted or directly measured maximum heart rate. The near linear relationship between heart rate and oxygen uptake is such that exercise intensity can also be expressed as a percentage of VO_2max.

Limitations Maximum heart rate is best determined in a graded exercise test, but a maximal exercise test can be inappropriate, especially in less well-trained individuals. Maximum heart rate can be predicted from the formula 220-age, from the formula 210 – (age x 0.65), or from the formula 207 – (age x 0.7); however, all predictions are subject to error[5,6]. The variation in heart rate among the normal population is such that the predicted maximum heart rate of 95% of individuals of a given age will lie within a range of 40 beats/minute[5].

Figure 1: Heart rate and blood lactate responses to incremental cycling



It is an oversimplification to suggest that there is a linear relationship between heart rate and oxygen uptake. For example, oxygen uptake often increases relatively more than heart rate during high-intensity exercise. The relationship between oxygen uptake and heart rate can be predicted more accurately when oxygen uptake is expressed as a percentage of heart rate reserve (HRR, the difference between maximum heart rate and resting heart rate)[7]. In fit people, for example HRR (beats/min) = $1.05VO_2 - 4.1$. Don't concern yourself with these equations however; the next section explains that lactate threshold should be used to determine exercise intensity, not VO_2 or heart rate.

Determining training zones

Strengths Heart rate monitoring allows individuals to train at the intensity recommended to improve aerobic fitness, which is 50-90 % of maximum heart rate[8].

Limitations Too many athletes don't reach their true potential because they adhere to ill-conceived heart rate training zones. Untrained individuals will enjoy improvements in fitness at 50% of maximum heart rate. Trained individuals require more individualised exercise prescription.

'Too many athletes don't reach their true potential because they adhere to ill-conceived heart rate training zones. Untrained individuals will enjoy improvements in fitness at 50% of maximum heart rate. Trained individuals however require more individualised exercise prescription'

Training zones are best determined from the blood lactate response to exercise. Figure 1 shows the blood lactate response to incremental exercise in a 46-year-old club cyclist. Notice that blood lactate does not increase above resting levels until power output reaches 210 watts. In this individual, exercise up to 210 watts is comfortable, sustainable, and ideal for long-duration or recovery training.

As exercise intensity increases, the cyclist recruits more fast-twitch muscle fibres and produces more lactic acid. His body attempts to buffer lactic acid by combining it with carbonic acid, a weaker acid that splits in the lungs into water and exhalable CO_2. From 210-270 watts, the cyclist's increased breathing is sufficient to expel CO_2 and buffer blood lactate. In this individual, exercise at 210-270 watts is difficult, but it will improve his ability to tolerate and dispose of blood lactate.

At 270 watts, there is a rapid rise in blood lactate concentration. This is known as the 'lactate threshold'. The increase in blood pH (acidity) stimulates a dramatic increase in breathing (as the body attempts to expel CO_2) and exercise beyond the lactate threshold is not sustainable. Exercise beyond the lactate threshold is ideal for interval training, however. In order to improve endurance and 10-mile time trial performance in this individual, we might recommend three or four 5-minute bouts at 280 watts with 5-minute recovery bouts at 160 watts. In order to improve strength and sprinting speed, we might recommend 10 1-minute bouts at 330 watts with 3-minute recovery bouts at 160 watts.

Lactate and heart rates

The data in figure 1 were derived from a cyclist who had a power meter on his road bike. Thus, he was able to train at the correct intensity outside of the lab. Subsequent visits to the lab showed that his blood lactate curve shifted to the right and his power output at lactate threshold increased to 290 watts (*see figure 2*). This improvement in fitness would not have been detected if we had only used a heart rate monitor because his heart rate at each workload did not change over time.

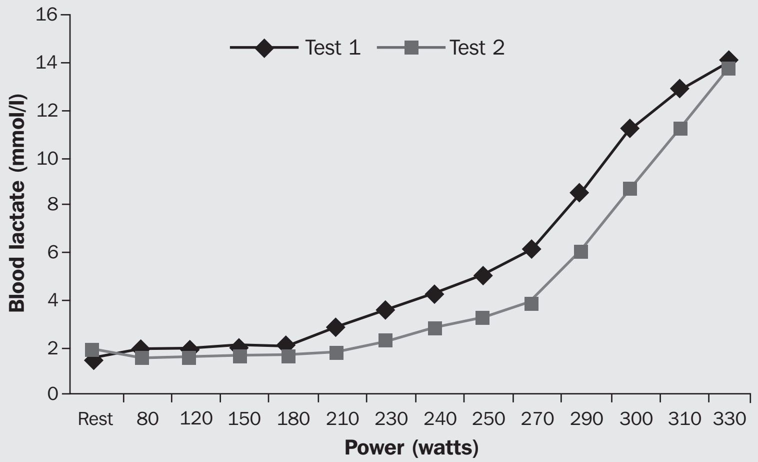
If the cyclist did not have a power meter, we would have anchored much of his training around the heart rate at the lactate threshold. We would also have advised him not to expect his heart rate to recover between intervals and to ignore increases in heart rate of 5-15% during an hour of steady state exercise[4].

In runners, we often prescribe exercise intensity around the speed at lactate threshold rather than the heart rate at lactate threshold. In runners, cyclists and all athletes[4], it is important to stress that there is no predictable relationship between heart rate and lactate threshold. Lactate threshold tends to occur at around 90% of maximum heart rate in well-trained individuals, but it can occur at 50-90% of maximum heart rate[9].

When used in accordance with the author's instructions, Borg's[10] rating of perceived exertion (RPE) scale can also be used to determine exercise intensity outside of the lab because an RPE of 13-14 often occurs at the lactate threshold, regardless of gender, mode of exercise, and training status[11-13]. We recognise that many individuals will find RPE too subjective, and will be reluctant to train without a heart rate monitor. However, the running and cycling workouts in table 1 and table 2 are designed to show that it is possible to train effectively without a heart rate monitor (or a power meter).

The running workouts can readily be adapted for faster runners (and pace calculators are available online; for example: www.nemonisimors.com/anders/sports/paceCalculator.php). A runner wishing to run 10k in 39 minutes should decrease the duration of the 400m intervals to around 1:22 (with 1:10 rest intervals), decrease the duration of the 1,000m intervals to around 3:45 (with 2:45 rest intervals), and run at 15.4km/h for 15 minutes (equivalent to 3:54 per km) during the weekly moderate session. The all-out, self-paced nature of the cycling workouts is such that they will automatically adjust to changes in fitness.

Figure 2: Blood lactate responses to exercise before and after 12 weeks of training



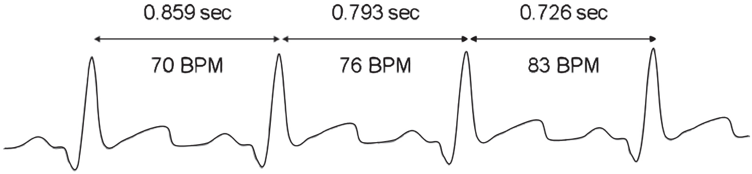
Fat burning

Strengths None.

Limitations Many so-called fitness professionals would have you believe that a 'fat-burning zone' exists at 60-70% of age-predicted maximum heart rate. This is nonsense. It is true that the rate of fat metabolism is greater during moderate-intensity exercise, but fuel utilisation cannot usually be measured outside of the lab. What's more, when fuel use has been measured in the lab, it has been found that the optimum intensity for fat burning is different in each individual, varying from 54-92% of maximum heart rate(14).

Some fitness professionals have purchased expensive gas analysers and are measuring fuel use outside of the lab. However, this still misses the point. Weight loss is induced by negative energy balance; you'll burn more calories during high-intensity exercise than during moderate-intensity 'fat-burning' exercise. For example, an 80-kg individual will burn around 11 calories per minute when jogging at 5mph (12 min/mile),

Figure 3: Heart rate variability



Heart rate variability describes the subtle variations in the intervals between consecutive heartbeats. Even when heart rate is stable, the time between two consecutive beats can vary considerably. At rest, heart rate variability is larger in aerobically trained individuals than in untrained individuals – probably as a result of healthy nervous activity in the brain's cardio-inhibitory centre. There is increasing evidence that heart rate variability is lower at rest in the overtrained state. Low heart rate variability is also a risk factor for cardiovascular disease.

Table 1: Using RPE to train effectively without a heart rate monitor

Day	Time	Intensity (RPE)	Distance*
Mon	60 min	Light (10-11)	10-11km
Tue	45 min	Hard (14-16)	6 x 400m in 1:37 (1:20 recovery between reps)†
Wed	Rest	-	-
Thurs	40 min	Light (10-11)	7km
Fri	60 min	Hard (14-16)	4 x 1000m in 4:15 (2:45 recovery between reps)†
Sat	Rest	-	-
Sun	45 min	Moderate (12-13)	15 min at 13.33km/h (4:40 per km, about 3.4km)‡

Table shows the first week of a four-week training programme designed for an individual aiming to run 10k in 45 minutes (time is min:sec). Do one of the following at the start of week two and week three: slightly increase the number of reps; slightly decrease the recovery time; or, slightly increase the speed. The fourth week (racing week) should be an easy one, including some intense but very short sessions. *Using a cycle and cycle computer, measure a safe path or a safe loop that you are used to running, and place a mark at 400m and at every kilometre. †Moderate and hard sessions should be accompanied by a 20-minute warm-up and a 10-minute cool-down. ‡The moderate session can be performed all year round in order to improve your ability to sustain race pace. The duration of the moderate session should be increased as fitness improves, for example: 20 or 25 minutes at 13.33km/h in this context.

Table 2: Cycling workouts without heart rate monitoring

Session	Objective	Format
Boardman Specials[16]	Improve 1-hour time trial performance	Twenty to sixty 10-second efforts at 1-hour average power with 20-second recovery intervals
All-out sprints[17]	Improve acceleration and ability to tolerate blood lactate	Eight to twelve 30-second all-out efforts with 4:40 recovery intervals
Eric Snider's weekly cadence workout[18]	Cycle like Lance Armstrong to avoid fatiguing large gears!	Spin as fast as possible for 1 min in easy gear such as 39 x 19. Shift back to your usual pace gear for two min. Repeat 6-10 times.
CTS Time trial	Improve endurance and 10-mile time trial performance	Three or four 5-minute sprints at around 110 rpm with 5-minute recovery intervals at 90 rpm

Each session is best performed on a stationary cycle or turbo trainer, and should be accompanied by 1) a 10-minute warm-up with a 1-minute sprint at 03:00 and a 1-minute sprint at 05:00, and 2) a 6-10 minute cool-down. The CTS Time Trial is adapted from the excellent Carmichael Training Systems Train Right Video Series, which is available at www.wiggle.co.uk (each DVD includes a heart rate test that can be ignored – just go by perceived effort during the intervals).

around 16 Calories per minute when running at 7mph (8.5 min/mile), and around 22 Calories per minute when running at 10mph (6 min/mile). Advocates of the fat-burning zone also fail to realise that high-intensity training is more effective in improving one's ability to burn fat. This 'carbohydrate-sparing' effect does not accompany moderate-intensity training.

Preventing overreaching and overtraining

Strengths Overreaching is characterised by signs and symptoms that last from a few days to two weeks, including fatigue, muscle soreness, insomnia and underperformance[4]. Overreaching is often utilised in a training cycle because 'supercompensation' may occur after an appropriate period of recovery[15]. It is thought that fatigue, performance decline, mood disturbance and other symptoms are more severe in the overtrained state than in the overreached state[4]. An athlete may take months or years to recover from overtraining. Some top-of-the-range heart rate monitors can detect a 5-10 beat/min increase in resting heart rate and a decrease in resting heart rate variability (*see figure 3*), which might be early signs of overreaching and overtraining[4].

Limitations There is increasing evidence that heart rate variability is lower at rest in the overtrained state, but there is no diagnostic tool for overtraining; the condition is 'diagnosed' by excluding all other explanations for the decline in performance and mood[4]. Perform any overtraining test at least 24 hours after training because heart rate variability can be influenced by a prior exercise bout.

Summary

Heart rate monitors can be used to estimate VO_2 max, to identify changes in fitness, and, possibly, to detect the early signs of overtraining. Heart rate training zones are meaningless unless they are identified from the blood lactate response to incremental exercise. Heart rate training is particularly inappropriate during interval training. Most well trained individuals don't need a heart rate monitor to know what constitutes an all-out one-minute interval, an all-out 5-minute interval, or an easy recovery interval!

Practical implications

- Sportsmen and women should be aware of the limitations of adhering too rigidly to pre-prescribed heart rate zones, especially when determining ideal training intensities;
- Athletes should also be aware that other methods of monitoring training intensity (such as perceived rate of exertion) can be equally (if not more) effective in certain circumstances.

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Maximising strength – time to tear up the old rulebook?

At a glance

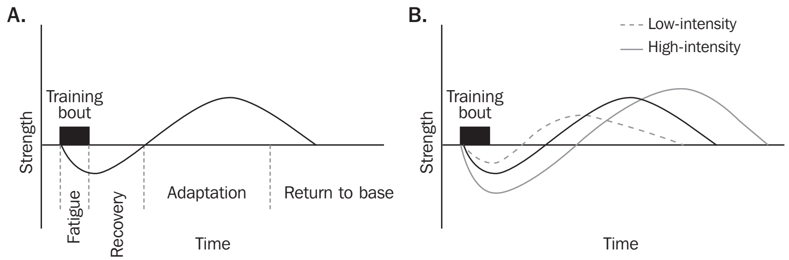
- The physiological responses to strength training are outlined and the role of a key regulator of muscle growth called mTOR is explained;
- Research showing how to optimise mTOR activation and so increase muscle growth is presented;
- Practical training recommendations are given for maximum strength gains.

For thousands of years, athletes have used resistance training to increase their strength and sport fitness. But as Keith Baar and Mike Gittleson explain, recent scientific advances suggest that the traditional methods of resistance training might not be the most effective way to do this...

Over 2,500 years ago, Milo of Crotona, a Greek farmer and Olympic wrestler, performed his morning exercises with a calf draped across his shoulders. As the calf grew so did Milo's strength. At the time of the Olympiad, his strength was so great that he could complete his exercises with the calf, now a full-grown bull, on his shoulders, making his strength unparalleled. The scientific theory described in this fable has been termed the 'overload principle' – *ie* that strength gains occur as a result of systematic and progressive exercise of sufficient frequency, intensity and duration to cause adaptation.

While we have recognised the importance of the overload

Figure 1: A schematic diagram of the adaptation of muscle to a single bout of exercise



A) Acute resistance exercise progressively results in fatigue, recovery, and adaptation. B) Changing the intensity of the resistance exercise decreases (low-intensity) or increases (high-intensity) the time of each of the phases after resistance exercise.

principle for a very long time, the exact frequency, intensity and duration of exercise to maximally increase muscle strength is still open to debate. A number of factors impact optimal training frequency, how hard to train and how long to train. These include the equipment and coaching available, individual rates of recovery after hard weight training and the individual's ability to sustain intense exercise.

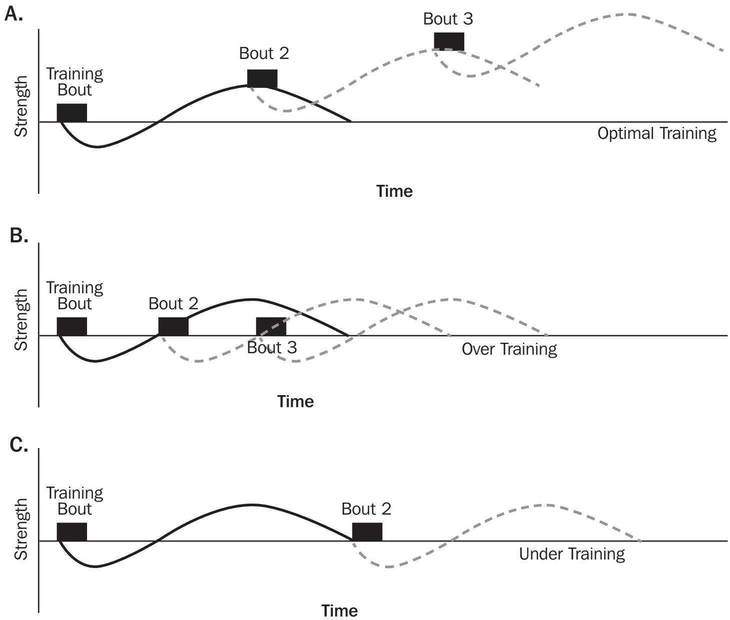
Response to training

It is easiest to view an individual's response to resistance exercise in pictorial form (*see figure 1*). A training session can be separated into four phases (*see figure 1A*):

1. The training bout itself where the muscle fatigues and strength decreases;
2. The recovery phase, including both the immediate recovery from the exercise and the delayed recovery when damaged muscle fibres are removed and replaced;
3. The adaptation or supercompensation phase;
4. The return phase where any strength gains from the bout of exercise are lost.

Changing the intensity of the exercise increases or decreases the length of each of the phases (*figure 1B*) making it even

Figure 2: Schematic representation of the effect of timing training on the adaptive response



The effects on strength over a period of time of A) optimal timing of training, B) training too frequently and C) not training frequently enough

harder for the strength coach to time the next training session.

The goal of the athlete and coach is to provide the next training session at the optimal frequency (*see figure 2*). If each of the sessions is optimally timed (at the peak of the adaptation phase), the athlete will increase strength at a maximal rate. If the sessions are too frequent (as is common for elite athletes – *see figure 2B*), the muscle doesn't have sufficient time to adapt and strength gains are slow. Poor strength gains are also seen if the sessions are not frequent enough.

Molecular response to training

So what is it that actually causes an increase in strength? One

Box 1: Programme rules for maximising mTOR activation and strength gains

- **Target:** The weight is increased when the athlete completes a fixed number of repetitions. Targets are normally used at the beginning of a training program, when increases are made more rapidly.
- **Range:** Contains both upper and lower limits of repetitions (*eg* six to eight reps). When the athlete performs the reps at the lower limit of the range (*ie* six reps) the weight remains the same and the number of repetitions increases through the range. The weight is increased only when the athlete completes the upper limit of the repetition range (*ie* eight reps) and the number of repetitions is decreased to the lower limit.
- **Number of repetitions:** As stated above, sets should last no longer than 60 seconds. Therefore, each set should have no more than 10 reps. Since forced repetitions are to be used, the maximal number of positive reps should be eight so that two forced reps can be added.
- **Adding weight:** When progressing, the weight added should be at least twice the smallest weight available in the gym – *eg* if the smallest weight in the gym is 1kg, the smallest weight that should be added is 2kg.
- **No progression:** If the athlete shows no progress for three workouts, the weight is reduced. The weight removed should be half of the last added weight and the number of reps should stay the same.
- **Momentary muscular failure:** Momentary muscular failure is achieved when the athlete can no longer either lift the weight or provide resistance during the negative phase.

possibility is that muscle repair results in a newer, stronger muscle. But while it is true that muscles repair themselves after a training session, there's nothing in the repair process itself that causes the muscles to grow stronger. This can be seen by comparing muscle strength following a training session to muscle strength after a minor muscle injury. In both cases, muscle repair has occurred. However, only the training session increases muscle strength.

If not repair, then what? In every scientific model of muscle hypertrophy (growth), including mice, rats, rabbits, chickens and humans, the first response to a strength-training session is an increase in protein synthesis. If the increase in protein synthesis is more than the increase in muscle breakdown, the muscle will get bigger and stronger.

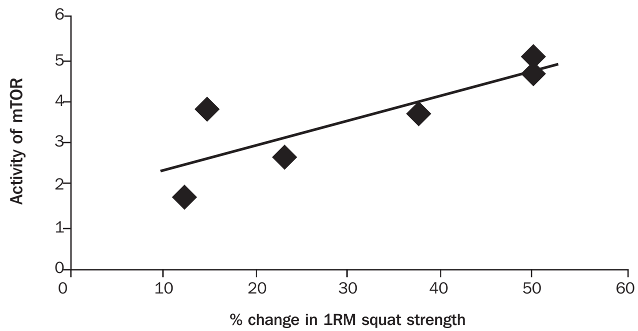
Over the past 10 years molecular exercise physiologists have identified the key regulator of muscle protein synthesis after strength-training. The technical name for this protein is the 'mammalian target of rapamycin', or mTOR for short. The activity of mTOR is directly related to the intensity of the training session and, over time, to the increase in muscle size and strength[1] (*see figure 3*).

Maximising muscle growth

If activating mTOR is the key to increasing strength, then understanding how to maximally activate this enzyme will tell us how to optimise our strength-training. To do this, we have to understand what turns mTOR on and off, and from a number of beautiful scientific studies, this is now clear.

The load on a muscle is directly related to the activation of mTOR. This means that the heavier the weight, or the greater the absolute amount of power produced by the muscle, the

Figure 3: The relationship between the activity of mTOR and strength gains



The activity of muscle protein synthesis regulator mTOR 30 minutes after strength training is directly related to the increase in squat strength after 14 weeks of training. This suggests that mTOR activity causes muscle growth.

better the activation of mTOR[2]. The only time where this relationship is not seen is when the weight-lifting is done while blood flow is restricted, but this is only really applicable to populations that can't lift heavy weights for medical reasons. Therefore, the goal should be to lift as much weight as possible.

On the other side of the equation, mTOR activity is blocked by metabolic stress. This means that we want to use as little muscular ATP (an energy yielding molecule used in muscle contraction) as possible when we are doing our resistance training. The best way to decrease ATP consumption is to not work very long and to do exercises that use less ATP. Put together, this means that the best way to increase the activity of mTOR is to do exercise at high absolute power and low energy cost.

'The heavier the weight, or the greater the absolute amount of power produced by the muscle, the better the activation of mTOR'

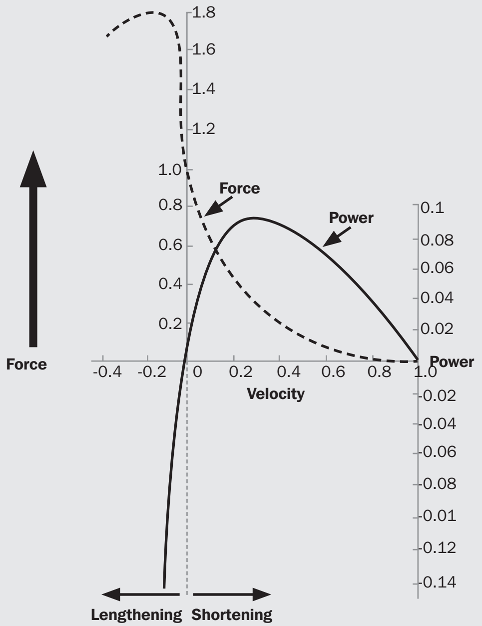
There are two ways to produce high power in muscle (*see figure 4*). The first is to perform shortening (concentric) muscle contractions with a medium amount of force, while the second is to perform lengthening (eccentric) contractions at a high force. Because of the architecture of our muscles we are able to produce about 1.8 times as much force when our muscles are lengthening than when they are shortening, resulting in much more power (even though it is negative).

Even though shortening and lengthening contractions can both result in high absolute power, they have very different energy costs. Shortening contractions are the most energy-consuming contractions, isometric contractions are the least energy-consuming (but result in the lowest amount of power) and lengthening contractions are in-between, requiring one-half of the ATP of shortening contractions[3]. This information suggests activation of mTOR (and therefore strength gains) should be greatest when training with forced lengthening contractions against a very high load.

Training to maximise mTOR activation

The type of contraction is one thing that can be used to maximise mTOR activation, but are there others? The short answer is yes. Here, we will discuss one nutritional strategy and a few training

Figure 4: Force-velocity (relative power) relationship in muscle



The force-velocity relationship in muscle is depicted by the red line with the relative power superimposed with the black line. Note that there are two areas where there is high power, one during shortening (positive power) and one during lengthening (negative power).

programme factors that can maximise activation of mTOR.

One of the things that can activate mTOR inside muscles is an increase in circulating blood amino acids (from digested protein). Specifically, foods that are high in the branched chain amino acids (*eg* leucine) such as milk, can increase the response to resistance exercise. We have known for some time that adding amino acids to a strength-training programme can improve the resulting increase in strength, and now we think that we know why. When amino acids are taken into muscle, they can directly activate mTOR and improve protein synthesis and muscle growth.

There is also the suggestion that when we consume amino acids might be important in the effects on mTOR and protein synthesis, but this is still controversial. We have just finished experiments that suggest that the if amino acids are taken within one hour after training they will have a bigger effect then if they are taken later. This is because we have found that the 'leucine transporter' is increased in muscle between 30 and 90 minutes post-training and this might be important in mTOR activation and therefore strength gains.

It is important to remember that keeping amino acid levels high for extended periods of time can actually result in a decrease in both protein synthesis and insulin sensitivity(4). Therefore, it is unwise consume to excessive amounts of protein.

Programme features to optimise mTOR activation

Although we said we want to maximise power when we train, there is a caveat. The highest absolute power is seen when performing fast lengthening contractions with a lot of weight (high jerk), or heavy plyometric exercises. This type of exercise is very effective in activating mTOR, but unfortunately can be very bad for tendon health, and as a result can lead to injuries. Since the tendon adapts more slowly than muscle, if heavy plyometric exercises are used, providing adequate recovery time following these exercises is absolutely essential.

Another consequence of the slow recovery rate of tendon for high-jerk resistance exercise is the use of periodised training. As described elsewhere in this report, non-linear periodised programmes can result in greater strength gains than traditional linear progression methods. Athough it has been demonstrated numerous times, there doesn't seem to be a reason for this at the muscle level. Instead, this likely represents the fact that the majority of elite athletes are overtraining and periodically decreasing the load allows the required rest for muscle adaptation and tendon recovery from the high-jerk exercises.

An alternative way to promote tendon health is to use slow lengthening, or forced contractions. This type of movement has been shown to improve tendon health and recovery from injury. Further, since there is no need for prolonged tendon rest periods, linear progression programmes can be used effectively when this type of movement is included.

Second, since minimising metabolic stress is one of the keys to activation of mTOR, each set should last less than 60 seconds. This is the amount of high-energy phosphate stored in a normal muscle. Any longer and the muscle will turn on processes that shut down mTOR, decreasing the response to the training. When performing controlled repetitions this means a maximum of 10 reps per set is optimal for strength gains.

Last, in order to minimise the metabolic stress of each set, the programme should preferably consist of only one set, which should end with two to three forced repetitions. If more than one set is used, enough time must be taken between sets to allow full recovery of phosphocreatine and ATP. This takes two to three times as long as the exercise itself (around two to four minutes).

'In order to minimise the metabolic stress of each set, a resistance programme should preferably consist of only one set per exercise, which should end with two to three forced repetitions'

Putting together a strength programme

So how can these ideas be put together into a coherent fitness programme to optimise strength gains? What follows is a programme built on the molecular ideas described above and the experience of 30 years of working with elite strength athletes. This programme is a linear progression system that uses one set to momentary muscular failure and push-pull methodology to maximise power and minimise metabolic stress (*see box 1*).

Correct form

During the positive phase:

- Limit momentum: *do not* bounce or throw the weight upwards;
- Limit leverage: *do not* change the angle of any joint other than the target joint;
- Constant tension throughout the exercise: *do not* rest on the way down or at the bottom of the movement;

- Shortening of the target muscle should take one to two seconds; the weight should then be stopped at the top of the movement before lowering the weight with tension during the lengthening phase.

During the negative phase (forced repetitions):

- When the athlete can no longer lift the weight, the coach and athlete combine for a number of forced repetitions. In this phase, the coach assists in the shortening phase and then challenges the athlete to lower as much weight as possible taking six to eight seconds. The coach can also provide extra resistance if needed.

Push-pull methodology

To minimise the metabolic stress on each muscle group, athletes should progress from a pushing exercise to a pulling exercise and vice-versa. A pushing exercise is a movement away from centre of body during the shortening contraction of the target muscle (*eg* chest/shoulder/triceps press, leg extension, leg press). A pulling exercise is a movement toward centre of body during the shortening contraction of the target muscle (*eg* pulldown, row, biceps curl, leg curl). Progressing from a pushing to a pulling exercise allows full recovery and resynthesis of ATP and PCr in helper muscles between exercises, decreasing metabolic stress and allowing better activation of mTOR.

Recovery

After a workout, your body begins recovery by replenishing oxygen supply, high-energy phosphate fuels and glycogen (carbohydrate) in muscle, and importantly begins to degrade and synthesise muscle proteins. This requires rest and proper nutrition. The amount of rest varies from athlete to athlete and with the intensity of exercise as discussed above, while proper nutrition can be as simple as consuming 6g of essential amino acids and 35g carbohydrate (700mls of skimmed milk is sufficient to provide these) within 30 minutes of training[5].

Practical implications

- Athletes wishing to build strength should aim to produce high intensity with low energy costs in their workouts to maximise mTOR activation;
- High-rep or multiple sets should be discouraged; instead, single sets of six to eight reps with two to three assisted forced (negative) reps are preferred;
- Sets should be performed in a ‘push-pull fashion and where more than one set is performed, at least two minutes should elapse between sets.

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Power and the glory – building power for winning performance!

At a glance:

- The importance of power in sport and the distinction between power and strength is explained;
- Research into optimal loadings for developing power in the weights room is discussed;
- The issue of fixed versus free weight training for power is addressed;
- The benefits of 'power-combination' training in power development are explained.

Although power and strength are intimately connected, they're not the same thing. And, as John Shepherd explains, training for power in sports requires a significantly different approach to traditional conventional strength-training methods

Although strength is important for the majority of sports, it's invariably the most *powerful* athlete who is blessed with superior performance. Elite rugby provides a case in point. The power of some of the tackles makes for a truly awesome spectacle. These athletes demonstrate incredible power – that is they are able to overcome resistance as quickly as possible. And with a high power to weight ratio, they show that they can move themselves or an object (such as an opponent!) very quickly, in split seconds. This contrasts with gross strength, which is about developing the ability to lift as heavy a weight, or overcome as much resistance as possible regardless of the speed of the movement – but usually slowly!

Developing sports-specific power in the weights room

As noted, most coaches advocate fast movement lifting with weights in the region of 70% of 1RM as a means of developing athletic power. Typical exercises would include squats, **hang pulls** and bench presses. Jumping/throwing weight exercises such as the jump squat and bench throw are also commonly performed, often with similar loadings. But are these the optimum loads?

Researchers from Connecticut looked precisely at this and whether the training response varied between men and women[1]. Their study involved National Collegiate Athletic Association Division I athletes. Each performed power testing at 30, 40, 50, 60, and 70% of individual 1RM in the squat jump, bench throw, and hang pull exercises.

The team discovered that there were differences between genders in maximal power output during the squat jump (30-40% of 1RM for men; 30-50% of 1RM for women) and bench throw (30% of 1RM for men; 30-50% of 1RM for women)

Weight training and strength versus power

As touched upon previously, strength is defined for the purposes of this article as the ability to lift as heavy a load or overcome as much resistance as possible. This is normally achieved in the weights room by lifting weights in excess of 75% of **1 repetition maximum** (1RM). Low repetitions (1-6) are normally used to achieve this goal.

In comparison, power is defined as the ability to overcome resistance as fast as possible. In terms of weight training, it's normally developed by lifting weights in the region of 60-75% of 1RM, as fast as possible, but safely with control (6-12 repetitions would normally be used). However, as we shall see, this may not actually be the optimum load for achieving the greatest power gains – particularly when it comes to improving acceleration, jumping ability and hitting, for example.

exercises. The women were able to generate more power with heavier loads. There were no gender differences for the hang pull exercise, where maximal power output occurred at 30-60% of 1RM.

This led the researchers to conclude that about 30% of 1RM elicited peak power outputs for both genders and all exercises used in the study and also that this should be the starting point for developing power in these lifts in strength trained athletes. Thirty per cent may seem pretty light to many coaches and athletes and it could be reasoned that heavier loads could develop greater power. However, moving greater weights inevitably slows down the speed of the lift, jump or throw. And, as power is all about applying maximum force at the highest velocities, it is easy to understand how too heavy a weight could compromise the development of this vital sporting quality!

‘Although fast twitch, “intermediate” type IIA fibres are not as adept at producing out and out power as their IIB counterparts’

Other researchers have considered the validity of the ‘30% marker’ for developing power with dynamic weight exercises. For example, a team from Australia looked specifically at the jump squat[2]. Twenty-six athletic men with varying levels of resistance training experience performed sessions of jump squats. Heavy loads (80% of 1RM squat best) and light loads (30% of 1RM squat best) were used across an eight-week programme. **EMG** and other measures of performance were used to determine the results.

It was discovered that the light-load jump squat group significantly improved their power and velocity. It also improved their squat 1RM. Although the heavy-load group also significantly increased power and their 1RM (*ie* absolute strength), they were significantly slower over a 20m-sprint test – a crucial marker of sports performance. This investigation again validates that jumping with 30% 1RM loads seems to produce the greatest power returns in terms of improved athletic ability.

Weight training protocols, strength type and muscle fibre adaptation

The theme of the previous research was reflected in another study performed by a team from Ohio[3]. They specifically considered the number of repetitions performed and the effect they had on muscle fibre adaptation, maximal strength (1RM), local muscular endurance (maximal number of repetitions performed with 60% of 1RM), and various cardio-respiratory measures (for example, maximum oxygen consumption, maximal aerobic power and time to exhaustion).

Thirty-two untrained men were involved in the study and were divided into four groups. The exercises used were the leg press, squat, and leg extension. They were performed two days a week for the first four weeks and three days a week for the final four weeks:

1) Low repetition group (Low Rep) who performed 3-5 RM for four sets of each exercise with 3 minutes' rest between sets and exercises;
2) Intermediate repetition group (Int Rep) who performed 9-11 RM for three sets with 2 minutes' rest;
3) High repetition group (High Rep) who performed 20-28 RM for two sets with 1 minute of rest;
4) A non-exercising control group (Con).

Crucially, in the light of the subject matter of this article, pre- and post-training muscle biopsy samples were analysed for fibre-type composition, cross-sectional area and **capillarisation**. In particular, fibre-type changes would indicate what effects the training was having. An increase in **fast-twitch fibre**, for example, would indicate an increase in power and strength capability among the subjects.

Not surprisingly, it was discovered that maximal strength improved significantly in the Low Rep group compared to the other training groups. For the High Rep group the maximal number of repetitions at 60% 1RM improved the most. In addition, maximal aerobic power and time to exhaustion significantly increased at the end of the study for the High Rep group only – indicating a positive transference to endurance ability.

All three major fibre types (types I, IIA, and IIB) hypertrophied (increased in size) for the Low Rep and Int Rep groups, whereas no significant increases were demonstrated for either the High Rep or Con groups. More interestingly, the percentage of type IIB fibres decreased, with a concomitant increase in IIA fibres, in all three resistance-trained groups. This is significant for power training athletes; type IIB fibres are the big power providers and are the ones that will get you to the finish line the quickest in a 100m sprint.

In this instance, weight training seems to have blunted their power potential by changing them to type IIA fibres. Although fast-twitch, these 'intermediate' type IIA fibres are not as adept at producing out and out power as their IIB counterparts. Other researchers have discovered similar findings when it comes to the effect of weight training on fast-twitch fibres(4). There are ways of getting round this; for example eliminating or reducing the amount of medium/heavy weight, weight training performed as important competitions near, allowing for a reversion of IIA fibres back to IIB and also 'power combination training' – of which more later.

'Athletes may derive greater benefits from using free weights to develop sports-specific power due to the additional balance requirements associated with free weights'

Fixed path versus free-form weight training

What about the way athletes lift weights? Athletes may use different types of weight training equipment across the training year. Will one method be the same as another? Is, for example, a 75kg bench the same on a Smith machine as performed on a bench using free weights? Researchers from Iowa considered this(5). Smith machine exercises were termed 'fixed path' and the lifts performed outside of the Smith machine 'free-form path'. Specifically, the team wanted to compare muscle force production using a 1RM for the parallel back squat and bench press. From this they then wanted to predict the 1RM for one mode from 1RM on the other mode.

Sixteen men and 16 women alternately completed 1RM testing for squat and bench press using Smith machine and free weight methods. The team discovered a 'significant difference' between bench press and squat 1RMs for each mode of equipment for all participants. Specifically:

- Squat 1RM was greater for the Smith machine than for free weights;
- Bench 1RM was greater for free weights than the Smith machine.

Combining weight training with plyometric exercises for an enhanced power output

Although the prime focus of this article is on gaining power through the use of weight training exercises, it would be remiss not to consider the potential that combining plyometrics (jumping-type exercises) and weight-training exercises in the same workout has on boosting muscular power outputs. This is called 'power combination training'. Coach/athlete should select exercises that work the same muscle groups, for example, the jump squat and the squat, the split jump and the lunge and the plyometric press-up and the press-up. Combining these in a workout can be achieved in two ways.

Contrast power combination method – The athlete performs a set of plyometric exercises (or a set of weights exercises) and then a set of weights (or plyometric) exercises. They continue their workout in this alternate fashion.

Complex power combination method – The athlete performs all their sets of the plyometric exercise (or weights exercise) first, before completing all their sets of the weights (or plyometric) exercise – these are known as the complexes.

Power combination training is seen to boost the power output of fast-twitch muscle fibres above and beyond that achieved by either method (plyometrics or weights) alone. The weight used for the weights exercises is usually recommended to be about 75% of 1RM (akin to the weight training methodology*). This is thought to be as a result of **potentiation**.

Although, research does exist that questions the validity of power combination training(6), other research indicates that it does work especially with experienced strength trained athletes. For example, a team from Greece indicated this and found that pre-squatting significantly enhanced the vertical jumping ability of their survey's stronger participants by 4.01% and that of the weaker group by 0.45%(7). It would thus appear prudent for the athlete looking to increase their muscular power output to power combination train, once they have developed high strength gains over a number of years.

Formulae relating Smith machine 1 RM to free weight 1RM

For both sexes: Smith machine bench 1RM (kgs) = -6.76 + 0.95 (free weights bench 1RM)

For women only: Smith machine squat 1RM (kgs) = 28.3 + 0.73 (free weights squat 1RM).

This is slightly surprising, as it might seem intuitive that exercises performed using a Smith machine would permit greater force production, due to the safety aspect and crucially the confined/guided path that the bar has to follow. Free weight exercises on the other hand, require balance and greater control to be imparted on the bar throughout the movement – using numerous additional stabilising muscles. Although it could be argued that these muscles could assist the movement of the weight, the inherent instability created by the unconfined lift channels their input away from directly overcoming the resistance, instead providing balance.

It is possible that, had experienced weight trainers/athletes been involved in the study, the Smith machine protocol would have resulted in higher power outputs, as they would have had the ability to recruit more muscle fibre. The fixed path would have facilitated their use of their strength.

When the researchers broke down the findings by gender they found:

- The bench 1RM for free weights was greater than Smith machine for men and women;
- The squat 1RM was greater for Smith machine than free weights for women only.

Not surprisingly the 1RM on one mode of equipment was the best predictor of 1RM for the other mode. This enabled the researchers to formulate an equation that can be used to predict performances on each mode of weight lifting for these lifts (*see box above*):

These findings are useful as they allow coaches to prescribe similar 'effect' weight training programmes across different methods of weight training although, of course, the weight lifting experience of the athletes might become a determining factor. Having said that, many athletes may derive greater benefits from using free weights to develop sports-specific power due to the additional balance requirements associated with free weights. That's because in nearly all sports, movements are performed in an 'open' environment where balance is an important factor in the muscular actions of that sport – for example, a football striker leaping off balance to attempt a header on goal!

Summary

Developing power in the weights room is a complex area with so many variables. I have deliberately steered clear of the 'Olympic lifting debate', which, depending on your perspective and research, is or is not beneficial for sports performance, or the hormonal effects of weight training to focus on more specific forms of weight training and equipment use. The information presented here should enable you to construct a power-developing programme opposed to a strength developing one. The key recommendations are as follows:

- Use 30% of 1RM loads when performing dynamic weight-training exercises, such as jump squats;
- Use circa 75% of 1RM loads when standard weight lifting (preferably free weights);
- Finally, include some power combination training in your routine!

Practical implications

- Sportsmen and women should be aware of the importance of power development in a fitness programme and also that power and strength are not the same thing;
- The speed of movement and the loading used is more important for power development than the mode of resistance used (free or machine weights), so all athletes should be able to incorporate power training into their routines.

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CHAOS: a better way to organise speed training

At a glance

This article:
- Discusses the requirements for developing speed fitness;
- Explains the limitations of using programmed ‘closed’ drills;
- Explores the CHAOS theory and gives a number of practical examples of its use to develop sports speed.

In the world of sport, the ability to effectively accelerate, decelerate and change direction is crucial and in many sports, the most successful athletes are typically the most explosive and efficient movers. Nick Grantham explains how CHAOS training can help develop multidimensional speed

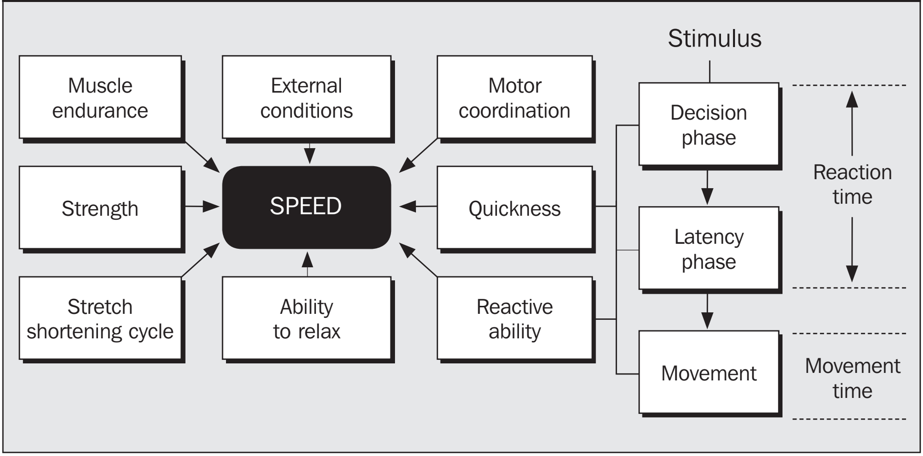
Speed is defined as the distance travelled per unit of time while multidimensional speed can be defined as a series of complex movements in the shortest time possible. More particularly, it’s the ability to change direction or orientation of the body based on internal and external information without significant loss of speed[1].

To some extent, it can be argued that an individual’s ability to develop speed is largely predetermined. The dominant influences on speed include inherited traits, childhood movement experiences and exposure to training. However, it is possible to optimise an athlete’s multidimensional speed and agility with a well-structured training programme[1].

A to B

As we can see from figure 1 (*overleaf*), trying to get from point A to point B as quickly as possible calls upon a number of

Figure 1: Factors determining speed of movement



qualities including explosive strength, acceleration, development and maintenance of maximum movement speed, and resistance to fatigue[2].

Traditionally, multidimensional speed development for sport has relied heavily on highly programmed (closed) speed and agility drills. Some coaches even go down the route of using track-orientated drills and workouts to improve speed for athletes competing in multidimensional sports. However, there's a fundamental flaw with this highly structured approach to training. Sport is chaotic – it's not programmed! The last time I watched a football match I didn't see any ladders on the pitch or lots of cones to determine the direction in which a player ran. What I saw was chaos (albeit it controlled chaos).

We can see in figure 1 that factors such as quickness, reactive ability, and motor coordination can all be improved during a closed drill. These are all important components and training must adequately address each area. The problem is that many coaches and athletes only use this form of speed and agility training, resulting in athletes who can perform drills but can't transfer that into the sports arena. Athletes quickly master the drill and whilst they will appear to be improving their multidimensional speed and agility, the 'trainability' of these types of drills does not adequately address the processing that needs to occur (very quickly!) in unforeseen situations[3]. What's needed are drills that present a stimulus, allow for a decision to be made and then produce the appropriate movement. We don't need ladders, hurdles and cones… we need CHAOS!

CHAOS training

American collegiate strength and conditioning coach Robert Dos Remedios has developed the CHAOS sport speed training system that targets the development of 'real life' sports speed. Dos Remedios has set out a simple framework that shows coaches how to progress from basic 'closed' drills to more open and challenging drills. By using 'open' drills he provides outside stimulus for athletes to recognise, process, and react to, and makes sure that training is as close to the actual speed demands of sport as possible.

One of the key aspects of CHAOS training is developing the decision making/reaction time process in a chaotic environment to ensure that the trainable patterns that often come with traditional 'closed' agility drills are broken. During the early stages of CHAOS training, the fundamental skills contributing to speed (*figure 1*) are developed. In the later stages however, the drills become more complex in nature, developing the all important detection, reaction and decision making skills.

CHAOS training is a progressive system – not just a set of drills (*see figure 2*). You can't just throw athletes in at the deep end and demand that they process and react to chaotic patterns with lightning fast speed. You need to progress your athlete through the system.

'One of the key aspects of CHAOS training is developing the decision making/reaction time process in a chaotic environment to ensure that the trainable patterns that often come with traditional 'closed' agility drills are broken'

Progress to CHAOS

It's beyond the scope of this article to list the huge range of drills and progressions that can be used to develop multidimensional speed and agility, but once you understand the progressions the only limit you have is your imagination.

Figure 2: CHAOS sport speed training system	
C	**Conscious to subconscious** – teaching progression should be constantly 'coached' (stopping, body position, optimal angles, plant foot, *etc*) and the athlete should be aware of the learning process.
H	**Have unpredictability** – the key to developing true sport speed is the variable of unpredictability.
A	**Active to reactive** – progression should start with set agility patterns and slowly progress to reactive movements.
O	**Open drills** – players are put 'on the spot' and forced to not only move fast but also to factor in reaction time due the processing of visual or auditory cues.
S	**Slow to fast** – start with more simple open drills and keep increasing the difficulty based on your athlete's progress. You must walk before you can run!

Stage 1 – strength training

One of the fundamental components of speed development is establishing a good strength base to get maximal gains. You can't be fast unless you are strong! It's important that you develop strength through a wide range of movements (bilateral, unilateral, multiplanar). Traditional exercises such as squats, lunges, split squats and stiff leg deadlifts are all great for establishing a solid strength base (*see figures 3-5*).

To complement the above strength drills, it's also worth incorporate some simple 'jump and stick' or 'hop and stop' drills, which are fantastic for developing movement specific strength. These involve jumping (or hopping) from a static position and then upon landing, sticking and holding the landing position, ensuring the ankle, knee and hip joints are all flexed and the position is held constant for a count of two. Both the jumps and hops can be performed forwards, sideways and backwards. You can even add a rotational component by adding a turn before landing (90 degree or 180 degree).

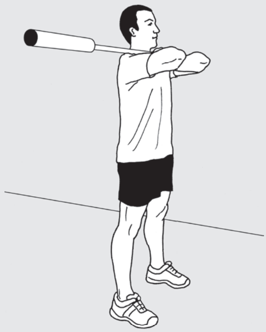
Figure 3: front squat

Explanation

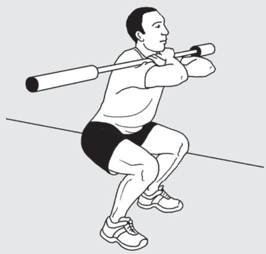
1. Place the bar across the front deltoids in contact with the throat. It is important that you get used to carrying the bar on the shoulders.
2. Cross your arms and hold onto the bar.
3. Take a deep breath and make a 'big' chest.
4. Descend slowly until the top of the thighs are parallel to the floor. Whilst descending into the squat, concentrate on sitting back so that your body weight shifts toward the heels.
5. Return to the start position, concentrating on keeping your chest up and out, bringing the hips up and forward.
6. Remember to exhale on the way up!

The front squat is arguably more difficult to learn than the back squat, but the payoff is that you will develop a great squatting technique with perfect body positioning. The crossover grip is the simplest grip to master. However, you can also perform the front squat using the 'clean' grip.

Start/finish



Midpoint



Stage 2 – closed drills

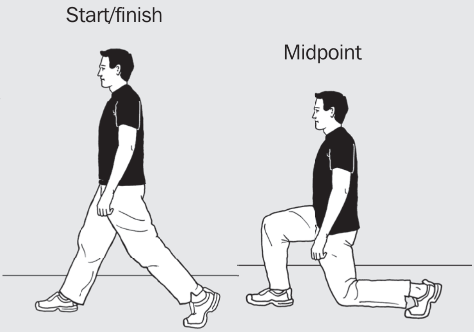
Closed drills are not bad per se and closed drills actually have an important role to play in speed development using the CHAOS system. The problem can be that the use of closed drills in training is where multidimensional speed and agility training stops, when it should only be the second stage! If you look again at figure 1, you can see how simple closed drills can provide a great training stimulus for the key components influencing speed of movement. When using closed drills, work on movement in a familiar pattern first, using standard cone drills (box drills, zigzags, shuttle runs, *etc*).

Out and back drill – this is a regular in my speed and agility training sessions and I've used it with athletes competing in a

Figure 4: split squat

Explanation

1. Take up a split stance with one foot out in front of the other in a staggered position.
2. Descend as deep as possible.
3. Make sure the front heel remains firmly on the floor and the rear heel slightly raised.



range of sports, from rugby and football to Taekwondo and tennis. It's a great drill for establishing short acceleration bursts (the first 3-5 steps). It also develops, deceleration and change of direction.

The drill is as simple as it sounds. The athlete simply accelerates forward for three steps, slams on the brakes and then backpedals for three steps. What I love about this drill is you don't need any equipment (your athletes just need the ability to count!) and you can have a whole squad training in a very small space. Complexity can be added to the drill by changing the start and finish position to a sport specific movement, and altering the number and pattern of the changes in direction.

Stage 3 – basic reaction training

This is the first real step toward CHAOS, where the goal is to develop the ability of the athlete to detect and react to a stimulus. Using basic movement patterns, the key is to work on first step quickness and covering ground as quickly as possible from a range of start positions (lying on floor, kneeling, *etc*). You can use a range of cues (visual/auditory or physical) depending on the nature of the sport and the skill that you want to develop.

An example of basic reaction training is 'ball drops'. The coach stands 5-10 metres away from the athlete with a ball in hand (I like tennis balls but basically, if it bounces you can use it). The coach drops the ball so that the athlete has to react and sprint out and pick the ball up. If you want to really make life tricky, you can use specially designed 'agility-balls' that bounce off all over the place and add some unpredictability into the drill. You can also increase the difficulty by controlling the number of bounces allowed before the player can pick the ball up.

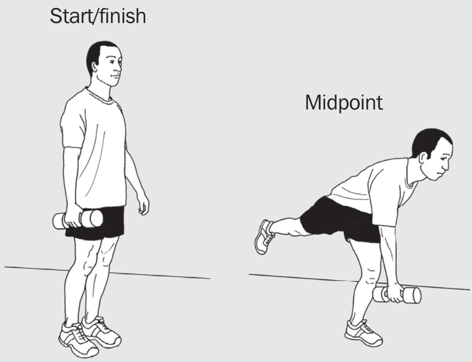
Stage 4 – verbal/visual/physical simple patterns
The closed drills that you used at stages 2 and 3 can still be used as the basis for the drills in stage 4. This stage uses multiple level, multiple cue drills using simple movement patterns such as a box drill. The main change is that there is an increase in complexity provided by verbal/visual and physical cues to change direction. The athlete is familiar with the pattern but not how they will be expected to execute it.

Box drill – Level 1: You can easily train a large group of athletes using this drill; I've used this drill at tennis summer camps with

Figure 5: single leg stiff leg deadlift

Explanation

1. Hold a dumbbell in the right hand with the palm in toward the thighs (neutral grip).
2. Lean forward at the waist, while lifting the left leg to the rear in line with the torso.
3. Attempt to place the dumbbell on the ground outside the left foot



This is a great exercise that develops the entire posterior chain while also improving balance and coordination.
A common mistake is to 'break' at the hips. To avoid the upper and lower body moving separately, imagine a metal rod travelling down from the shoulder to the heel with a pivot point through hips.

Figure 6: Example of box drill with numbered corners

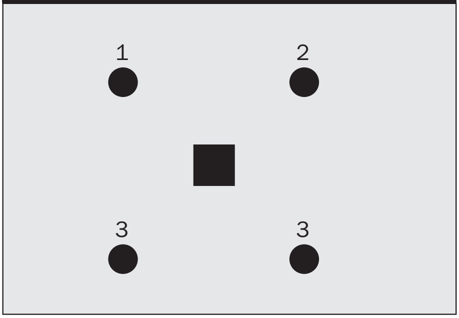
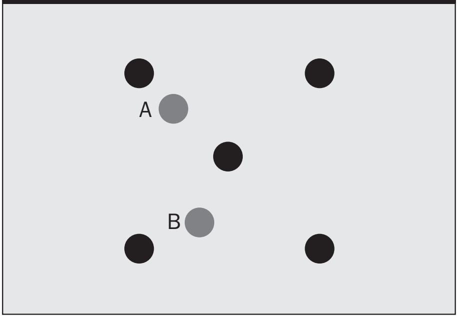


Figure 7: Example of rabbit drill in box with centre marker and two athletes (A and B)



a large grid and 20 players all facing me. This adds an element of competition to the mix, which is another important consideration for CHAOS training drills.

Create a box between 5-8 metres on each side (the exact distance will vary according to the demands of your sport). Have your player stand in the middle and then set to work on their speed and agility! There's a huge amount of complexity that can be added to this drill but I like to start things off with a simple verbal cue. Give each corner of the box a number or letter and then call out the letter/number that you want the player to run towards (*see figure 6*). You can control how they get there (sprint, side shuffle, *etc*) and if you want them to return back to the centre spot to complete the drill.

Stage 5 – verbal/visual/physical advanced patterns

This stage uses multiple level, multiple cue drills using simple movement patterns such as a box drill. Life starts to get pretty interesting at stage 5 and the complexity of the drill starts to increase as multiple cues can be used during any one drill. The athlete not only has to complete the drill, he or she also has to process a wide range of information (verbal/visual/physical), react and then move. This is not just a physical workout, the brain gets a pounding as well!

Box drill – Level 2 To take the box drill up a level, you can work on opposites. Using the same configuration as above, make the player run to the opposite number (if you call 1, they run to 3, if you call 3 they run to 1, *etc*). You can move it on another step by working on diagonals (*ie* if you call 2 they run to 3; if you call 1 they run to 4). This all sounds very simple but trust me when I tell you that just getting athletes to make these simple decisions with a bit of pressure on them dramatically increases the difficulty of a very basic drill. Don't be surprised when they appear to be rooted to the spot as they try to process the information they are receiving!

Stage 6 – visual/physical/rabbit drills

The final progression is where we really start to work on CHAOS. Rabbit drills can be used to take pretty much any closed drill and turn it into a demanding CHAOS drill full of multiple-level cues. Once your players start training at stage 6 they will really be training in a manner that will have maximum transfer to their chosen sport.

Box drill –Level 3 In the final stage we increase the difficulty by introducing 'rabbit' drills. Let's take the same box shown in figure 6 and add an extra cone (if you have access to poles this works really well, as your athletes have to physically get round the pole and therefore can't cheat – an alternative is to use a fifth athlete as a marker).

In this drill athlete 'A' sets the pace and is the 'rabbit'. Athlete 'B' has to get after 'A' and chase them down (*see figure 7*). Athlete 'B' has to follow the exact path that athlete 'A' takes, even down the way they turn. This drill is great; it's unpredictable and it also has the benefit of added competition.

'Getting athletes to make simple decisions with a bit of pressure on them dramatically increases the difficulty of a very basic drill'

Conclusion

To effectively train multidimensional speed and agility, effective fitness drills need to develop balance and spatial awareness, must develop the reaction to signals and response to a variety of cues, and utilise movements appropriate to the task. Many coaches have been good at producing athletes and players who are great at performing running patterns and drills but who can't actually detect and react to a stimulus and then effectively replicate speed of movement in a chaotic environment – *ie* sport! What we need is to practice CHAOS.

Practical implications

- Traditional 'closed' drills and linear speed drills should only form the first stages of a multidimensional speed and agility programme;
- Athletes should use drills that progress from closed, programmed movements to open, random patterns, including various stimuli that allow for decision making;
- Strength training shouldn't be overlooked, as strength underpins all good speed and agility programmes.

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