To Make A Triathlete

(Triathlon Conditioing)

By : Farshad Najafipour, MD, PhD. &
Farzad Najafipour, Physiotherapist.

To Make A Triathlete

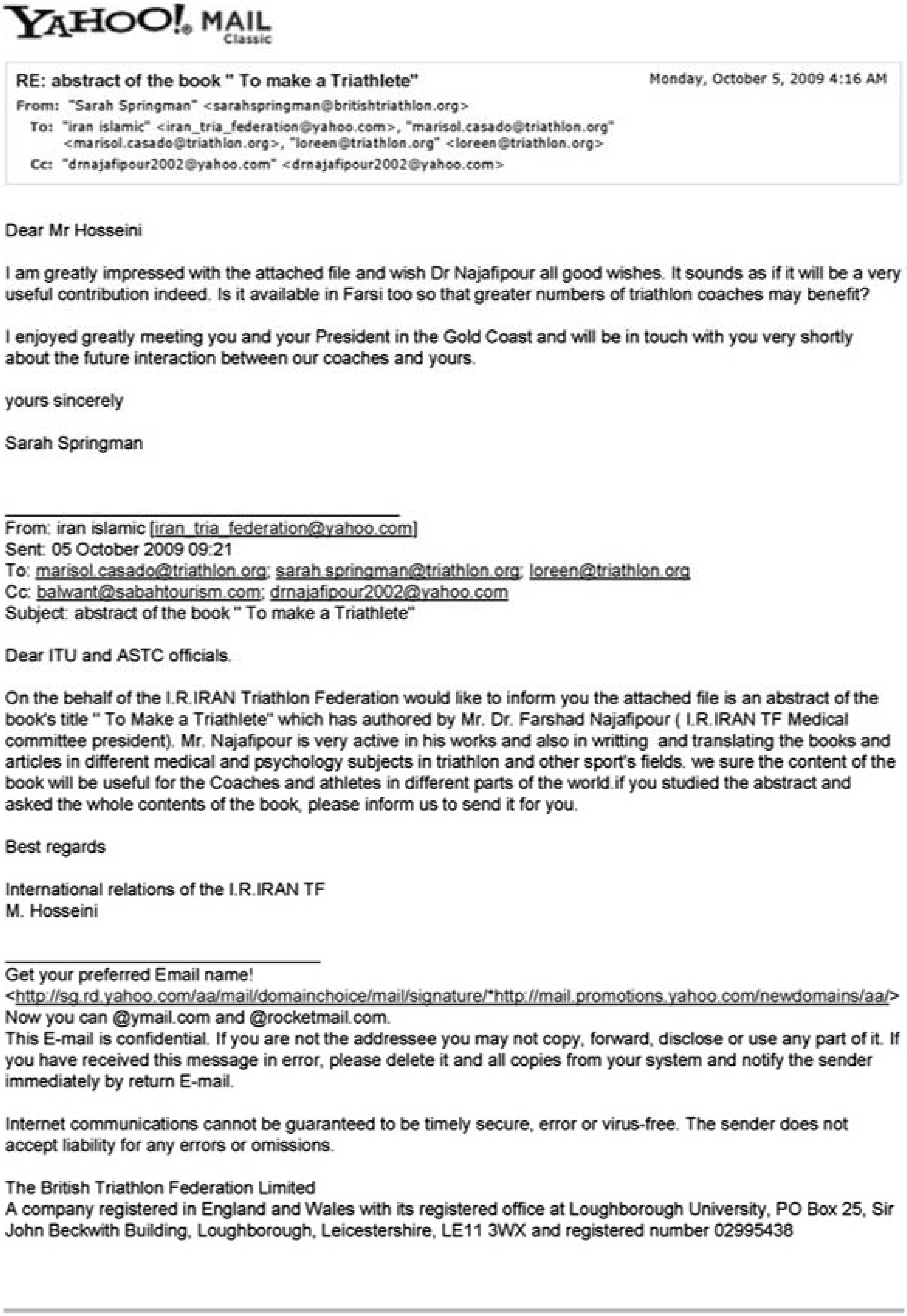
By: Farshad Najafipour, MD, PhD &
Farzad Najafipour, Physiotherapist

سرشناسه : نجفی‌پور، فرشاد، ١٣٤٥
عنوان و نام پدیدآور : To Make A Triathlete
مشخصات نشر : تهران: دانشیاران ایران، ١٣٩٤
مشخصات ظاهری : ٢٣٦ ص
شابک : ٩٧٨-٦٠٠-٧٨٥٩-٢١-٦
وضعیت فهرست‌نویسی : فیپای مختصر
یادداشت : فهرستنویسی کامل این اثر در نشانی: http://opac.nlai.ir قابل دسترسی است.
شناسه افزوده : نجفی‌پور، فرزاد، ١٣٤٥
شماره کتابشناسی ملی : ٣٨١٦٢٦٢

شناسنامه کتاب

نام کتاب: .... To Make A Triathlete
مولفین: .... فرشاد نجفی‌پور، فرزاد نجفی‌پور
مدیریت انتشارات: .... روح‌الله گلستانی
مسئول امور نشر: .... محمد رسول نصرتی
صفحه‌آرا: .... نسیم امیری
طراحی جلد: .... شبنم امیری
ناشر: .... انتشارات دانشیاران ایران
چاپ و صحافی: .... پرستش
قیمت: .... ١٤٠٠٠ تومان
نوبت چاپ: .... اوّل/١٣٩٤
شمارگان: .... ١٠٠٠ نسخه

مرکز پخش :
تهران، میدان بهارستان، خیابان مجاهدین اسلام، کوچه آذر
همراه : ٠٩١٢١٣٨٣٧١٨ تلفن : ٧٧٦٧٠٥٦٩ ، ٧٧٦٧٠٧٣١
فروشگاه اینترنتی کتاب پایابوک : www.payabook.com



YAHOO! MAIL Classic

RE: abstract of the book " To make a Triathlete" Monday, October 5, 2009 4:16 AM

From: "Sarah Springman" <sarahspringman@britishtriathlon.org>
To: "iran islamic" <iran_tria_federation@yahoo.com>, "marisol.casado@triathlon.org" <marisol.casado@triathlon.org>, "loreen@triathlon.org" <loreen@triathlon.org>
Cc: "drnajafipour2002@yahoo.com" <drnajafipour2002@yahoo.com>

Dear Mr Hosseini

I am greatly impressed with the attached file and wish Dr Najafipour all good wishes. It sounds as if it will be a very useful contribution indeed. Is it available in Farsi too so that greater numbers of triathlon coaches may benefit?

I enjoyed greatly meeting you and your President in the Gold Coast and will be in touch with you very shortly about the future interaction between our coaches and yours.

yours sincerely

Sarah Springman

From: iran islamic [iran_tria_federation@yahoo.com]
Sent: 05 October 2009 09:21
To: marisol.casado@triathlon.org; sarah.springman@triathlon.org; loreen@triathlon.org
Cc: balwant@sabahtourism.com; drnajafipour2002@yahoo.com
Subject: abstract of the book " To make a Triathlete"

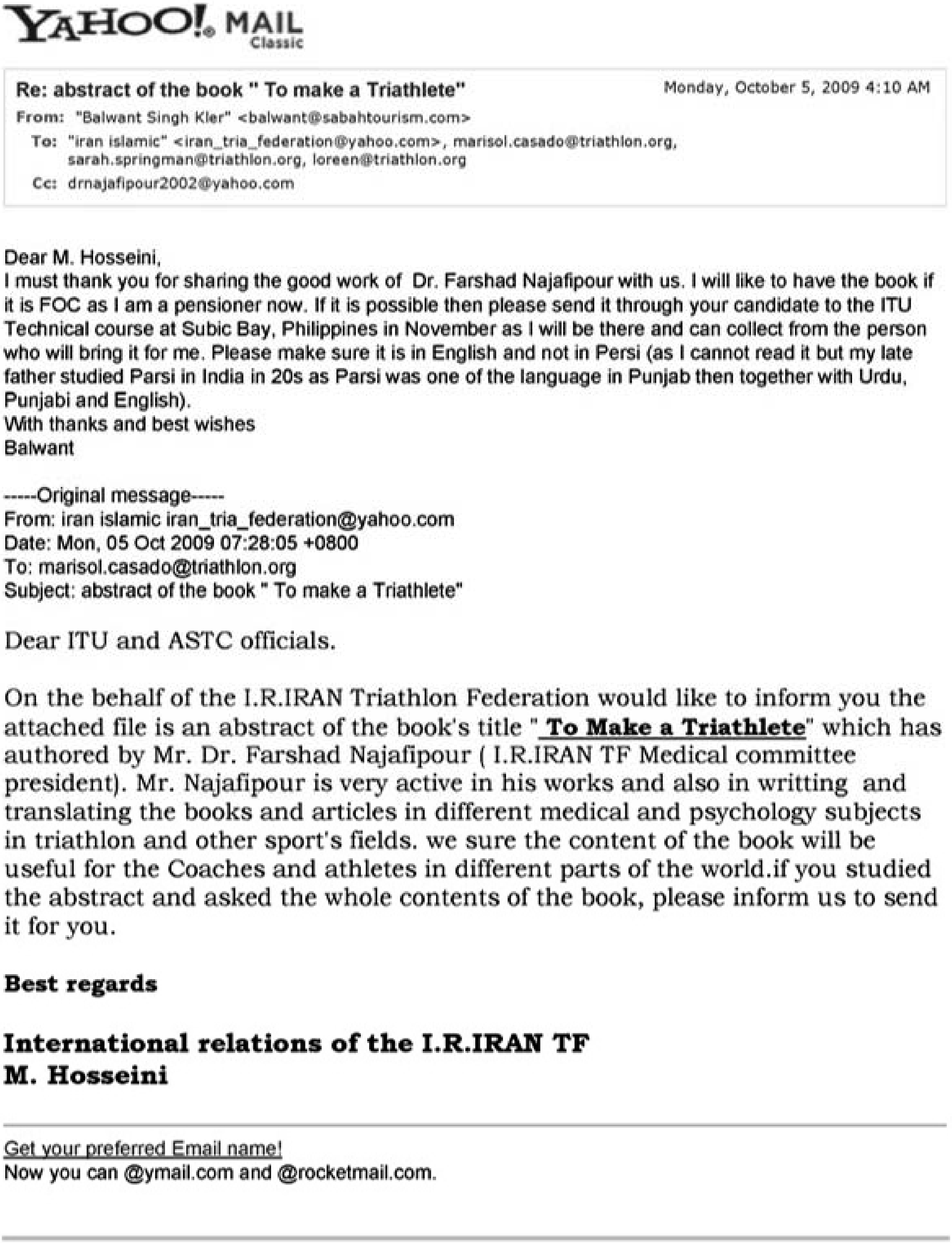
Dear ITU and ASTC officials.

On the behalf of the I.R.IRAN Triathlon Federation would like to inform you the attached file is an abstract of the book's title " To Make a Triathlete" which has authored by Mr. Dr. Farshad Najafipour (I.R.IRAN TF Medical committee president). Mr. Najafipour is very active in his works and also in writting and translating the books and articles in different medical and psychology subjects in triathlon and other sport's fields. we sure the content of the book will be useful for the Coaches and athletes in different parts of the world.if you studied the abstract and asked the whole contents of the book, please inform us to send it for you.

Best regards

International relations of the I.R.IRAN TF
M. Hosseini

The British Triathlon Federation Limited
A company registered in England and Wales with its registered office at Loughborough University, PO Box 25, Sir John Beckwith Building, Loughborough, Leicestershire, LE11 3WX and registered number 02995438



Re: abstract of the book " To make a Triathlete"

Monday, October 5, 2009 4:10 AM

From: "Balwant Singh Kler" <balwant@sabahtourism.com>
To: "iran islamic" <iran_tria_federation@yahoo.com>, marisol.casado@triathlon.org, sarah.springman@triathlon.org, loreen@triathlon.org
Cc: drnajafipour2002@yahoo.com

Dear M. Hosseini,
I must thank you for sharing the good work of Dr. Farshad Najafipour with us. I will like to have the book if it is FOC as I am a pensioner now. If it is possible then please send it through your candidate to the ITU Technical course at Subic Bay, Philippines in November as I will be there and can collect from the person who will bring it for me. Please make sure it is in English and not in Persi (as I cannot read it but my late father studied Parsi in India in 20s as Parsi was one of the language in Punjab then together with Urdu, Punjabi and English).
With thanks and best wishes
Balwant

-----Original message-----
From: iran islamic iran_tria_federation@yahoo.com
Date: Mon, 05 Oct 2009 07:28:05 +0800
To: marisol.casado@triathlon.org
Subject: abstract of the book " To make a Triathlete"

Dear ITU and ASTC officials.

On the behalf of the I.R.IRAN Triathlon Federation would like to inform you the attached file is an abstract of the book's title " **To Make a Triathlete**" which has authored by Mr. Dr. Farshad Najafipour (I.R.IRAN TF Medical committee president). Mr. Najafipour is very active in his works and also in writting and translating the books and articles in different medical and psychology subjects in triathlon and other sport's fields. we sure the content of the book will be useful for the Coaches and athletes in different parts of the world.if you studied the abstract and asked the whole contents of the book, please inform us to send it for you.

Best regards

International relations of the I.R.IRAN TF
M. Hosseini

To Make A Triathlete

(Triathlon Conditioning)

By:
Farshad Najafipour, MD, PhD.
&
Farzad Najafipour, Physiotherapist.

TABLE OF CONTENTS

PREFACE 9

AEROBIC ENDURANCE TRAINING 11

LONG SLOW DISTANCE TRAINING 12
PACE/TEMPO TRAINING 12
INTERVAL TRAINING 13
REPETITION TRAINING 14
FARTLEK TRAINING 14

LACTATE THRESHOLD TRAINING 15

LACTATE THRESHOLD TRAINING SESSIONS 16

THE LACTATE THRESHOLD 18

LACTATE THRESHOLD AS A PERCENTAGE OF VO 2 MAX 19
LACTATE THRESHOLD AND TRAINING 21

VO2 MAX, AEROBIC POWER& MAXIMAL OXYGEN UPTAKE 23

VO2 MAX IN ATHLETES AND NON ATHLETES 24
TRAINING & VO2 MAX 26
VO2 MAX AS A PREDICTOR OF PERFORMANCE 27
FACTORS AFFECTING VO2 MAX 27
DETERMINING VO2 MAX 28
VO2 MAX AT ALTITUDE 29
EFFECTS OF AGING ON VO2 MAX 29

HOW TO DETERMINE LACTATE / ANAEROBIC THRESHOLD 31

LABORATORY TESTING OF ANAEROBIC THRESHOLD 31
PORTABLE LACTATE ANALYZER 34
CONCONI TEST 34
10KM RUN, 30KM CYCLE, 30 MIN TIME TRIAL 35
HEART RATE PERCENTAGE 35
THE LACTATE THRESHOLD DEBATE 35

LACTIC ACID, BLOOD LACTATE & THE “LACTIC ACID MYTH” 37

LACTIC ACID AND OXYGEN 37
LACTATE IS NOT A WASTE PRODUCT 38
LACTATE ACCUMULATION 40
LACTIC ACIDOSIS 40
ACIDOSIS AND FATIGUE 41
LACTATE ACCUMULATION AND EXERCISE 42
TO SUMMERIZE 42

ENERGY SYSTEMS IN SPORT & EXERCISE 44

ATP – THE BODY'S ENERGY CURRENCY 44
ENERGY SOURCES TO REPLENISH ATP 45
THE THREE ENERGY SYSTEMS 47
THE ATP-PCR SYSTEM 47
THE GLYCOLYTIC SYSTEM 48
THE OXIDATIVE SYSTEM 49
ENERGY SYSTEMS & TRAINING 51
ENERGY SYSTEMS USED IN SPORTS 51
A NEW MODEL FOR ENERGY SYSTEMS? 52

DELAYED ONSET MUSCLE SORENESS (DOMS) 54

CAUSES OF DELAYED ONSET MUSCLE SORENESS 54
REDUCING THE EFFECTS OF DELAYED ONSET MUSCLE SORENESS 56

MUSCLE ANATOMY & STRUCTURE 57

THE SLIDING FILAMENT THEORY OF MUSCLE ACTION 61

THE SARCOPLASMIC RETICULUM 62
EXCITATION-CONTRACTION COUPLING 62

HEART RATE TRAINING: FINDING THE RIGHT ZONE FOR YOU 64

THE LIMITATIONS OF HEART RATE TRAINING 64
HEART RATE TRAINING ZONES 65
THE KARVONEN FORMULA (HEART RATE RESERVE) 66
THE CONCONI TEST FOR MEASURING LACTATE THRESHOLD 67
HEART RATE TRAINING TO INCREASE LACTATE THRESHOLD 69

THE BRUCE TREADMILL TEST 70

ENDURANCE TESTS 72

BALKE 15 MINUTE RUN 72
COOPER 12 MINUTE RUN 73
MULTISTAGE SHUTTLE RUN 73

ROCKPORT TEST 73

ACCLIMATIZATION TO ALTITUDE 74

HIGH ALTITUDE ENVIRONMENT 74
ACUTE RESPONSE TO ALTITUDE 75
ACCLIMATIZATION TO ALTITUDE 77
PREPARING FOR COMPETITION AT ALTITUDE 80

ALTITUDE TRAINING 81

LIVE HIGH - TRAIN LOW 82

HEART RATE RESERVE... HOW TO DETERMINE YOUR HEART RATE TRAINING ZONE 83

INTERVAL TRAINING FOR SPORT SPECIFIC ENDURANCE 85

INTERVAL TRAINING IS SUITABLE FOR MANY SPORTS 86
INTERVAL TRAINING SESSIONS 87

THE CARDIOVASCULAR SYSTEM AND EXERCISE 89

IMMEDIATE RESPONSE OF THE CARDIOVASCULAR SYSTEM TO EXERCISE....... 90
ADAPTATIONS IN THE CARDIOVASCULAR SYSTEM 93

HYPERTROPHY IN HUMAN MUSCLE 96

HYPERPLASIA IN HUMAN MUSCLE 98

HOW TO DESIGN A RESISTANCE TRAINING PROGRAM FOR YOUR SPORT... 100

STEP 1 - EVALUATION AND ASSESSMENT 100
STEP 2 - EXERCISE SELECTION 101
STEP 3 - FREQUENCY 103
STEP 4 - EXERCISE ORDER 104
STEP 5 - LOADING & REPETITIONS 106
STEP 6 - VOLUME 107
STEP 7 - PROGRESSION 108

STRENGTH TESTS 110

MAXIMAL STRENGTH ASSESSMENT (1-RM) 110
STRENGTH ENDURANCE ASSESSMENT 115

MUSCULAR ENDURANCE TRAINING 116

THE DIFFERENT TYPES OF MUSCULAR ENDURANCE 116

WEIGHT TRAINING PROGRAMS FOR BUILDING MAXIMUM STRENGTH...... 121

MAXIMAL STRENGTH TRAINING OVER BODYBUILDING 121
DESIGNING MAXIMAL STRENGTH WEIGHT TRAINING PROGRAMS 122
SAMPLE MAXIMAL STRENGTH WEIGHT TRAINING PROGRAM 123

WEIGHT TRAINING PROGRAMS FOR INCREASING MUSCLE MASS 124

DESIGNING HYPERTROPHY WEIGHT TRAINING PROGRAMS............................ 125
SAMPLE HYPERTROPHY WEIGHT TRAINING PROGRAMS................................ 126

THE SPORT SPECIFIC APPROACH TO STRENGTH TRAINING PROGRAMS...... 129

EXERCISE SELECTION... 129
DIFFERENT TYPES OF STRENGTH TRAINING 130
THE PERIODIZATION OF STRENGTH.. 132

POWER TRAINING FOR SPORT 136

THE FORCE - VELOCITY RELATIONSHIP.. 136
THE DIFFERENT TYPES OF POWER TRAINING 138
WHICH IS THE BEST FORM OF POWER TRAINING?.. 141

ISOMETRIC EXERCISES & STATIC STRENGTH TRAINING 143

GUIDELINES FOR ISOMETRIC EXERCISES 144
EXAMPLE FULL BODY ISOMETRIC EXERCISES.. 145
EXAMPLE UPPER & LOWER BODY ISOMETRIC EXERCISES............................. 146

MEDICINE BALL EXERCISES 149

INCORPORATING MEDICINE BALL EXERCISES INTO A PROGRAM 150
GENERAL GUIDELINES 150
SAMPLE MEDICINE BALL EXERCISES... 151

CIRCUIT TRAINING SECTION.. 154

CIRCUIT TRAINING ARTICLES 155

PLYOMETRIC TRAINING 156

KETTLEBELL EXERCISES 157

KETTLEBELL EXERCISES 157

STATIC STRETCHING EXERCISES & FLEXIBILITY PROGRAM 160

KEY POINTS FOR EFFECTIVE STRETCHING 160
UPPER AND LOWER BODY STRETCHING EXERCISES 161

STATIC STRETCHING 163

STATIC STRETCHES BEFORE PERFORMANCE 163
LONG-TERM STATIC STRETCHING PROGRAMS 163

DYNAMIC STRETCHES & STRETCHING ROUTINE 165

DYNAMIC STRETCHES 165

STATIC ACTIVE STRETCHING 168

WEIGHT TRAINING PROGRAMS FOR BASIC STRENGTH 169

DESIGNING WEIGHT TRAINING PROGRAMS FOR BASIC STRENGTH................ 171
SAMPLE WEIGHT TRAINING PROGRAMS FOR BASIC STRENGTH..................... 172

CORE STRENGTH TRAINING FOR ATHLETES... 175

EQUIPMENT USED FOR CORE STRENGTH TRAINING...................................... 177
POPULAR CORE STRENGTH TRAINING EXERCISES... 177

SPEED ENDURANCE TRAINING.. 180

SPEED ENDURANCE DRILLS 181

HOW TO DESIGN FARTLEK TRAINING SESSIONS FOR YOUR SPORT............ 183

SAMPLE FARTLEK TRAINING SESSIONS 184

PLYOMETRIC TRAINING FOR SPORT SPECIFIC POWER 186

PLYOMETRICS & THE STRENGTH TRAINING PROGRAM................................. 186
PLYOMETRIC EXERCISE SELECTION... 186
EXERCISE INTENSITY... 187
VOLUME 188
FREQUENCY... 188
REST INTERVALS 189
WARMING UP 189
SAFETY CONSIDERATIONS 189
SAMPLE PLYOMETRIC TRAINING SESSIONS 190
HOW TO LITERALLY DOUBLE YOUR VERTICAL JUMP (OR INCREASE BY 12 INCHES OR MORE!) 191

LOWER BODY PLYOMETRIC EXERCISES 192

PLYOMETRIC EXERCISE INTENSITY.. 192
LOWER BODY PLYOMETRIC EXERCISES (LOW INTENSITY) 193
LOWER BODY PLYOMETRIC EXERCISES (MODERATE INTENSITY) 194
LOWER BODY PLYOMETRIC EXERCISES (HIGH INTENSITY) 196

UPPER BODY PLYOMETRIC DRILLS 198

UPPER BODY PLYOMETRIC DRILLS 199

THE PHYSIOLOGY OF PLYOMETRICS 202

HOW PLYOMETRIC EXERCISES WORK 202
THE STRETCH-SHORTENING CYCLE 203
HOW TO INCREASE YOUR VERTICAL JUMP 203
IS PLYOMETRIC TRAINING REALLY THAT EFFECTIVE? 204
PLYOMETRICS & CONCURRENT STRENGTH TRAINING 204
PLYOMETRICS & INJURY 205

FLEXIBILITY EXERCISES 207

UPPER BODY FLEXIBILITY EXERCISES 208
LOWER BODY FLEXIBILITY EXERCISES 208

FLEXIBILITY TRAINING SECTION 210

THE BENEFITS OF FLEXIBILITY TRAINING 210
TYPES OF FLEXIBILITY AND STRETCHING 211
FLEXIBILITY TRAINING ARTICLES 212

ISOMETRIC STRETCHING EXPLAINED 213

HOW ISOMETRIC STRETCHING WORKS 213
ISOMETRIC STRETCHING GUIDELINES 214

PNF STRETCHING 215

SELF MYOFASCIAL RELEASE 218

FASCIA & TRIGGER POINTS 218
SELF MYOFASCIAL RELEASE EXERCISES 220
GENERAL GUIDELINES 221

THE WINGATE TEST FOR ANAEROBIC POWER 222

WINGATE TEST PROTOCOL 223

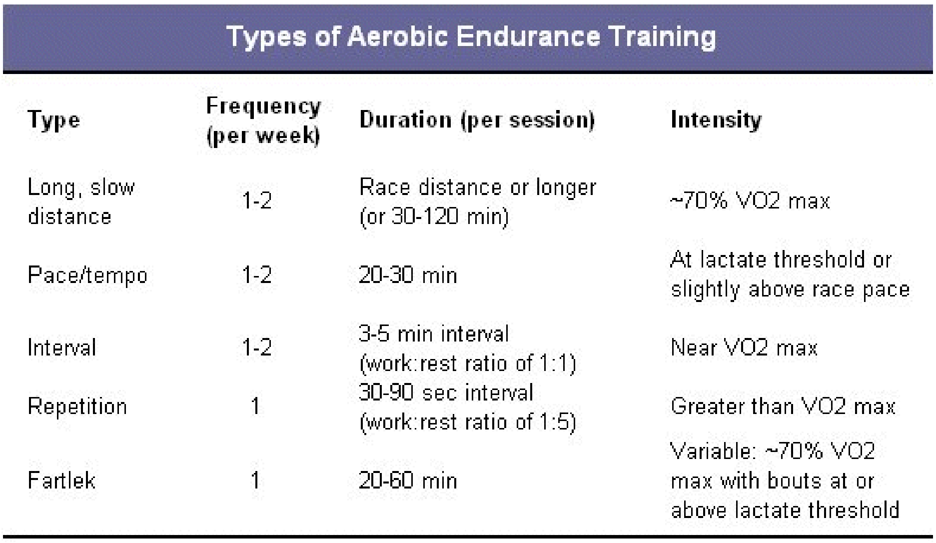
REFFERENCES: 225

1

Aerobic Endurance Training

There are several different types of aerobic endurance training - each with a different, specific outcome and suitable for different events and sports.

The duration, frequency and intensity of sessions varies with each form of training leading to different physiological adaptations within the body. The table below summarizes the main types of aerobic endurance training and suggested parameters:



Types of Aerobic Endurance Training

Type	Frequency (per week)	Duration (per session)	Intensity
Long, slow distance	1-2	Race distance or longer (or 30-120 min)	~70% VO2 max
Pace/tempo	1-2	20-30 min	At lactate threshold or slightly above race pace
Interval	1-2	3-5 min interval (work:rest ratio of 1:1)	Near VO2 max
Repetition	1	30-90 sec interval (work:rest ratio of 1:5)	Greater than VO2 max
Fartlek	1	20-60 min	Variable: ~70% VO2 max with bouts at or above lactate threshold

Adapted from Essentials of Strength Training & Conditioning (2000) (8)

Long Slow Distance Training

As you would expect this type of training is typical of a long distance runner. Intensity is usually less than 70% VO_2max, or equivalent to about 80% maximum heart rate. Duration should be near to race distance or at least 30 minutes to 2 hours long. Intensity for long, slow distance endurance training is often gauged using the "talk" test whereby the athlete can hold a conversation without being too winded.

Adaptations to this form of aerobic endurance training include improved cardiovascular and thermoregulatory function, improved mitochondrial energy production, increased oxidative capacity of skeletal muscle and increased utilization as fat for fuel (which spares muscle glycogen). Anaerobic or lactate threshold is also likely to improve with a body better able to remove lactate.

Because long distance training is low intensity (lower than competition) too great a reliance on this form of endurance running in the athlete's training program can be disadvantageous. Here is a sample training program for a marathon runner:

Sample Half Marathon Training Plan						
Sunday	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
Rest	Fartlek Run (45 min)	Long Slow Distance Run (60 min)	Interval Training (45 min)	Pace/Tempo Run (60 min)	Repetition Run (45 min)	Long Slow Distance Run (120 min)

Notice how the two long distance runs are split up with plenty of rest between? Only one run per week that approaches half marathon distance. The other types of training are covered below...

Pace/Tempo Training

Also referred to as lactate threshold training, pace/tempo training is designed to improve energy production from both aerobic and anaerobic energy pathways. Intensity is slightly higher than race pace and corresponds to the lactate threshold. Duration is usually 20-30 minutes at a steady pace.

Tempo/pace training can also be performed intermittently or in intervals. Intensity is the same as steady state tempo/pace training except the session consists of a series of shorter bouts with brief recovery periods. It is important to keep intensity at or slightly higher than competition pace for either type of pace/tempo training. Progression should be in the form of increased duration rather than a faster running/ cycling/ swimming/ rowing velocity etc.

Interval Training

Interval training allows the athlete to work close to their aerobic limit (VO_2max) for a longer duration compared to a continuous type session. Short bouts of 3-5 minutes at an intensity close to VO_2max are interspersed by periods of active recovery. Work to rest ratio should be 1:1 so a 3 minute run should be followed by 3 minutes of rest .

Because this type of aerobic endurance training is very demanding, sessions should be limited both in duration and in frequency each week. Duration is usually 30-45 minutes and frequency is one or two sessions per week, with ample rest days between. Below is a sample program for a 10k runner:

Sample 10K Training Plan

Sunday	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
Rest	10 x 0.5km	10km run (easy)	Long Slow Distance Run (45 min)	5 x 1km	Long Slow Distance Run (45 min)	Fartlek Run (45 min)

Taking the time for each 0.5km interval, allocate the same amount of time for the rest periods between. Rest should be in the form of active recovery such as brisk walking or very light jogging.

Repetition Training

This is the most intense form of aerobic endurance training. Performed at a pace greater than VO_2max it places a high demand on the anaerobic energy systems. Work intervals are usually only 60-90 seconds separated by rest intervals of 5 minutes or more. Typically work to rest ratio is 1:5 . Repetition training helps to improve running speed, running economy and builds a greater tolerance to lactic acid. Endurance athletes often use repetition training to help in the final kick of a race. Due to the high intensity nature, only one session per week is required.

Fartlek Training

Fartlek training combines some or all of the above aerobic endurance training techniques. A long slow run/cycle (at about 70% VO_2max) form the foundation of the session and is combined with short bursts of higher intensity work. There is no set format for a Fartlek session although there are some standard sessions that have been developed by coaches over the years. Fartlek endurance training will improve VO_2max, exercise economy and lactate threshold. It also adds a nice change of pace to the more monotonous steady-state training. The table below outlines a sample program for an amateur Cross Country Runner:

Sample Cross Country Training Plan

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Rest	Long slow distance run (60 min)	Fartlek run (45 min)	Pace/Tempo Run (25 min)	Long Slow Distance Run (45 min)	25 min Long Slow Distance Run	Race Day

There are literally dozens of fartlek sessions that can be adopted into an aerobic endurance training program. For more information see How to Design a Fartlek Training Session for Your Sport.

2

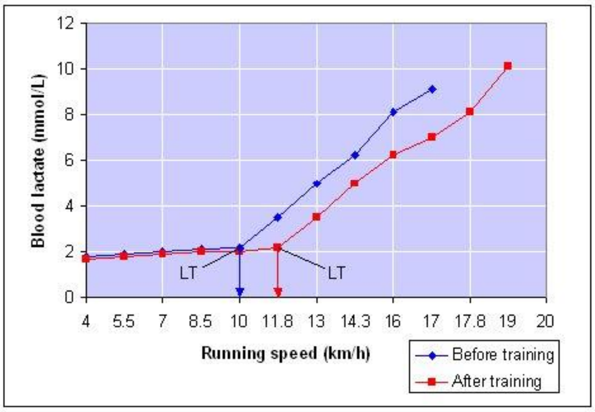
Lactate Threshold Training

Lactate threshold training will help to improve performance times in endurance events such as distance running, cycling and swimming. As its name suggests, this form of conditioning is designed to increase the exercise intensity at which the anaerobic or lactate threshold occurs.

There is some confusion amongst coaches and athletes as to the role of blood lactate and lactic acid in the body. Central to this confusion is how it contributes to fatigue. But regardless of the underlying causes, the accumulation of blood lactate remains a good indicator for subsequent exhaustion and can predict performance in many endurance events.

During submaximal exercise, lactate concentration in the plasma remains at a near resting level. As the intensity increases, there comes a point when blood lactate begins to accumulate rapidly in the blood. Some researchers contest this suggesting that no specific breakpoint or threshold exists and that lactate accumulation is continuous .

However, from a practical point of view what is most important is that lactate threshold training can delay blood lactate accumulation, in effect shifting the lactate curve to the right. See the graph below:



Although it is difficult to accurately measure lactate threshold outside of a laboratory setting, there are some field tests that may be worth considering in order to determine your own anaerobic threshold. You may even want to consider using a portable lactate monitor and testing kit, which have become much less expensive in recent years.

There is a substantial body of research that shows training at or close to the lactate threshold increases the intensity at which it occurs . Recall that lactate threshold is often expressed as a percentage of VO2 max. For example, if an athlete reaches VO2 max at a running speed of 24km/h (15mph) and lactate begins to accumulate at 16 km/h (10mph), they are said to have a lactate threshold of 67%.

World-class endurance athletes typically have thresholds of up to 90% VO2 max compared to 50% in untrained individuals.

Lactate Threshold Training Sessions

Threshold training (also known as pace, tempo or aerobic/anaerobic training) can be either continuous or intermittent in nature. Both require an exercise intensity at or slightly above the lactate threshold.

One of the most common ways to gauge lactate threshold training intensity is to monitor heart rate. While, a very quick and simple method is to simply assume your lactate threshold will occur at 85-90% of your maximum heart rate, this method lacks accuracy and reliability for many athletes. If you do want to determine training intensity this way, use the Karvonen formula rather than simply deducting your age from 220.

A more reliable method is to determine your heart rate at the lactate threshold and then to train at this heart rate intensity. This is by no means flawless however, especially as heart rate often tends to rise slowly over prolonged exercise periods without increases in intensity – a phenomenon known as cardiac drift.

Cyclists can use a power meter to determine the work rate at lactate threshold and thus a suitable intensity for lactate threshold training sessions.

Here is a typical interval lactate threshold training session:

Interval Training Session	
Frequency	2x week
Intensity	95-105% LT*
No. intervals	3-5
Interval time	10mins
Rest intervals	2-3mins

* LT = Training intensity at Lactate Threshold measured via heart rate or power output etc.

And here is a sample continuous lactate threshold training session:

Continuous Training Session	
Frequency	2x week
Intensity	95-105% LT
Time	20-30mins

3

The Lactate Threshold

If VO2 max is your ‘aerobic endurance potential’ then your lactate threshold plays a significant role in how much of that potential you are tapping.

Lactate threshold has been defined as:

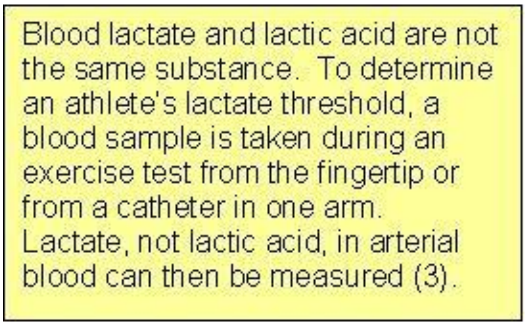
> *”The point during exercise of increasing intensity at which blood lactate begins to accumulate above resting levels, where lactate clearance is no longer able to keep up with lactate production.”*

During low intensity exercise, blood lactate remains at or near to resting levels. As exercise intensity increases there comes a break point where blood lactate levels rise sharply . Researchers in the past have suggested that this signifies a significant shift from predominantly aerobic metabolism to predominantly anaerobic energy production.

Several terms have been used to describe this shift and many coaches and athletes believe it is the same phenomenon:

- Lactate threshold
- Anaerobic threshold
- Aerobic threshold
- Onset of blood lactate accumulation (OBLA)
- Maximal lactate steady state

Although these terms are used interchangeably, they do not describe the same thing. Lactate accumulation only determines the balance between lactate production and its clearance and suggests nothing about the availability or lack of oxygen so the terms ‘aerobic’ and ‘anaerobic’ become a bit misleading.



Blood lactate and lactic acid are not the same substance. To determine an athlete's lactate threshold, a blood sample is taken during an exercise test from the fingertip or from a catheter in one arm. Lactate, not lactic acid, in arterial blood can then be measured (3).

The reasons for lactate accumulation are complex and varied and not yet fully understood. For more information on this topic see the lactic acid article.

OBLA

At a slightly higher exercise intensity than lactate threshold a second increase in lactate accumulation can be seen and is often referred to as the onset of blood lactate accumulation or OBLA. OBLA generally occurs when the concentration of blood lactate reaches about 4mmol/L. The break point that corresponds to lactate threshold can often be hard to pinpoint and so some Exercise Physiologists often prefer using OBLA.

Maximal Lactate Steady State

Maximal lactate steady state is defined as the exercise intensity at which maximal lactate clearance is equal to maximal lactate production . Maximal lactate steady state is considered one of the best indicators of performance perhaps even more efficient than lactate threshold .

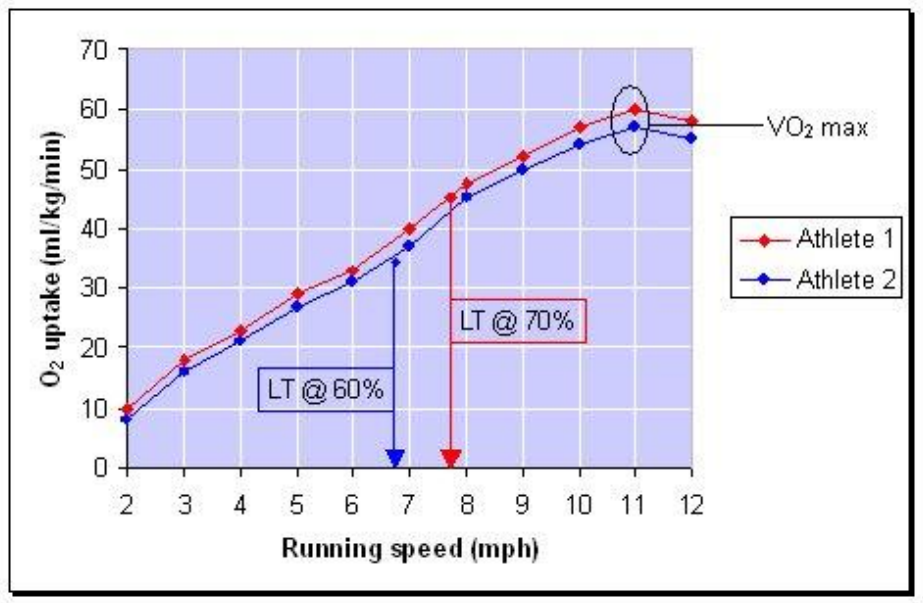
Lactate Threshold as a Percentage of VO 2 Max

The lactate threshold is normally expressed as a percentage of an individual’s VO2 max. For example, if VO2 max occurs at 24 km/h on a treadmill test and a sharp rise in blood lactate concentration above resting levels is seen at 12 km/h then the lactate threshold is said to be 50% VO2 max.

In theory, an individual could exercise at any intensity up to their VO2 max indefinitely. However, this is not the case even amongst elite athletes.

As the exercise intensity draws closer to that at VO2 max, a sharp increase in blood lactate accumulation and subsequent fatigue occurs – the lactate threshold is broken. In world-class athletes lactate threshold typically occurs at 70-80% VO2 max. In untrained individual's it occurs much sooner, at 50-60% VO2 max .

Generally, in two people with the same VO2 max, the one with a higher lactate threshold will perform better in continuous-type endurance events. See the graph below:



Although both Athlete 1 and Athlete 2 reach VO2 max at a similar running speed, Athlete 1 has a lactate threshold at 70% and Athlete 2 has a lactate threshold at 60%. Theoretically, Athlete 1 can maintain a pace of about 7.5 mph (12 km/h) compared to Athlete 2's pace of about 6.5 mph (10.5km/h).

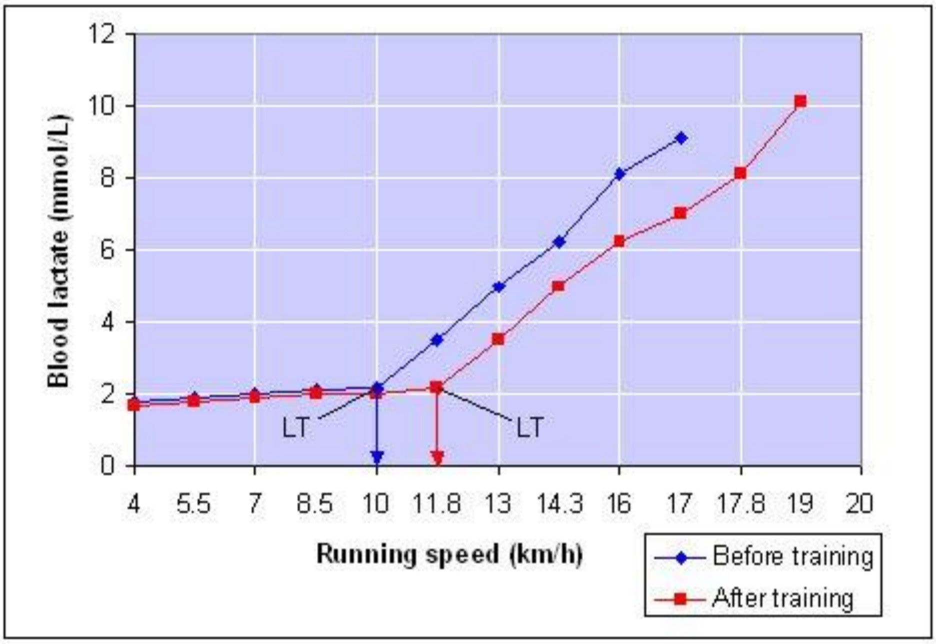
VO2 max has been used to predict performance in endurance events such as distance running and cycling but the lactate threshold is much more reliable. Race pace has been closely associated with lactate threshold.

There are several non-invasive methods used to determine the lactate or anaerobic threshold. For more information see How to Determine Your

Anaerobic Threshold.

Lactate Threshold and Training

With training, lactate threshold as a percentage of VO2 max can be increased. Even if there are no improvements in maximal oxygen uptake, increasing the relative intensity or speed at which lactate threshold occurs will improve performance. In effect, proper training can shift the lactate curve to the right:



Following training, the reductions in lactate concentration at any given intensity may be due to a decrease in lactate production and an increase in lactate clearance. However, Donovan and Brooks suggest that endurance training affects only lactate clearance rather than production.

Blood lactate levels after an intense exercise bout are also lower following training. For example, immediately after a 200m swim at a fixed pace, blood lactate may be as high as 13-14 mmol/L. Following 7 months of training these levels can decrease to under 4mmol/L . Before training, a swim leading to such high levels of lactate would force the swimmer to slow down dramatically or stop after the 200m. But following training, lactate levels of under 4mmol/L would probably allow the swimmer to continue after 200m, at the same pace, indefinitely.

Studies have shown that training at or slightly above the lactate threshold can increase the relative intensity at which it occurs . For more information and sample training sessions for improving lactate threshold see the lactate threshold training article.

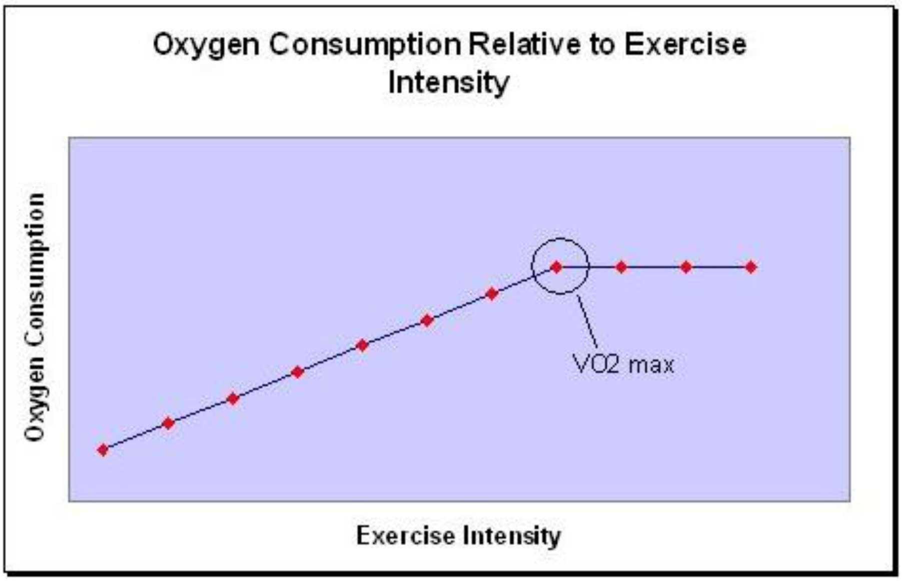
4

VO2 Max, Aerobic Power& Maximal Oxygen Uptake

VO2 max has been defined as:

> *"the highest rate of oxygen consumption attainable during maximal or exhaustive exercise"* .

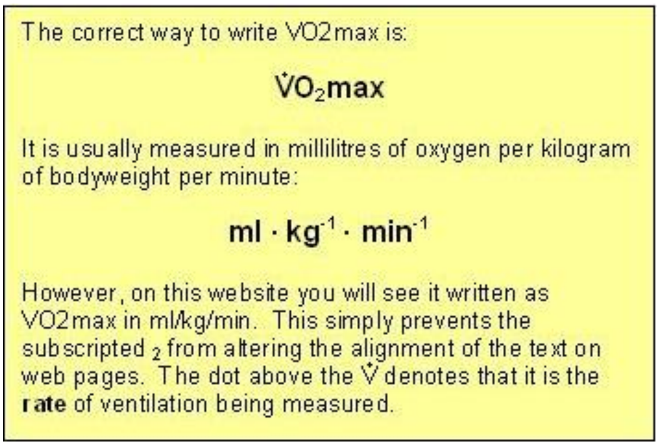
As exercise intensity increases so does oxygen consumption. However, a point is reached where exercise intensity can continue to increase without the associated rise in oxygen consumption. To understand this in more practical terms, take a look at the diagram below:



The point at which oxygen consumption plateaus defines the VO2 max or an individual's maximal aerobic capacity. It is generally considered the best indicator of cardiorespiratory endurance and aerobic fitness. However, as we’ll discuss in a moment, it is more useful as an indicator of a person's aerobic potential or upper limit than as a predictor of success in endurance events.

Aerobic power, aerobic capacity and maximal oxygen uptake are all terms used interchangeably with VO2 max.

VO2 max is usually expressed relative to bodyweight because oxygen and energy needs differ relative to size. It can also be expressed relative to body surface area and this may be a more accurate when comparing children and oxygen uptake between sexes.



The correct way to write VO2max is:

$$\dot{V}O_2max$$

It is usually measured in millilitres of oxygen per kilogram of bodyweight per minute:

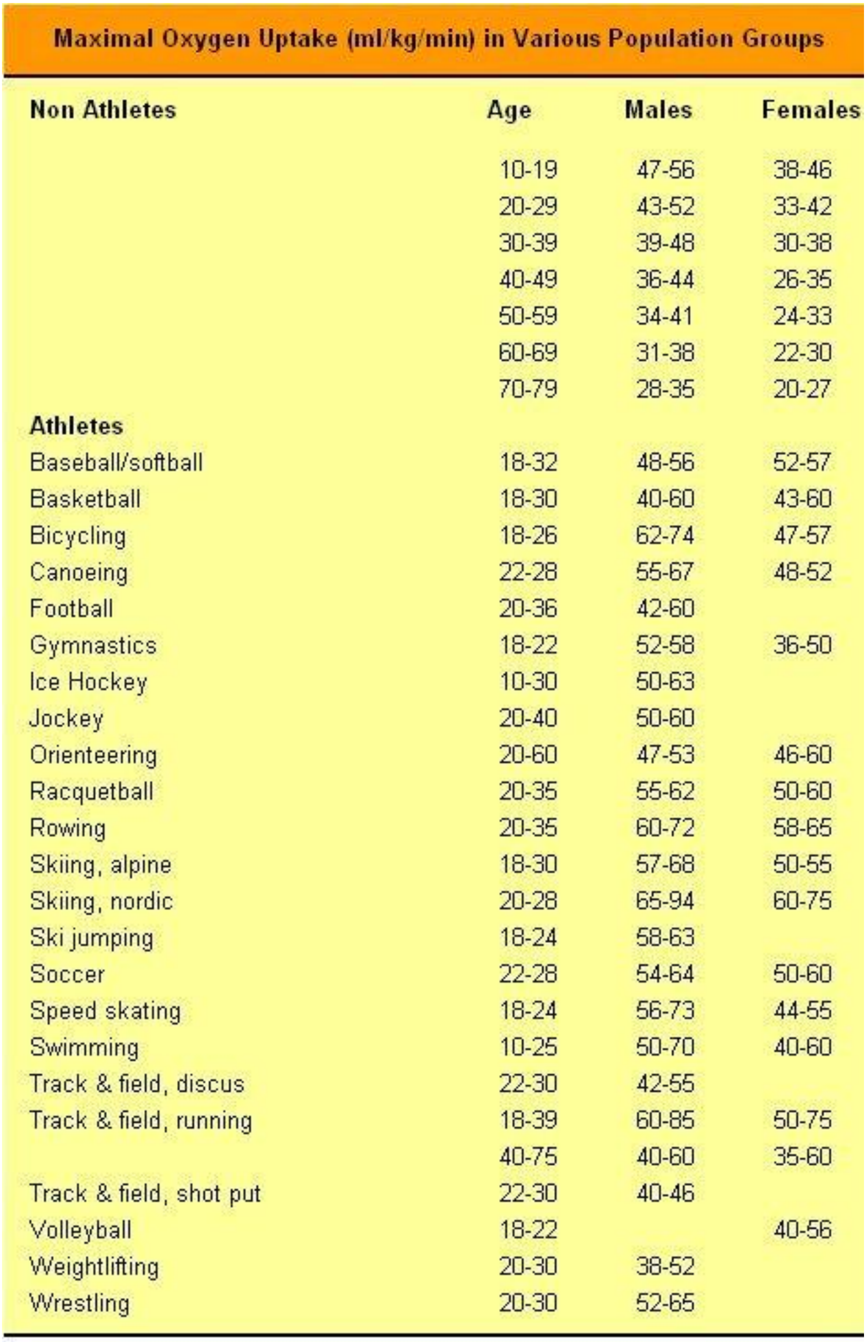
$$ml \cdot kg^{-1} \cdot min^{-1}$$

However, on this website you will see it written as VO2max in ml/kg/min. This simply prevents the subscripted $_2$ from altering the alignment of the text on web pages. The dot above the $\dot{V}$ denotes that it is the **rate** of ventilation being measured.

One study followed a group of 12-year-old boys through to the age of 20 - half of which were trained, the other half untrained but active. Relative to bodyweight no differences in VO2 max were found between the groups suggesting that training had no influence on maximal oxygen uptake. However, when VO2 max was expressed relative to body surface area, there was a significant difference between groups and maximal oxygen uptake did indeed increase in proportion to training.

VO2 Max In Athletes and Non Athletes

VO2 max varies greatly between individuals and even between elite athletes that compete in the same sport. The table below lists normative data for VO2 max in various population groups:



Maximal Oxygen Uptake (ml/kg/min) in Various Population Groups

Non Athletes	**Age**	**Males**	**Females**
	10-19	47-56	38-46
	20-29	43-52	33-42
	30-39	39-48	30-38
	40-49	36-44	26-35
	50-59	34-41	24-33
	60-69	31-38	22-30
	70-79	28-35	20-27
Athletes			
Baseball/softball	18-32	48-56	52-57
Basketball	18-30	40-60	43-60
Bicycling	18-26	62-74	47-57
Canoeing	22-28	55-67	48-52
Football	20-36	42-60	
Gymnastics	18-22	52-58	36-50
Ice Hockey	10-30	50-63	
Jockey	20-40	50-60	
Orienteering	20-60	47-53	46-60
Racquetball	20-35	55-62	50-60
Rowing	20-35	60-72	58-65
Skiing, alpine	18-30	57-68	50-55
Skiing, nordic	20-28	65-94	60-75
Ski jumping	18-24	58-63	
Soccer	22-28	54-64	50-60
Speed skating	18-24	56-73	44-55
Swimming	10-25	50-70	40-60
Track & field, discus	22-30	42-55	
Track & field, running	18-39	60-85	50-75
	40-75	40-60	35-60
Track & field, shot put	22-30	40-46	
Volleyball	18-22		40-56
Weightlifting	20-30	38-52	
Wrestling	20-30	52-65	

Taken from Wilmore and Costill (2005) (3)

Genetics plays a major role in a person’s VO2 max and heredity can account for up to 25-50% of the variance seen between individuals. The highest ever recorded VO2 max is 94 ml/kg/min in men and 77 ml/kg/min in women. Both were cross-country skiers.

Untrained girls and women typically have a maximal oxygen uptake 20-25% lower than untrained men. However, when comparing elite athletes, the gap tends to close to about 10%. Taking it step further, if VO2 max is adjusted to account for fat free mass in elite male and female athletes, the differences disappear in some studies. Cureton and Collins suggest that sex-specific essential fat stores account for the majority of metabolic differences in running between men and women.

Training & VO2 Max

In previously sedentary people, training at 75% of aerobic power, for 30 minutes, 3 times a week over 6 months increases VO2 max an average of 15-20% . However, this is an average and there are large individual variations with increases as wide ranging as 4% to 93% reported.

Amongst groups of people following the same training protocol there will be responders - those who make large gains, and non-responders - those who make little or no gains. This was originally put down to a simple issue of compliance but more recent research suggests that genetics plays a role in how well any one individual responds to an endurance training program.

The extent by which VO2 max can change with training also depends on the starting point. The fitter an individual is to begin with, the less potential there is for an increase and most elite athletes hit this peak early in their career. There also seems to be a genetic upper limit beyond which, further increases in either intensity or volume have no effect on aerobic power. This upper limit is thought to be reached within 8 to 18 months.

Crucially, once a plateau in VO2 max has been reached further improvements in performance are still seen with training. This is because the athlete is able to perform at a higher percentage of their VO2 max for prolonged periods. Two major reasons for this are improvements in anaerobic threshold and running economy.

Resistance training and intense 'burst-type' anaerobic training have little effect on VO2 max. Any improvements that do occur are usually small and in subjects who had a low level of fitness to begin with. Resistance training alone does not increase VO2 max even when short rest intervals are used between sets and exercises.

Considerable training is required to reach the upper limit for VO2 max. However, much less is required to maintain it. In fact peak aerobic power can be maintained even when training is decreased by two thirds (18). Runners and swimmers have reduced training volume by 60% for a period of 15-21 days prior to competition (a technique known as tapering) with no loss in VO2 max.

VO2 Max as a Predictor of Performance

In elite athletes, VO2 max is not a good predictor of performance. The winner of a marathon race for example, cannot be predicted from maximal oxygen uptake.

Perhaps more significant than VO2 max is the speed at which an athlete can run, bike or swim at VO2 max. Two athletes may have the same level of aerobic power but one may reach their VO2 max at a running speed of 20 km/hr and the other at 22 km/hr.

While a high VO2 max may be a prerequisite for performance in endurance events at the highest level, other markers such as lactate threshold are more predictive of performance. Again, the speed at lactate threshold is more significant than the actual value itself.

Think of VO2 max as an athlete’s aerobic potential and the lactate threshold as the marker for how much of that potential they are tapping.

Factors Affecting VO2 Max

There are many physiological factors that combine to determine VO2 max but which of these are most important? Two theories have been proposed:

Utilization Theory

This theory maintains that aerobic capacity is limited by lack of sufficient oxidative enzymes within the cell's mitochondria. It is the body's ability to utilize the available oxygen that determines aerobic capacity. Proponents of this theory point to numerous studies that show oxidative enzymes and the number and size of mitochondria increase with training. This is coupled with increased differences between arterial and venous blood oxygen concentrations (a-vO2 difference) accounting for improved oxygen utilization and hence improved VO2max.

Presentation Theory

Presentation theory suggests that aerobic capacity is limited not predominantly by utilization, but by the ability of the cardiovascular system to deliver oxygen to active tissues. Proponents of this theory maintain that an increase in blood volume, maximal cardiac output (due to increased stroke volume) and better perfusion of blood into the muscles account for the changes in VO2max with training.

So what plays the greater role in determining an athlete's VO2 max - their body's ability to utilize oxygen or supply oxygen to the active tissues?

In a review of the literature, Saltin and Rowell concluded that it is oxygen supply that is the major limiter to endurance performance. Studies have shown only a weak relationship between an increase in oxidative enzymes and an increase in VO2 max . One of these studies measured the effects of a 6-month swim training program on aerobic function. While oxidative enzymes continued to increase until the end, there was no change in VO2 max in the final 6 weeks of the program .

Determining VO2 Max

VO2 max can be determined through a number of physical evaluations. These tests can be direct or indirect. Direct testing requires sophisticated equipment to measure the volume and gas concentrations of inspired and expired air. There are many protocols used on treadmills, cycle ergometers and other exercise equipment to measure VO2 max directly.

One of the most common is the Bruce protocol often used for testing VO2 max in athletes or for signs of coronary heart disease in high risk individuals.

Indirect testing is much more widely used by coaches as it requires little or no expensive equipment. There are many indirect tests used to estimate VO2 max. Some are more reliable and accurate than others but none are as accurate as direct testing. Examples include the multistage shuttle run (bleep test), 12 minute walk test and 1.5 mile run.

VO2 Max at Altitude

VO2 max decreases as altitude increases above 1600m or about the altitude of Denver, Colorado. For every 1000m above that, maximal oxygen uptake decreases further by approximately 8-11%. Anyone with a VO2 max lower than 50 ml/kg/min would struggle to survive at the summit of Everest without supplemental oxygen.

The decrease is mainly due to a decrease in maximal cardiac output. Recall that cardiac output is the product of heart rate and stroke volume. Stoke volume decreases due to the immediate decrease in blood plasma volume. Maximal heart rate may also decrease and the net effect is that less oxygen is "pushed" from the blood into the muscles .

Effects of Aging on VO2 Max

VO2 max decreases with age. The average rate of decline is generally accepted to be about 1% per year or 10% per decade after the age of 25. One large cross sectional study found the average decrease was 0.46 ml/kg/min per year in men (1.2%) and 0.54 ml/kg/min in women (1.7%).

However, this deterioration is not necessarily due to the aging process. In some cases the decease may be purely a reflection of increased body weight with no change in absolute values for ventilation of oxygen. Recall, that VO2 max is usually expressed relative to body weight. If this increases, as tends to happen with age, and aerobic fitness stays the same then VO2 max measured in ml/kg/min will decrease.

Usually, the decline in age-related VO2 max can be accounted for by a reduction in maximum heart rate, maximal stoke volume and maximal a-vO2 difference i.e. the difference between oxygen concentration arterial blood and venus blood.

Can training have an affect on this age-related decline?

Vigorous training at a younger age does not seem to prevent the fall in

VO2 max if training is ceased altogether. Elite athletes have been shown to decline by 43% from ages 23 to 50 (from 70 ml/kg/min to 40 ml/kg/min) when they stop training after their careers are over. In some cases, the relative decline is greater than for the average population - as much as 15% per decade or 1.5% per year.

However in comparison, master athletes who continue to keep fit only show a decrease of 5-6% per decade or 0.5-0.6% per year . When they maintain the same relative intensity of training, a decrease of only 3.6% over 25 years has been reported and most of that was attributable to a small increase in bodyweight.

It seems that training can slow the rate of decline in VO2 max but becomes less effective after the age of about 50.

5

How To Determine Lactate / Anaerobic Threshold

There are several methods used to determine an athlete’s lactate or anaerobic threshold. While the most accurate and reliable is through the direct testing of blood samples during a graded exercise test, this is often inaccessible to most performers.

There are several field tests that can also be used to estimate lactate threshold. They vary in their reliability but some offer an acceptable alternative for most amateur athletes.

Several terms such as onset of blood lactate accumulation and maximal lactate steady state are used interchangeably with anaerobic threshold. Technically, they do not describe precisely the same thing. In fact, although lactate threshold and anaerobic threshold occur together under most conditions, strictly speaking even these two terms are not the same. For this article however, lactate threshold and anaerobic threshold will be used interchangeably. See the lactate threshold article for more details on this topic.

It is also worth bearing in mind that blood lactate and lactic acid are not the same substance. Blood lactate production is actually thought to be beneficial to endurance performance and may delay fatigue. Nevertheless, its accumulation still remains a good marker for the onset of fatigue. See the lactic acid article for more information.

Laboratory Testing of Anaerobic Threshold

The most accurate way to determine lactate threshold is via a graded exercise test in a laboratory setting. During the test the velocity or resistance on a treadmill, cycle ergometer or rowing ergometer is increased at regular intervals (i.e. every 1min, 3min or 4min) and blood samples are taken at each increment. Very often VO2 max, maximum heart rate and other physiological kinetics are measured during the same test.

Blood lactate is then plotted against each workload interval to give a lactate performance curve. Heart rate is also usually recorded at each interval often with a more accurate electrocardiogram as opposed to a standard heart rate monitor.

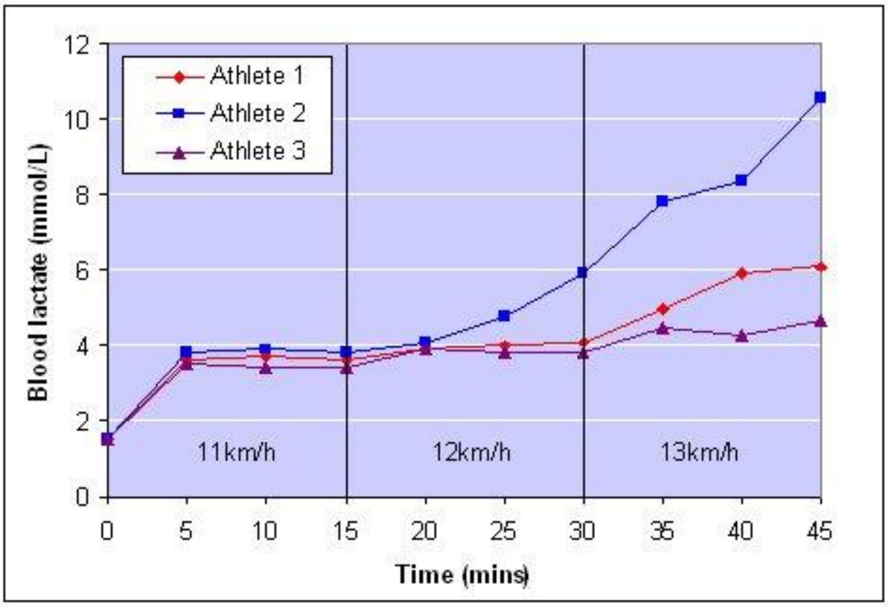
Once the lactate curve has been plotted, the anaerobic threshold can be determined. A sudden or sharp rise in the curve above base level is said to indicate the anaerobic threshold. However, from a practical perspective this sudden rise or inflection is often difficult to pinpoint.

Assuming the inflection is clear (as in the graph above), the relative speed or workload at which it occurs can be determined. In this example, the athlete's anaerobic threshold occurs at about 12km/h. This means, in theory they can maintain a pace at or just below 2km/h for a prolonged period, indefinitely. Of course, this is purely hypothetical as there are many other factors involved in fatigue – not least the amount of carbohydrate stores an athlete has in reserve. A crossover to fat metabolism will significantly reduce the athlete's race pace.

By recording heart rate data alongside workload and blood lactate levels, an athlete can use a heart rate monitor to plan and complete training sessions. Although monitoring heart rate is never completely reliable and varies greatly between and within individuals combining it with lactate measurements is probably more reliable than using the Conconi test (see below) for example.

Confirmatory Test

When anaerobic threshold is read from the lactate curve, an additional test can be used to verify its accuracy. Using the example above, the athlete's threshold is thought to occur at about 12km/h on the treadmill. The confirmatory test involves running for 15 minutes at a pace just below threshold, 15 minutes at threshold and 15 minutes at a pace just above threshold. See the curves below of three athletes whose thresholds have all been determined to occur at approximately 12kmh.



Notice that for Athlete 1, blood lactate remains steady at their estimated anaerobic threshold (12km/h) and lactate begins to accumulate when the pace is increased to 13km/h in the final 15 minutes. For athlete 1, this is confirmation that their anaerobic threshold pace is reasonably accurate.

For Athlete 2, lactate begins to accumulate during the middle 15minute segment (their estimated threshold) and continues to do so during the final 15 minutes. For this athlete, anaerobic threshold occurs at a slightly slower pace than was determined originally.

Finally, Athlete 3's lactate curve does not rise significantly even during the final 15 minutes segment. Anaerobic threshold for them occurs at a slightly higher pace then was originally determined.

Assuming, you don't have access to facilities that directly monitor your or your athlete's lactate response, are there other acceptable alternatives?

Portable Lactate Analyzer

Portable lactate analysers are becoming more popular amongst coaches and athletes at all levels. A good portable analyzer should have the same validity and reliability as laboratory testing equipment. The Accutrend Lactate Analyzer for example, has been tested using guidelines of the European Committee for Clinical Laboratory Standards and is cleared for sports medicine use by the Federal Drug Administration in the United States.

Needless to say a portable analyser is only one half of the equation. A suitable and sport-specific exercise test is still required and selecting the most appropriate protocol takes knowledge and experience. Any physiological test is only as reliable as the tester's ability to follow a set protocol. Even when a suitable assessment has been chosen, numerous variables must be kept constant for the test to remain accurate and reliable. See the fitness tests section for guidelines on keeping physiological assessments repeatable and sample tests that can be used for various sports.

Conconi Test

In 1982 Conconi *et a* stated that the anaerobic threshold correlated to a deflection point in the heart rate. Essentially, heart rate and exercise intensity is linear i.e. as exercise intensity increases so will heart rate. However, Conconi et a found that in all their tested subjects, including those in a follow up test, heart rate reached a plateau at near maximal exercise intensities.

Although this is a relatively simple field test that would be useful for coaches and athletes at all levels, its accuracy has been contested by subsequent researchers. Studies have found that the deflection point or plateau in heart rate only occurs in a certain number of individuals and that when it does, it significantly overestimates directly measured lactate threshold. Conconi and co-workers themselves acknowledge this controversy and cite studies that both support and contradict their original findings.

For guidelines on performing the Conconi test see the heart rate training page.

10km Run, 30Km Cycle, 30 Min Time Trial

More experienced athletes often run a 10km race or cycle 30km race at or close to anaerobic threshold. By simulating a race in training and recording heart rate, the anaerobic threshold may be determined. Alternatively, exercising for 30 minutes at the fastest sustainable pace can be used. The key is to sustain a steady pace which is why this test is more suited to experienced athletes who can gauge how fast to set off. A heart rate monitor with split time facility is required to record heart rate at each 1-minute interval. Take the average heart rate over the final 20 minutes as the heart rate corresponding to anaerobic threshold.

Heart Rate Percentage

A very simply method for estimating the anaerobic threshold is to assume anaerobic threshold occurs at 85-90% maximum heart rate (220-age). As mentioned earlier, heart rate varies greatly between individuals and even within the same individual so this is not a reliable test.

The Lactate Threshold Debate

Some researchers have questioned the validity of determining the lactate or anaerobic threshold even in laboratory settings. Yet more researchers question whether a definite point or threshold exists at all. Instead they suggest blood lactate accumulation is continuous in nature and no specific point can be determined.

Rather than get bogged down in the debate it is sensible to remember that regardless of the underlying mechanisms, the physiological changes that accompany lactate accumulation have important implications for endurance athletes. Any delay in the blood lactate accumulation that can be achieved through training is beneficial to performance. With that in mind, why not take a look through the lactate threshold training article?

6

Lactic Acid, Blood Lactate & The “Lactic Acid Myth”

Many coaches and athletes routinely perceive lactic acid, or more specifically lactate, as a dead end waste product that is completely unfavourable to all athletic performance. This assumption however, may longer be considered accurate - so much so that it has been labelled ‘the mythology of lactic acid’ .

While Sports Scientists are largely in agreement that lactate behaves more like an athlete’s friend than foe, recent research has now begun to question one of the basic tenets of muscular fatigue – increased acidity or lactic acidosis.

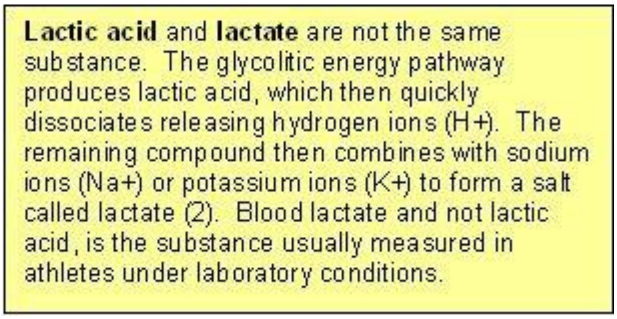
This article explores some of the current understanding about how lactate and lactic acid functions in the human body, particularly during exercise. It examines the compounds’ roles in fatigue and energy metabolism and as a limiting factor in performance.

A basic understanding of energy metabolism during exercise is helpful to appreciate some of the current issues surrounding lactic acid. Please refer to the energy systems article for an explanation of how energy and lactic acid is produced during activity.

Lactic Acid and Oxygen

Recall that the end product of glycolysis is pyruvic acid. Traditionally, it was believed that oxygen availability, or lack thereof, lead to the conversion of pyruvic acid into lactic acid and accompanying increases in muscle and blood lactate.

Over the past 35 years, evidence has mounted against this idea . The best evidence seems to suggest that oxygen availability is only one of several factors that cause an increase in muscle and blood lactate during submaximal exercise. In fact, lactic acid can be formed anytime glycolysis takes place regardless of the presence or absence of oxygen and is even produced at rest.



Lactic acid and **lactate** are not the same substance. The glycolitic energy pathway produces lactic acid, which then quickly dissociates releasing hydrogen ions (H+). The remaining compound then combines with sodium ions (Na+) or potassium ions (K+) to form a salt called lactate (2). Blood lactate and not lactic acid, is the substance usually measured in athletes under laboratory conditions.

Historically, the lactate threshold has often been referred to as the point at which energy is generated through predominantly anaerobic metabolism. Yet the onset of blood lactate accumulation (OBLA) only represents the balance between lactate production and removal and suggests nothing about the aerobic or anaerobic metabolism per se.

Researchers have been unable to show a lack of oxygen in the muscles at an exercise intensity above the lactate threshold. Instead OBLA may be caused by many different factors other than those associated with anoxia or dysoxia.

For a more detailed discussion of other factors leading to the increased production of lactic acid and blood lactate, see Gladden’s 2003 paper *Lactate metabolism during exercise*.

Lactate is Not a Waste Product

Before the 1970’s lactic acid was considered a waste by-product resulting from a lack of available oxygen to the working muscles. It was blamed for the ‘burning’ sensation during vigorous exercise, delayed onset muscle soreness and central to the process of fatigue. The general consensus was, and still is amongst many coaches and athletes, that lactic acid is responsible for fatigue and exhaustion in all types of exercise.

On the contrary, lactic acid only accumulates within muscle during relatively short, highly intense exercise such as sprint swimming or running.

Endurance athletes, such as marathon runners for example can have near-resting lactic acid levels following a race despite being exhausted .

In 1984, George Brooks proposed the lactate shuttle hypothesis and at present, the cell-to-cell lactate shuttle has almost unanimous experimental support. This hypothesis questioned many of the widely held beliefs about lactate.

Far from being a waste product, the formation of lactate allows the metabolism of carbohydrates to continue through glycolysis . Keep in mind from the energy systems article that glycolysis allows rapid production of energy required to sustain intense exercise.

The heart, brain and most slow twitch fibres are very apt at clearing lactate from the blood – to the extent that they prefer lactate as a source of fuel. Note however, that lactate must first be converted into pyruvate before it can be used as a source of energy.

Clearance of lactate from the blood can occur either through oxidation within the muscle fibre in which it was produced or it can be transported to other muscles fibres for oxidation. Lactate that is not oxidized in this way diffuses from the exercising muscle into the capillaries and it is transported via the blood to the liver. Through a process known as the Cori cycle, lactate can be converted to pyruvate in the presence of oxygen, which can then be converted into glucose . This glucose can either be metabolized by working muscles or stored in the muscles as glycogen for later use .

So lactate should be viewed as a useful form of potential energy that is oxidized during moderate-low intensity exercise, during recovery and at rest. Unlike lactic acid, lactate is not thought to be fatigue-producing.

Based on this more sympathetic view of lactate, sports nutrition companies have introduced sodium lactate into sports drinks and there is some tentative support that these may have an ergogenic effect .

What the lactate shuttle model essentially shows is that lactate is a crucial intermediary in numerous cellular, localized and whole body metabolic processes, and may help to prolong submaximal activity, rather than hinder it.

Lactate Accumulation

During intense exercise, muscle and blood lactate can rise to very high levels . This accumulation above resting levels represents the balance of production and removal. It says nothing about whether accumulation is due to an increased rate of production or decreased rate of removal, or both. Similarly, if lactate concentrations in the blood do not rise above resting levels during or immediately following exercise, it also infers nothing about lactate or lactic acid production during that activity. It may be that lactic acid production is several times higher than at rest but that it is matched by its removal showing no net increase.

A common misinterpretation is that blood lactate or even lactic acid, has a direct detrimental effect on muscle performance. However, most researchers agree that any negative effect on performance associated with blood lactate accumulation is due to an increase in hydrogen ions. When lactic acid dissociates it forms lactate and hydrogen ions - which leads to an increase in acidity. So it is not accurate to blame either lactate or lactic acid for having a direct negative impact on muscular performance.

The increase in hydrogen ions and subsequent acidity of the internal environment is called acidosis. It is thought to have an unfavorable effect on muscle contraction and there has been considerable research to demonstrate that this is the case .

Lactic Acidosis

So this unfavourable acidosis is the result of an increased concentration or accumulation of hydrogen ions. It may seem logical to conclude then, that any increase in production of lactic acid and hence lactate is detrimental as it will increase the production of hydrogen ions.

However, accumulation is the key term here as an increased production of hydrogen ions (due to an increase production of lactic acid) will have no detrimental effect if clearance is just as fast. In fact Robergs *et al.* takes it a step further…

They suggest that lactate production (especially if accompanied by a high capacity for lactate removal) may be more likely to delay the onset of acidosis. The reasons for this, amongst others, are that lactate serves to consume hydrogen ions and allows the transport of hydrogen ions from the cell. Similarly, they maintain, there is a wealth of research evidence to show that acidosis is caused by reactions other than lactate production.

Rogers *et al.* do conclude however, that increased lactate concentration, although not causative, coincides with cellular acidosis and remains a good indirect marker for the onset of fatigue.

Acidosis and Fatigue

As mentioned earlier, there has been substantial research to show that an increase concentration of hydrogen ions and a decrease in pH (increase in acidity) within muscle or plasma, causes fatigue. Additionally, induced acidosis can impair muscle contractility even in non-fatigued humans and several mechanisms to explain such effects have been provided.

Yet in the last 10 years a number of high profile papers have challenged even this most basic assumption of fatigue. A 2006 review of these by Cairns suggests that experiments on isolated muscle show that acidosis has little detrimental effect or may even improve muscle performance during high-intensity exercise.

In place of acidosis it may be inorganic phosphate that is major cause of muscle fatigue. Recall that an inorganic phosphate is produced during the breakdown of ATP to ADP. However, there are several limitations regarding this phosphate hypothesis. Another proposal for a major contributor to fatigue, rather than acidosis, is the accumulation of potassium ions in muscle interstitium.

Contrary to this new research (which is by no means definitive) is the argument that if acidosis plays no role in fatigue then it is surprising that alkalosis (through sodium bicarbonate consumption for example) can improve exercise performance in events lasting 1-10 minutes. To reconcile this, Cairns hypothesizes that while acidosis has little detrimental effect or may even improve muscle performance in isolated muscle, severe blood plasma acidosis may impair performance by causing a reduced central nervous system drive to muscle.

Lactate Accumulation and Exercise

At rest the normal range for blood lactate is 0.5 – 2.2 mmol per litre. It is thought that complete exhaustion occurs somewhere in the range of 20 – 25 mmol/L for most individuals although values greater than 30 mmol/L have been recorded.

Blood lactate concentrations peak about 5 minutes after the cessation of intense exercise (assuming cessation is due to exhaustion from acidosis). The delay is attributed to the time required to buffer and transport lactic acid from the tissue to the blood. A return to pre-exercise levels of blood lactate usually occurs within an hour and light activity during the post-exercise period has been shown to accelerate this clearance. Training can also increase the rate of lactate clearance in both aerobically and anaerobically trained athletes compared to untrained individuals.

Interestingly, Stone *et al* noted that trained individuals generated higher levels of blood lactate at the point of failure compared to untrained subjects when exercising intensely (squats). The time and amount of work they completed, unsurprisingly, was greater in the trained group. This seems to suggest that training may induce greater tolerance to lactate accumulation and it may also add weight to the argument that lactate serves to delay acidosis and fatigue. At any absolute workload (i.e. when both groups were lifting the same weight) the trained group had lower levels of blood lactate.

This indicates that training-induced adaptations include a lower blood lactate concentration at any given workload and higher blood lactate concentration during maximal exercise.

The ‘anaerobic’ or lactate threshold is based on the point at which blood lactate abruptly accumulates. It can be used as a prediction for race performance and to prescribe training intensity.

To Summerize...

- Lack of oxygen is not necessarily responsible for an increase in lactate production or even lactate accumulation. Other causative factors may play a more significant role.
- Blood lactate accumulation represents only the balance of production and removal. It says nothing about the absolute values of either of these.

- Only relatively short, very intense activity causes lactc acid to accumulate. Lactic acid is not thought to be a contributor to fatigue in low-moderate intensity activity of any duration.
- Lactate is an important substrate that can be used during submaximal exercise, recovery and at rest. It is the preferred source of fuel for the heart and brain.
- Lactic acid or lactate 'pooling' is not the cause of delayed muscle soreness.
- Lactate accumulation and not necessarily an increase in production, causes an increase concentration of hydrogen ions and corresponding acidosis. Lactate production may actually help to curb the development of acidosis.
- Acidosis is thought to be a primary factor in muscular fatigue and is based on a good deal of research. Recent research is contesting this claim but it is still too early to dismiss acidity as a cause of fatigue.
- Training accelerates lactate clearance, reduces lactate accumulation at any given workload and results in a greater level of lactate accumulation during maximal effort.

This is clearly an area that is far from resolved but what seems clear is that lactate can no longer be labelled definitively as the athlete's enemy. On the contrary, gathering evidence suggests that many aspects of lactate production are beneficial to athletic performance.

7

Energy Systems in Sport & Exercise

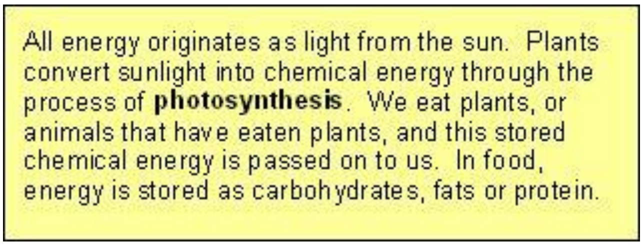
Understanding energy systems underpins the study of exercise and the effect it has on the human body.

Bioenergetics... or the study of energy flow through living systems – is usually one of the first chapters in any good exercise physiology text. But the current model of human energy systems is being challenged...

Recent research and practical experience expose its limitations, in particular with regard to fatigue.

This article outlines the three basic energy pathways, their interactions with one another and their relevance to different sporting activities. It finishes with a brief look at some of the more recent research and subsequent new models of human energy dynamics that have been proposed as a result.

ATP – The Body's Energy Currency

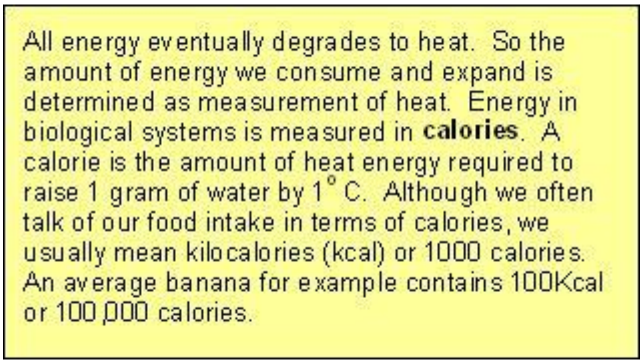


All energy originates as light from the sun. Plants convert sunlight into chemical energy through the process of **photosynthesis**. We eat plants, or animals that have eaten plants, and this stored chemical energy is passed on to us. In food, energy is stored as carbohydrates, fats or protein.

Energy is required for all kinds of bodily processes including growth and development, repair, the transport of various substances between cells and of course, muscle contraction. It is this last area that Exercise Scientists are most interested in when they talk about energy systems.

Whether it's during a 26-mile marathon run or one explosive movement like a tennis serve, skeletal muscle is powered by one and only one compound... adenosine triphosphate (ATP) . However, the body stores only a small quantity of this 'energy currency' within the cells and it’s enough to power just a few seconds of all-out exercise. So the body must replace or resynthesize ATP on an ongoing basis. Understanding how it does this is the key to understanding energy systems.

An ATP molecule consists of adenosine and three (tri) inorganic phosphate groups. When a molecule of ATP is combined with water (a process called hydrolysis), the last phosphate group splits away and releases energy. The molecule of adenosine triphosphate now becomes adenosine diphosphate or ADP.

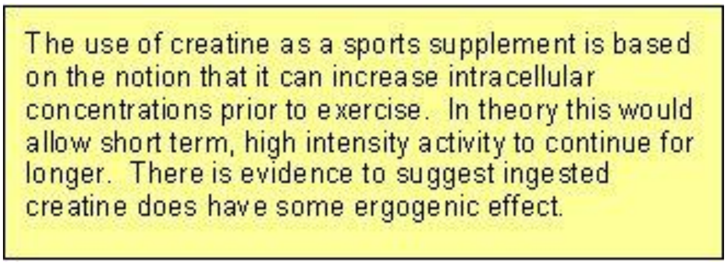


All energy eventually degrades to heat. So the amount of energy we consume and expand is determined as measurement of heat. Energy in biological systems is measured in **calories**. A calorie is the amount of heat energy required to raise 1 gram of water by 1° C. Although we often talk of our food intake in terms of calories, we usually mean kilocalories (kcal) or 1000 calories. An average banana for example contains 100Kcal or 100,000 calories.

To replenish the limited stores of ATP, chemical reactions add a phosphate group back to ADP to create ATP. This process is called phosphorylation. If this occurs in the presence of oxygen it is labelled aerobic metabolism or oxidative phosphorylation. If it occurs without oxygen it is labelled anaerobic metabolism .

Energy Sources to Replenish ATP

Several energy sources or substrates are available which can be used to power the production of ATP. One of these substrates, like existing ATP, is stored inside the cell and is called creatine phosphate.



The use of creatine as a sports supplement is based on the notion that it can increase intracellular concentrations prior to exercise. In theory this would allow short term, high intensity activity to continue for longer. There is evidence to suggest ingested creatine does have some ergogenic effect.

Creatine Phosphate

Creatine phosphate is readily available to the cells and rapidly produces ATP. It also exists in limited concentrations and it is estimated that there is only about 100g of ATP and about 120g of creatine phosphate stored in the body, mostly within the muscles. Together ATP and creatine phosphate are called the ‘high-energy’ phosphogens .

Fat

The other substrates that can the body can use to produce ATP include fat, carbohydrate and protein. Fat is stored predominantly as adipose tissue throughout the body and is a substantial energy reservoir. Fat is less accessible for cellular metabolism as it must first be reduced from its complex form, triglyceride, to the simpler components of glycerol and free fatty acids. So although fat acts as a vast stockpile of fuel, energy release is too slow for very intense activity.

Carbohydrate

Unlike fat, carbohydrate is not stored in peripheral deposits throughout the body. At rest, carbohydrate is taken up by the muscles and liver and converted into glycogen. Glycogen can be used to form ATP and in the liver it can be converted into glucose and transported to the muscles via the blood. A heavy training session can deplete carbohydrate stores in the muscles and liver, as can a restriction in dietary intake. Carbohydrate can release energy much more quickly than fat.

Protein

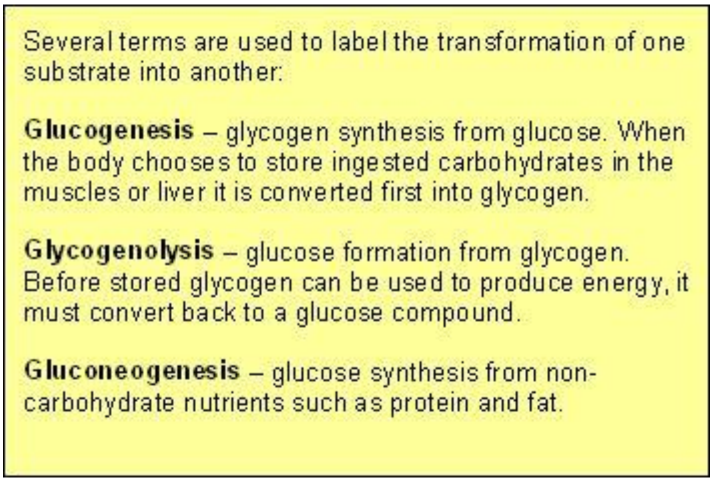
Protein is used as a source of energy, particularly during prolonged activity, however it must first be broken down into amino acids before then being converted into glucose. As with, fat, protein cannot supply energy at the same rate as carbohydrate. The rate at which is energy is released from the substrates is determined by a number of factors. For example, if there are large amounts of one type of fuel available, the body may rely more on this source than on others. The mass action effect is used to describe this phenomenon.

The Three Energy Systems

There are three separate energy systems through which ATP can be produced. A number of factors determine which of these energy systems is chosen, such as exercise intensity for example.

The ATP-PCr System

ATP and creatine phosphate (also called phosphocreatine or PCr for short) make up the ATP-PCr system. PCr is broken down releasing a phosphate and energy, which is then used to rebuild ATP. Recall, that ATP is ‘rebuilt’ by adding a phosphate to ADP in a process called phosphorylation. The enzyme that controls the break down of PCr is called creatine kinase.



Several terms are used to label the transformation of one substrate into another:

Glucogenesis – glycogen synthesis from glucose. When the body chooses to store ingested carbohydrates in the muscles or liver it is converted first into glycogen.

Glycogenolysis – glucose formation from glycogen. Before stored glycogen can be used to produce energy, it must convert back to a glucose compound.

Gluconeogenesis – glucose synthesis from non-carbohydrate nutrients such as protein and fat.

The ATP-PCr energy system can operate with or without oxygen but because it doesn't rely on the presence of oxygen it said to be anaerobic. During the first 5 seconds of exercise regardless of intensity, the ATP-PCr is relied on almost exclusively. ATP concentrations last only a few seconds with PCr buffering the drop in ATP for another 5-8 seconds or so. Combined, the ATP-PCr system can sustain all-out exercise for 3-15 seconds and it is during this time that the potential rate for power output is at its greatest.

If activity continues beyond this immediate period, the body must rely on another energy system to produce ATP…

The Glycolytic System

Glycolysis literally means the breakdown (lysis) of glucose and consists of a series of enzymatic reactions. Remember that the carbohydrates we eat supply the body with glucose, which can be stored as glycogen in the muscles or liver for later use.

The end product of glycolysis is pyruvic acid. Pyruvic acid can then be either funnelled through a process called the Krebs cycle (see the Oxidative System below) or converted into lactic acid. Traditionally, if the final product was lactic acid, the process was labelled anaerobic glycolysis and if the final product remained as pyruvate the process was labelled aerobic glycolysis.

However, oxygen availability only determines the fate of the end product and is not required for the actual process of glycolysis itself. In fact, oxygen availability has been shown to have little to do with which of the two end products, lactate or pyruvate is produced. Hence the terms aerobic meaning with oxygen and anaerobic meaning without oxygen become a bit misleading.

Alternative terms that are often used are fast glycolysis if the final product is lactic acid and slow glycolysis for the process that leads to pyruvate being funnelled through the Krebs cycle. As its name would suggest the fast glycolitic system can produce energy at a greater rate than slow glycolysis. However, because the end product of fast glycolysis is lactic acid, it can quickly accumulate and is thought to lead to muscular fatigue.

The contribution of the fast glycolytic system increases rapidly after the initial 10 seconds of exercise. This also coincides with a drop in maximal power output as the immediately available phosphogens, ATP and PCr, begin to run out. By about 30 seconds of sustained activity the majority of energy comes from fast glycolysis.

At 45 seconds of sustained activity there is a second decline in power output (the first decline being after about 10 seconds). Activity beyond this point corresponds with a growing reliance on the…

The Oxidative System

The oxidative system consists four processes to produce ATP:

- Slow glycolysis (aerobic glycolysis)
- Krebs cycle (citric acid cycle or tricarboxylic acid cycle)
- Electron transport chain
- Beta oxidation

Slow glycolysis is exactly the same series of reactions as fast glycolysis that metabolise glucose to form two ATPs. The difference, however, is that the end product pyruvic acid is converted into a substance called acetyl coenzyme A rather than lactic acid . Following glycolysis, further ATP can be produced by funnelling acetyl coenzyme A through the…

Krebs Cycle

The Krebs cycle is a complex series of chemical reactions that continues the oxidization of glucose that was started during glycolysis. Acetyl coenzyme A enters the Krebs cycle and is broken down in to carbon dioxide and hydrogen allowing more two more ATPs to be formed. However, the hydrogen produced in the Krebs cycle plus the hydrogen produced during glycolysis, left unchecked would cause cells to become too acidic . So hydrogen combines with two enzymes called NAD and FAD and is transported to the…

Electron Transport Chain

Hydrogen is carried to the electron transport chain, another series of chemical reactions, and here it combines with oxygen to form water thus preventing acidification. This chain, which requires the presence of oxygen, also results in 34 ATPs being formed .

Beta Oxidation

Unlike glycolysis, the Krebs cycle and electron transport chain can metabolise fat as well as carbohydrate to produce ATP. Lipolysis is the term used to describe the breakdown of fat (triglycerides) into the more basic units of glycerol and free fatty acids.

Before these free fatty acids can enter the Krebs cycle they must undergo a process of beta oxidation... a series of reactions to further reduce free fatty acids to acetyl coenzyme A and hydrogen. Acetyl coenzyme A can now enter the Krebs cycle and from this point on, fat metabolism follows the same path as carbohydrate metabolism.

Fat Metabolism

So to recap, the oxidative system can produce ATP through either fat (fatty acids) or carbohydrate (glucose). The key difference is that complete combustion of a fatty acid molecule produces significantly more acetyl coenzyme A and hydrogen (and hence ATP) compared to a glucose molecule. However, because fatty acids consist of more carbon atoms than glucose, they require more oxygen for their combustion .

So if your body is to use fat for fuel it must have sufficient oxygen supply to meet the demands of exercise. If exercise is intense and the cardiovascular system is unable to supply cells with oxygen quickly enough, carbohydrate must be used to produce ATP. Put another way, if you run out of carbohydrate stores (as in long duration events), exercise intensity must reduce as the body switches to fat as its primary source of fuel.

Protein Metabolism

Protein is thought to make only a small contribution (usually no more 5%) to energy production and is often overlooked. However, amino acids, the building blocks of protein, can be either converted into glucose or into other intermediates used by the Krebs cycle such as acetyl coenzyme A. Protein may make a more significant contribution during very prolonged activity, perhaps as much as 18% of total energy requirements.

The oxidative system as a whole is used primarily during rest and low-intensity exercise. At the start of exercise it takes about 90 seconds for the oxidative system to produce its maximal power output and training can help to make this transition earlier.

Beyond this point the Krebs cycle supplies the majority of energy requirements but slow glycolysis still makes a significant contribution. In fact, slow glycolysis is an important metabolic pathway even during events lasting several hours or more.

Energy Systems & Training

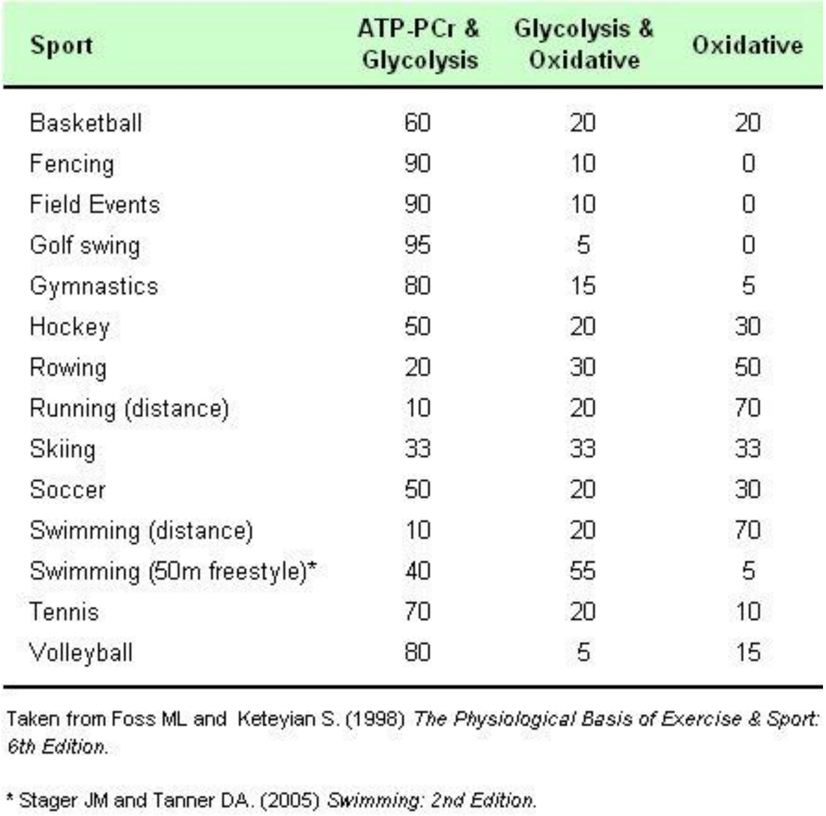
Each of the three energy systems can generate power to different capacities and varies within individuals. Best estimates suggest that the ATP-PCR systme can generate energy at a rate of roughly 36 kcal per minute. Glycolysis can generate energy only half as quickly at about 16 kcal per minute. The oxidative system has the lowest rate of power output at about 10 kcal per minute.

The capacity to generate power of each the three energy systems can vary with training. The ATP-PCr and glycolytic pathways may change by only 10-20% with training. The oxidative system seems to be far more trainable although genetics play a limiting role here too. VO2max, or aerobic power can be increased by as much as 50% but this is usually in untrained, sedentary individuals.

Energy Systems Used in Sports

The three energy systems do not work independently of one another. From very short, very intense exercise, to very light, prolonged activity, all three energy systems make a contribution however, one or two will usually predominate.

Two factors of any activity carried out affect energy systems more than any other variable – they are the intensity and duration of exercise. Here is a list of sports and approximately how the each of the energy systems contributes to meet the physical demands:



Sport	ATP-PCr & Glycolysis	Glycolysis & Oxidative	Oxidative
Basketball	60	20	20
Fencing	90	10	0
Field Events	90	10	0
Golf swing	95	5	0
Gymnastics	80	15	5
Hockey	50	20	30
Rowing	20	30	50
Running (distance)	10	20	70
Skiing	33	33	33
Soccer	50	20	30
Swimming (distance)	10	20	70
Swimming (50m freestyle)*	40	55	5
Tennis	70	20	10
Volleyball	80	5	15

Taken from Foss ML and Keteyian S. (1998) *The Physiological Basis of Exercise & Sport: 6th Edition.*

* Stager JM and Tanner DA. (2005) *Swimming: 2nd Edition.*

A New Model for Energy Systems?

In the year 2000, Noakes and colleagues questioned the classical model of energy systems. Their argument was based on the limitations this model has when it comes to explaining fatigue. In particular, the general concept that fatigue develops only when the cardiovascular system's capacity to supply oxygen falls behind demand (therefore initiating anaerobic metabolism) is seen as overly simplistic. More specifically, their argument centered around 5 key issues:

i. The heart and not skeletal muscle would be affected first by anaerobic metabolism.

ii. No study has definitively found a presence of anaerobic metabolism and hypoxia (lack of oxygen) in skeletal muscle during maximal exercise.

iii. The traditional model is unable to explain why fatigue ensues during prolonged exercise, at altitude and in hot conditions.

iv. Cardiorespiratory and metabolic measures such as VO2max and lactate threshold are only modest predictors of performance.

Undoubtedly, fatigue is a complex subject that can result from a range of physical and psychological factors. In an attempt to produce a more holistic explanation, Noakes developed a model that consisted of five sub-models:

i. The classical 'cardiovascular / anaerobic' model as it stands now.
ii. The energy supply / energy depletion model.
iii. The muscle recruitment (central fatigue) / muscle power model.
iv. The biomechanical model.
v. The psychological / motivational model.

Essentially this new model of energy systems recognizes what coaches have witnessed for decades... that performance and fatigue is multifactoral and complex. It adds strength to the synergistic and holistic approach to sport usually found in the most successful athletes.

8

Delayed Onset Muscle Soreness (DOMS)

There are several topics within exercise science that are not well understood and delayed onset muscle soreness or DOMS is one of them.

DOMS is a familiar experience for athletes at every level and can be described as muscles soreness that occurs 24 - 48 hours following intense exercise. The sensation can range from mild discomfort to debilitating pain.

Delayed onset muscle soreness differs from the acute muscle soreness that can be felt during or immediately following a heavy exercise bout. This is usually attributable to an increase in hydrogen ions associated with lactic acid accumulation or edema – that build up of fluid in the tissues often referred to by bodybuilders as being “pumped-up”.

Several theories have been proposed to explain the underlying cause of delayed onset muscle soreness, however none is universally accepted. There are also many anecdotal claims that the effects of DOMS can be reduced with various treatment modalities. Again, no method has any conclusive, empirical support; likewise for the prevention of delayed onset muscle soreness.

Causes of Delayed Onset Muscle Soreness

Although the actual pathophysiology of DOMS is debateable, most researchers agree that it results from strenuous eccentric muscle action.

Stone and co-workers found that static and concentric muscle actions caused little or no delayed soreness compared to the extreme soreness felt with eccentric resistance training.

Studies on endurance-based activity have found that the eccentric bias of running downhill on a treadmill results in a significantly higher level of delayed onset muscle soreness compared to running on the flat. This is a phenomenon many fell runners can testify to!

Lactic Acid

Lactic acid and its accumulation was once thought to be a major cause of DOMS, however this is not the case. Blood lactate returns to resting levels within one hour of exercise – even after extremely intense bouts of work . The studies on downhill running found that although it resulted in greater DOMS compared to level running, it produced significantly less blood lactate accumulation.

Tissue Breakdown

Delayed onset muscle soreness may be the result of muscle tissue breakdown. Muscle biopsies taken from marathon runners after competition or training, have highlighted considerable cell damage in these athletes' muscles . The sarcolemma (cell membrane) may be ruptured allowing the contents of the cell to seep between other muscle fibers. Damage to the contractile filaments actin and myosin as well as the z disc configuration (responsible for structural support), has also been reported .

Inflammatory Response

Heavy exercise of the kind that results in DOMS can often induce an immune system response. White blood cell count has been shown to increase following strenuous activity . This has led to the hypothesis that DOMS is caused by an inflammatory response in the muscles.

In an attempt to attenuate the effects of delayed onset muscle soreness, researchers have tried administering athletes with anti-inflammatory drugs. However, this approach has been unsuccessful at reducing either the occurrence or severity of soreness. More recently, it has been found that microscopic muscle damage caused by heavy exercise may indeed cause an inflammatory response in the muscles. See Tidall for an in-depth discussion on 'the inflammatory cell response to acute muscle injury'.

It seems likely that acute structural damage to muscle tissues initiates the occurrence of DOMS. This could then set up a chain of events that leads to necrosis (cell death) peaking about 48 hours after exercise. Intracellular contents and the by-products of an immuno-response then accumulate outside the cells stimulating the nerve endings of the muscle.

Reducing the Effects of Delayed Onset Muscle Soreness

DOMS results in loss of maximal force and can reduce performance in a 1-repetiton maximum test for example . This may be due to three factors:

1. Physical damage to the muscle tissue
2. Failure of the excitation-contraction coupling
3. Loss of contractile protein

DOMS also results in a loss of range of motion and muscle recruitment patterns.

No method has been shown to significantly speed the recovery from delayed onset muscle soreness.

Massage has shown varying results that may be attributed to the time of massage application and the type of massage technique used. It can reduce the discomfort associated with DOMS and perhaps even swelling but does not seem to affect muscle function. Cryotherapy (ice baths or ice packs), stretching, homeopathy, ultrasound and electrical current modalities have demonstrated no effect in clinical trials on the alleviation of muscle soreness or other DOMS related effects.

Vitamin C plays a role in repairing connective tissue and anecdotal reports suggest that antioxidant supplementation can attenuate the effects of delayed onset muscle soreness. However, this is not confirmed by clinical trials. Taking vitamin C in large doses is not recommended and can, in some cases, be harmful.

Finally, a recent study by Miller and co-workers demonstrated the effectiveness of a protease supplement on the prevention and recovery from DOMS...

The experimental group demonstrated significantly superior recovery of contractile function and diminished effects of delayed onset muscle soreness after downhill running when compared with a placebo group.

Although intense exercise, particularly after a prolonged layoff from activity, can cause DOMS, subsequent training sessions are less likely to result in delayed soreness.

9

Muscle Anatomy & Structure

What does skeletal muscle consist of? How does it contract?

Muscle anatomy can get quite complex... and that's even without mentioning the physiology of muscle contraction! This article breaks skeletal muscle down into its smallest parts and examines the amazing processes that bring about all our movements...

Every one of the body's 430 skeletal muscles consists of muscle tissue, connective tissue, nerves and blood vessels. A fibrous fascia called the epimysium covers each muscle and tendon. Tendons connect the muscle belly to bone and they attach to the bone periosteum - more connective tissue that covers all bones. Contraction of the muscle belly pulls on the tendon and in turn, the bone it is attached to.

Limb muscles (such as the biceps brachii in the upper arm) have two attachments to bone. The proximal or origin is the attachment closest to the trunk. The distal or insertion is the attachment furthest from the trunk. Trunk muscles (such as the rectus abdominus in the stomach) also have two attachments - superior (closer to the head) and inferior (further from the head).

A closer look at muscle anatomy shows that each muscle belly is made up of muscle cells or fibres. Muscle fibres are grouped into bundles (of up to 150 fibres) called fasciculi. Each fasiculus or bundle is surrounded by connective tissue called perimysium. Fibres within each bundle are surrounded by more connective tissue called endomysium.

Each individual fibre consists of a membrane (sarcolemma) and can be further broken down into hundreds or even thousands of myofibrils. Myofibrils are surrounded by sarcoplasm and together they make up the contractile components of a muscle. See the diagram below:

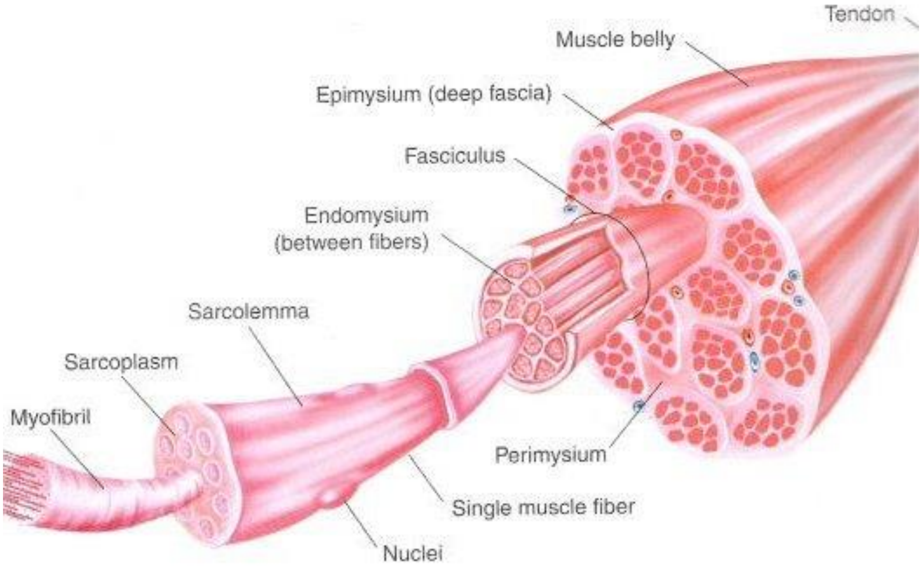


Figure 1: Muscle belly split into various component parts (from Essentials of Strength Training & Conditioning, National Strength & Conditioning Association)

Sarcoplasm contains glycogen, fat particles, enzymes and the mitochondria. The myofibrils it encases consist of two types of protien filaments or myofilaments. They are actin and myosin.

Myosin and actin filaments run in parallel to each other along the length of the muscle fibre. Myosin has tiny globular heads protruding from it at regular intervals. These are called cross bridges and play a pivotal role in muscle action. Each myofibril is organized into sections along its length. Each section is called a sarcomere and they are repeated right along the length of a muscle fibre. It's similar to how a meter ruler is split into centimeters and millimeters. Just as the millimeter is the smallest function of a ruler, the sarcomere is the smallest contractile portion of a muscle fibre.

The sarcomere is often divided up into different zones to show how it behaves during muscle action. See the diagram below:

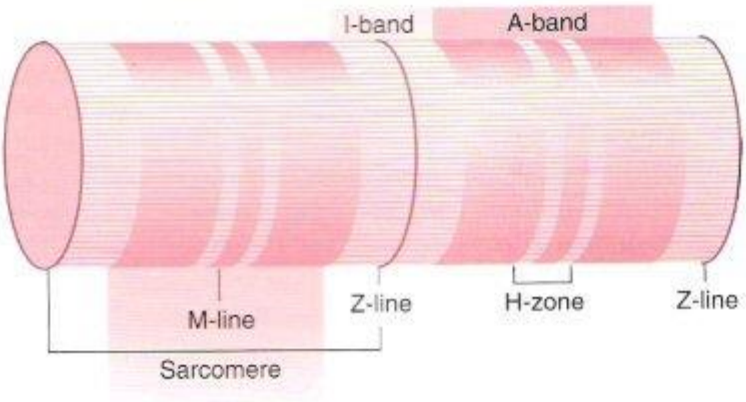


Figure 2: Myofibril divided into 2 sarcomeres

The Z-line seperates each sarcomere. The H-zone is the center of the sarcomere and the M-line is where adjacent myosin filaments anchor on to each other. On the diagram above the darker A-bands are where myosin filaments align and the lighter I-bands are where actin filaments align. When muscle contracts the H-zone and I-band both decrease as the z-lines are pulled towards each other. See the diagram below:

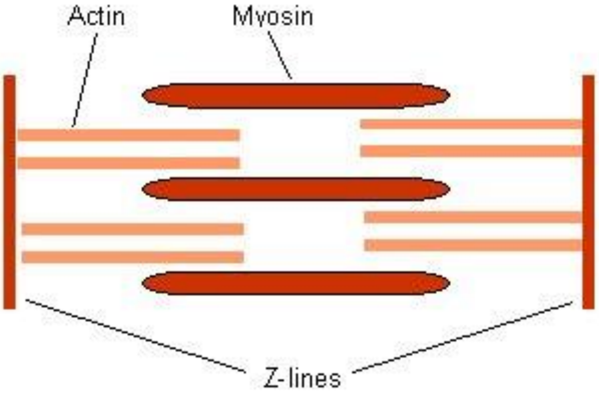


Figure 3: Arrangement of actin and myosin filaments in a single sarcomere

An examination of muscle anatomy wouldn't be complete without taking a closer look at how muscle contracts...

Sources

1. Baechle TR and Earle RW. (2000) Essentials of Strength Training and Conditioning: 2nd Edition. Champaign, IL: Human Kinetics
2. McArdle WD, Katch FI and Katch VL. (2000) Essentials of Exercise Physiology: 2nd Edition Philadelphia, PA: Lippincott Williams & Wilkins
3. Wilmore JH and Costill DL. (2005) Physiology of Sport and Exercise: 3rd Edition. Champaign, IL: Human Kinetics

10

The Sliding Filament Theory of Muscle Action

Sliding filament theory in its simplest form states that muscle fibres shorten when actin filaments slide inward on myosin filaments - pulling the z-lines closer together.

If that's all Greek to you then have a quick look at the article on muscle anatomy which outlines the different components of a muscle.

Have a look at the diagram below:

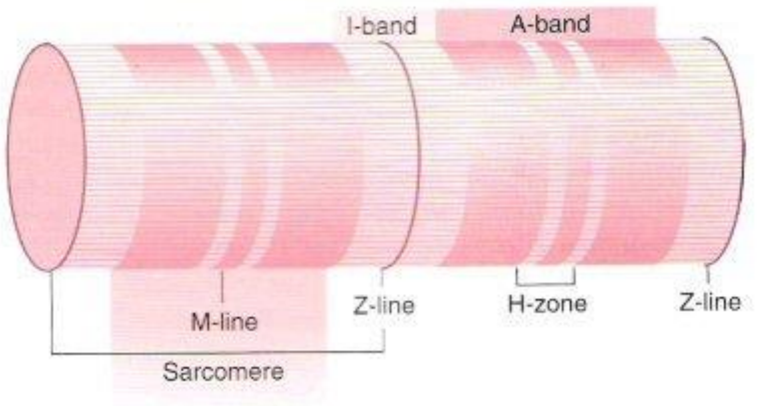


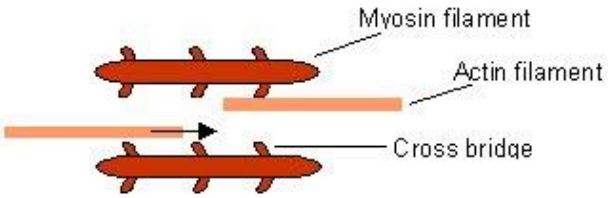
Figure 2: Myofibril divided into 2 sarcomeres

When actin filaments (the light bands in the diagram above) slide over myosin filaments (the dark bands) the H-zone and I-band decrease.

What causes actin filaments to move?

Myosin filaments contain tiny globular heads, called cross bridges at regular intervals. These cross bridges attach to the actin filaments pulling on them to create movement.

See figure 2 below:



Each flexion of a cross bridge produces only a very small movement in the actin filament so many cross bridges throughout the muscle must flex repeatedly and rapidly for any measurable movement to occur.

The Sarcoplasmic Reticulum

Surrounding each myofibril (remember a myofibril is the portion of the muscle fibre that houses actin and myosin) is a system of tubules called the sarcoplasmic reticulum. The sarcoplasmic reticulum stores calcium and it is the regluation of calcium release that causes muscular contraction.

During rest most of the calcium resides in the sarcoplasmic reticulum and and very few myosin cross bridges are attached to actin filaments - nor can they flex.

When the brain sends a nerve impulse (called an action potential)

How does that cause a muscle fibre to contract?

The action potential arrives at the nerve terminal and causes the release of a chemical called acetylcholine. Acetylcholine travels across the neuromuscualr junction and stimulates the sarcoplasmic reticulum to release its stored calcium ions throughout the muscle.

Excitation-Contraction Coupling

As calcium is relased it binds with a protein called troponin that is situated along the actin filaments. Sliding filament theory states that this binding causes a shift to occur in another chemical called tropomyosin. Because these chemicals have a high affinity for calcium ions they cause the myosin cross bridges to attach to actin and flex rapidly.

For contraction to contiune the myosin cross bridges must detach, "recock" and reattach. Significant muscle shortening depends on the continuous sequence of the following events:

- Calcium released by sarcoplasmic reticulum binds with troponin
- Myosin cross bridge couples with actin filament
- Cross bridge flexes and moves actin a small amount
- Cross bridge detaches and re-cocks
- Process is repeated

11

Heart Rate Training: Finding the Right Zone for You

Heart rate training makes use of the fact that the demand for oxygen rises with exercise intensity. As would be expected heart rate has a close relationship to oxygen consumption, especially at exercise intensities between 50 and 90% VO2 max .

Heart rate is easy to monitor and for the majority of athletes it offers a practical measure for assessing exercise intensity, which is why it is so popular.

It's important to monitor exercise intensity for a number of reasons. Firstly, the specific physiological adaptations to training change depending on what relative work load is employed. It's fundamental that the athlete or coach understands which type of endurance training (as a reflection of intensity) is best for their sport or event.

Secondly, monitoring the intensity of individual sessions allows the coach or athlete to manipulate the overall program, helping to prevent over training and in order to reach a physical peak for competition.

While heart rate is convenient and practical for most athletes, for many it can be inaccurate in determining the best exercise intensity .

The Limitations of Heart Rate Training

Most heart rate training programs are devised around an estimation of the maximum heart rate. The are two problems with this approach. The first is that maximum heart rate is estimated with the basic formula 220-age. For a significant number of athletes however, this estimation maybe out by as much as 25 beats per minute.

The only way to accurately determine maximum heart rate is perform a short, maximal stress test (to exhaustion). During the test heart rate will rise steadily until a plateau is reached despite the exercise intensity continuing to rise (assuming the individual is fit enough to last until such a time). This is a direct marker that the heart is beating as fast as possible.

The second problem is that, even if maximum heart rate is estimated accurately, prescribing exercise on the back of standardized zones makes no allowances for individual differences. For example, endurance performance improves when lactate threshold as a percentage of VO2 max is increased and it can be improved with training. A standard heart rate zone of 85-90% of the age-predicted maximum is commonly prescribed to improve lactate threshold but this may not be accurate. As with maximal heart rate, the only way to determine the correct heart rate training zone for improvement of lactate threshold is to measure it during laboratory testing.

Despite these limitations, heart rate training still offers a more objective method for determining exercise intensity than nothing at all.

Heart Rate Training Zones

Different exercise intensities tax the body's energy systems in different ways.

Exercising at 60% of maximum heart rate for example, is said to predominantly tax the aerobic system in most people. If exercise duration is long enough, the major source of fuel will be fat.

This type of intensity is often favoured by people who want to lose weight and are generally de-conditioned.

A heart rate training zone of 70-80% maximum will still predominantly tax the aerobic system in fitter individuals but the main source of fuel will be carbohydrate, or more specifically, glycogen. This is the heart rate training zone that endurance athletes typically aim for.

Here is a quick example of calculating a heart rate training zone using the age-predicted maximum of 220-age:

Rachel is 35 years old and wants to train for a 10km run.

- Maximum heart rate = 185bpm (220-35)
- Target heart rate zone = 70-80%
- Lower target heart rate = 130bpm (185 x 0.7)
- Upper target heart rate = 148bpm (185 x 0.8)

Target heart rate zone = 130 - 148bpm

The Karvonen Formula (Heart Rate Reserve)

Simply using 220-age makes no allowances for individual differences. All 35-year olds will have the same heart rate training zones according to this formula.

The Karvonen formula takes into account resting heart rate making it a slightly more specific to the individual. Because resting heart rate decreases with conditioning it also makes allowances for differing degrees of fitness to some extent.

Keeping with the example above, here's how Rachel (who has a resting heart rate of 65bpm) would use the Karvonen formula to achieve a more accurate heart rate training range for aerobic endurance conditioning...

Karvonen formula:

Maximum heart rate - resting heart rate x heart rate zone + resting heart rate

- 185 - 65 = 120bpm (this is called the working heart rate)
- 120 x 0.7 = 84bpm (70% zone)
- 84 + 65 = 149bpm (lower limit)
- 185 - 65 = 120bpm (this is called the 'working heart rate)
- 120 x 0.8 = 96bpm (80% zone)
- 84 + 65 = 161bpm (upper limit)

Target heart rate zone = 149 - 161pbm

You can see that the Karvonen formula calculates a higher training zone than just using 220-age and this is often the case.

It's often a good idea to use a rate of perceived exertion along side heart rate to make the intensity more specific to the individual. Rate of perceived exertion, although subjective, has been shown to correlate with heart rate (5). Essentially, it is a scale of difficulty that ranges from 6 (no exertion at all) to 20 (maximal exertion). It is often called the Borg Scale after its creator.

Swimming is a Little Different Maximum heart rate while swimming tends to be lower than for running events. To adjust for this subtract 13 from your maximum heart rate i.e. use 207-age rather than 220 - age. Use this adjustment for the Karvonen formula also.

Rating of Perceived Exertion (RPE)	
6	No exertion at all
7	
	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Vey hard
18	
19	Extremely hard
20	Maximal exertion

The Conconi Test for Measuring Lactate Threshold

As mentioned earlier, the simplest method for determining the lactate threshold is to assume it occurs at 85-90% of the maximum heart rate. An alternative is to use the Conconi test...

In 1982 Conconi *et al*, stated that the lactate threshold was linked to a deflection point in heart rate data. Heart rate plateaus briefly before rising sharply again and this is said to correspond with a sudden rise in blood lactate concentrations. There are various protocols used to elicit the plateau Conconi and co-workers refer to. Here is an example:

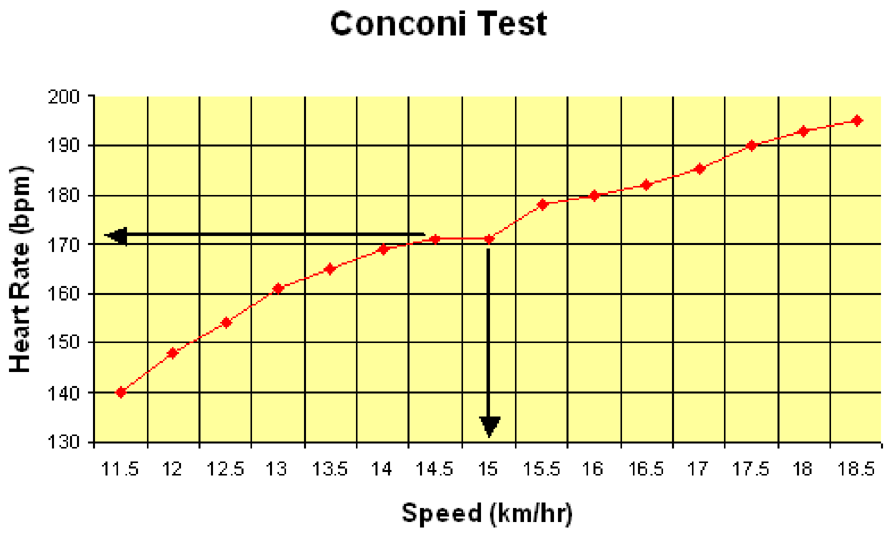
Equipment

- Treadmill (with metric setting - km/hr and meters)
- Heart rate monitor
- Assistant to take recordings

Procedure

- Begin by warming up at a light pace for 5 to 10 minutes. Set the treadmill to a 1% incline.
- The run should last between 2.5km and 4km to allow sufficient data to be collected.
- Gauge your starting speed. Speed is gradually increased every 200m so start too quickly and you won't last long enough. Start too slowly and you'll be there all day.
- As a guideline 8 - 10 km/hr is a good starting point.
- Increase the speed every 200m by 0.5 km/hr.
- Record the heart rate and speed at each 200m interval.
- Continue until exhaustion and complete a 10 minute cool down.

You can now plot a simple heart rate graph like the one below and read off lactate threshold:



You can see from the graph above the obvious plateau and deflection in heart rate. It seems to correspond with a heart rate of 172bpm. In theory, then an athlete could train at or just above this heart rate training zone and improve their lactate threshold. However, caution is required when using this test as subsequent research has questioned its validity . It has been argued that the deflection point occurrs only in a certain number of those tested and that it underestimates the lactate threshold exercise intensity.

Heart Rate Training to Increase Lactate Threshold

Here's a simple heart rate training program to increase lactate threshold...

- Assuming your heart rate at lactate threshold is 170bpm
- Start by completing two 6-10 minute runs approximately 5% below the lactate threshold heart rate. In this case it would be 162bpm.
- Rest for 2-3 minutes between runs and complete this twice a week.
- Gradually build up the length of each run or the number of repetitions (up to 6). Also increase your target heart rate up to your threshold (170bpm).
- The target eventually is to reach a sustained 20minute run at or just above your threshold heart rate.
- Complete a thorough cool down at the end of each session. Also re-test your lactate threshold every 6-8 weeks.

12

The Bruce Treadmill Test

The Bruce treadmill test has now become a standardized procedure used to evaluate the cardiovascular fitness of athletes... or anyone else for that matter.

The original Bruce protocol was developed by DR. Robert. A. Bruce in 1963.

This protocol for a multilevel treadmill test was developed as a means to detect chest pain and discomfort in patients as well as any evidence of possible heart attacks or ischaemic heart disease.

The test is now used:

- For athletes or coaches, to check the development of a sportsperson's general endurance or, what is known as VO2max. VO2max is simply the most amount of oxygen that a person can consume and utilize and is measured by the volume of oxygen per minute per kg body weight per time (mL/kg/min).
- For patients with suspected coronary heart disease. The Bruce treadmill test can be used by doctors as a non-invasive test procedure to determine whether there are any abnormalities in the electrical "firing patterns" of the myocardium (heart muscle).

When it's used in a medical context a treadmill test like this is often referred to an Exercise Tolerance Test or Exercise Stress Test.

The Bruce Treadmill test simply refers to the protocol used. Other protocols include Naughton, Astrand and Balke.

At 3-minute intervals both the speed and incline of the treadmill are increased. This can be better explained with the help of the following table...

The Bruce Treadmill Test Protocol

Level	Time (mins)	Speed (km/hr)	Grade (%)
1	0	2.74	10
2	3	4.02	12
3	6	5.47	14
4	9	6.76	16
4	12	8.05	18
5	15	8.85	20
6	18	9.65	22

So, from the chart above, we see that the test starts at 2.74km/hr at a gradient or incline of 10%. At minute 3 the speed is increased to 4.02km/hr and the gradient increased to 12%.

This is a maximal test - which means that the individual must continue until they are fatigued. Needless to say in a clinical setting, other parameters (such as blood pressure and ECG readings etc.) are used to determine the end of the test.

The Bruce Treadmill Test is also what's known as an indirect test. It only estimates VO2max using the formula below (as opposed to direct tests that use gas analysers to measure respired gases)...

For Men:

VO2 max = 14.8 - (1.379 x T) + (0.451 x T2) - (0.012 x T3)

For Women:

VO2 max = 4.38 x T - 3.9

In both cases T denotes the time in minutes spent on the treadmill. For example 10 min and 45 sec would be expressed as 10.75 minutes. Athletes can analyze their performances by comparing past and present test results.

They can also compare them to other athletes in their sport, although VO2max is certainly not the only indicator of performance - even in endurance sports.

13

Endurance Tests

Use these endurance tests before you begin your training program and then at 6-8 week intervals.

Balke 15 Minute Run

This is a very simple test to predict VO2max. You will require a stop watch and a standard 400m running track.

After warming up run for 15 minutes continuously. The idea is to maintain a steady pace throughout the run. The distance you cover is converted into a predicted VO2max using the following table:

Balke Test	
Distance (meters)	Predicted VO2max (ml/kg/min)
6000	80.0
5600	75.0
5200	70.0
4800	65.5
4400	61.0
4000	56.5

Cooper 12 Minute Run

This is another endurance test you can use to predict your VO2max. Again you only require a stopwatch and a 400m track.

Run or walk continuously for 12 minutes. Try to maintain a constant pace throughout. Note the total distance covered and use one of the following formulas to predict your VO2max:

For distance in Yards...
0.0206 x yards covered minus 11.3
For distance in Meters...
0.0225 x meters covered minus 11.3
So if you covered 3000 meters for example:
0.0225 x 3000 - 11.3 = 56.2 ml/kg/min

Multistage Shuttle Run

This is a maximal test which means it is performed until exhaustion. The test is excellent for multi-sprint sports such as soccer and rugby and it allows testing for an entire team simultaneously.

The test involves running 20 meter shuttles. The test is split into a series of 1-minute levels. Each level consists of a number of bleeps that dictates the pace at which each 20 meter shuttle must be run. As the levels progress the bleeps become quicker and more frequent so a greater number of shuttles has to be completed inside 1 minute. The starting speed (level 1) is 8.5km/hr and increases by 0.5km/hr for each level.

The test ends when the athlete(s) can no longer maintain the pace of the bleeps.

You can purchase the multistage shuttle test from www.1st4sport.com The test comes with a booklet and chart to help you convert performance into a score for VO2max.

Rockport Test

This is a great test for less fit and older individuals. Like all the endurance tests mentioned, the Rockport test will only predict your VO2max and is not a direct measurement.

For this test you need a stopwatch and 400m track. Walk for 1 mile (1600 meters) as quickly as possible. As soon as you complete the distance, record your time and your heart rate.

14

Acclimatization To Altitude

Acclimatization to altitude has become an important part of the preparation process for athletes competing above 1500m (4921ft).

Conditions above this level make physical activity more difficult and limits performance . But what is the most effective method for acclimation and can training at altitude improve performance at sea level?

This article focuses on the immediate physiological responses to a hypobaric (low atmospheric pressure) environment and the longer-term adaptations that take place in the body.

Although conditions at altitude have been known for many years, in 1968 the Olympic Games in Mexico City drew considerable attention to their specific effect on athletic performance.

High Altitude Environment

Air at altitude is commonly mistaken for being lower in oxygen but this is incorrect. Air, at any level, contains 20.93% oxygen, 0.03% carbon dioxide and 79.04% nitrogen. Instead, as elevation increases, oxygen has a progressively lower partial pressure…

At any point on earth, the more air that is above that point, the greater the barometric pressure will be. This is the same principle as being under water. The deeper a diver is the more water there is above her and the greater the pressure. At sea level, air exerts a pressure of approximately 760mmHg. At the summit of Mount Everest, 8848m (29,028ft) above sea level, air only exerts a pressure of about 231mmHg .

Recall that after we inhale, oxygen in the alveoli (tiny air sacs in the lungs) passes to the blood to be transported to the tissues. This gas exchange between the alveoli and blood takes place due to a pressure difference called a pressure gradient. The pressure oxygen exerts in the alveoli is greater than the pressure of oxygen in the blood surrounding the lungs. This drives oxygen from the lungs into the blood .

It makes sense then that any reduction in the pressure of oxygen entering the lungs will reduce the pressure difference or gradient. The result is less oxygen being driven from the lungs into the blood. At altitude that is exactly what happens.

The weight of air and the barometric pressure it exerts has an effect on the partial pressure of oxygen. At sea level, oxygen has a partial pressure of 159mmHg. In Mexico City it is approximately 125mmHg. At the top of Everest, it drops to 48mmHg, which is nearly equal to the blood surrounding the lungs . With very little pressure difference at this level oxygen exchange is severely hampered and it’s not surprising that supplemental oxygen becomes essential for most.

While there are other changes at altitude such as a drop in temperature, decreased humidity and increased solar radiation, the reduction in the partial pressure of oxygen (and so oxygen transport to the tissues) is thought to be the major cause of reduced exercise performance .

Acute Response to Altitude

Recall from the VO2 max article that the body’s ability to supply and utilize oxygen is a limiting factor in performance. Up to 1500m (4921ft), altitude has little effect on the body. Above this level, studies on men show the cardiovascular, respiratory and metabolic systems are affected. Unfortunately, there are few studies on women and children at altitude and their responses may differ slightly.

Respiratory System Response to Altitude

- Breathing rate increases at rest and during exercise. A smaller number of oxygen molecules per given amount of air means that increased ventilation is required to consume the same amount of oxygen as at sea level.
- Oxygen diffusion decreases. At sea level oxygen exchange from the lungs to the blood is unhindered and the oxygen-carrying component of

blood, hemoglobin, is about 98% saturated with oxygen. As altitude increases and the partial pressure of oxygen in the air drops, so does the pressure gradient between oxygen in the lungs and blood. This decreases the saturation of hemoglobin to about 90-92% at 2439m (8000ft). In effect, less oxygen passes (diffuses) from the lungs to the blood.

- The diffusion gradient at the active tissues decreases. As mentioned above, oxygen passes from the lungs to the blood due to a pressure gradient. The same process occurs when oxygen-rich arterial blood reaches the active tissues. The partial pressure of oxygen in arterial blood is about 100mmHg at sea level. In body tissue, it is a steady 40mmHg – a difference or pressure gradient of 60mmHg. At an altitude of 2439m (8000ft), arterial oxygen pressure decreases to 60mmHg so the difference or pressure gradient drops to just 20mmHg - a 70% reduction. In effect, less oxygen passes (diffuses) from the blood to the tissues .
- VO2 max decreases.Maximal oxygen uptake begins to decrease significantly above an altitude of 1600m (5249ft). For every 1000m (3281ft) above that VO2 max drops by approximately 8-11%. At the summit of Everest, an average sea level VO2 max of 62ml/kg/min can drop to 15ml/kgmin . For individuals with a sea level VO2 max less than 50 ml/kg/min would be unable to move as their VO2 max would drop to 5 ml/kg/min – enough only to support resting oxygen requirements .

Cardiovascular System Response to Altitude

- Blood volume decreases. Plasma volume decreases by up to 25% within the first few hours of exposure to altitude and doesn’t plateau until after a few weeks. This is partially a deliberate response by the body as reducing plasma (the watery part of blood) in effect increases the density of red blood cells. While no extra red blood cells have been produced in this acute phase, the amount of hemaglobin per unit of blood (called hematocrit) is now increased – resulting in greater oxygen transport for a given cardiac output.
- Cardiac output increases during rest submaximal exercise. During the first few hours at altitude stoke volume decreases during submaximal exercise, a result of the reduction in plasma volume. Heart rate increases enough to compensate for this and to actually slightly raise cardiac

output. After a few days however, oxygen extraction becomes more efficient reducing the need to increase cardiac output. In fact after 10 days acclimatization to altitude results in a lower cardiac output at any given, submaximal exercise intensity compared to sea level .

- Maximal cardiac output decreases. During exhaustive exercise at maximum levels both maximal stroke volume and maximal heart rate decrease with altitude . This obviously combines to have a significant effect on maximal cardiac output. In conjunction with the reduced diffusion gradient to drive oxygen from the blood to working tissues, it is easy to see why VO2 max and endurance performance is hindered.

Metabolic Responses to Altitude

Lack of oxygen availability and utilization at altitude places a greater demand on anaerobic metabolism to produce energy. This results in an increase in the concentration of lactic acid at any given submaximal exercise intensity compared to sea level. In contrast, lactate concentration is lower during maximal effort.

Athletic Performance Altitude

As would be expected the acute responses mentioned above have a detrimental effect on exercise performance – in particular the endurance events. VO2 max decreases significantly as altitude increases. Running at 12km/h for example will equate to a higher percentage of VO2 max when completed at altitude compared to sea level.

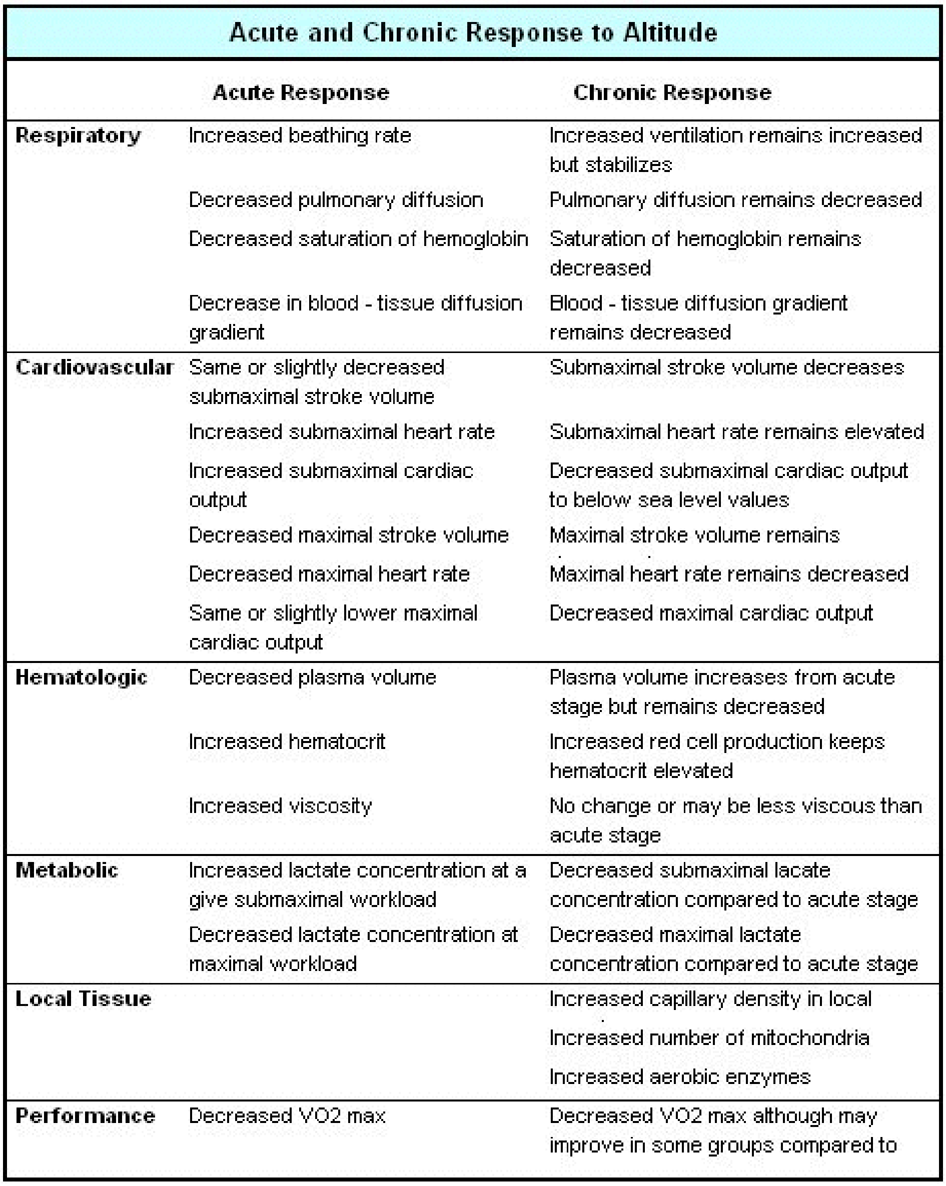
Conversely, ‘anaerobic’ events lasting under a minute such as sprinting, throwing and jumping activities are not impaired at moderate altitude. In fact, they can actually be improved due to the thinner air and less aerodynamic resistance.

Acclimatization to Altitude

It takes approximately two weeks to adapt to the changes associated with the hypobaric conditions at 2268m (7500ft), roughly that of Mexico City (1). Every 610m (2000ft) increase requires an additional week of acclimatization to altitude (1). But no matter how long an individual lives at altitude, they never fully compensate for the lack of oxygen and never regain the level of aerobic power or endurance performance they could at sea level. Below are the major adaptations occur with acclimatization to altitude:

- Red blood cell count increases. Lack of oxygen stimulates the release of erythropoietin, the hormone responsible for red blood cell production, within 3 hours and reaches a peak after 24 to 48 hours (8). The concentration of red blood cells within a given volume of blood is called hematocrit. In sea level residents, hematocrit is about 45-48%. With 6 weeks exposure to an altitude of 4540m (14895ft) these levels can increase to 59%. Initial exposure to altitude decreases plasma volume. However, this begins to increase slightly with long-term acclimatization to altitude.
- Pulmonary ventilation stabilizes. But it remains increased during rest and exercise compared to sea level.
- Submaximal cardiac output decreases. while submaximal cardiac output increases in the acute stage, following acclimatization to altitude it decreases to below sea level values. This is primarily due to a further reduction in stroke volume, which presumably occurs as changes in the oxygen-carrying capacity of the blood take the burden off the heart .
- Muscle cross sectional area decreases. Muscle biopsy studies following 4 to 6 weeks at altitude show that slow-twitch and fast-twitch fiber area decreases by as much as 20-25%. This decreases muscle area by 11-13%. It may be that muscle wasting of this nature is due to loss of appetite that often accompanies living at altitude.

The table below covers the major acute response and chronic changes associated with acclimatization to altitude:



Acute and Chronic Response to Altitude

	Acute Response	Chronic Response
Respiratory	Increased beathing rate	Increased ventilation remains increased but stabilizes
	Decreased pulmonary diffusion	Pulmonary diffusion remains decreased
	Decreased saturation of hemoglobin	Saturation of hemoglobin remains decreased
	Decrease in blood - tissue diffusion gradient	Blood - tissue diffusion gradient remains decreased
Cardiovascular	Same or slightly decreased submaximal stroke volume	Submaximal stroke volume decreases
	Increased submaximal heart rate	Submaximal heart rate remains elevated
	Increased submaximal cardiac output	Decreased submaximal cardiac output to below sea level values
	Decreased maximal stroke volume	Maximal stroke volume remains
	Decreased maximal heart rate	Maximal heart rate remains decreased
	Same or slightly lower maximal cardiac output	Decreased maximal cardiac output
Hematologic	Decreased plasma volume	Plasma volume increases from acute stage but remains decreased
	Increased hematocrit	Increased red cell production keeps hematocrit elevated
	Increased viscosity	No change or may be less viscous than acute stage
Metabolic	Increased lactate concentration at a give submaximal workload	Decreased submaximal lacate concentration compared to acute stage
	Decreased lactate concentration at maximal workload	Decreased maximal lactate concentration compared to acute stage
Local Tissue		Increased capillary density in local
		Increased number of mitochondria
		Increased aerobic enzymes
Performance	Decreased VO2 max	Decreased VO2 max although may improve in some groups compared to

Preparing for Competition at Altitude

How can athletes who live at sea level prepare for a competition at altitude?

One approach is to compete within 24 hours of arrival at altitude. Not much acclimatization will have taken place but most of the classical symptoms of altitude sickness will not have had time to manifest. After the intial 24 hours, dehydration and sleep disturbances become more prominent.

An alternative option is to train at a higher altitude for at least 2 weeks prior to competition. Although full acclimatization to altitude takes 4 to 6 weeks, many of the physiological adaptations occur in the first 2 weeks and the more severe disturbancs should have settled. It is important to remember that during the intial days at altitude work capacity is reduced, so athletes should train at 60-70% of sea level VO2 max and build up gradually over 10-14 days.

A third approach is to devote a greater percentage of training time at sea level to endurance training several weeks prior to competition. This is a strategy often adopted within many team sports, helping to raise players' VO2 max to a peak so that they can perform at a lower relative intensity without significant loss in performance.

Sleeping in altitude tents and hypobaric chambers may be able to adequately simulate the effects of altitude but these tend to be very expensive. Unfortunately, there is no evidence to suggest that spending 1-2 hours per day breathing hypobaric gases at sea level results in the same adaptations as living at altitude.

Can altitude training improve sea level performance? See the altitude training article for more details.

15

Altitude Training

Unquestionably, acclimatization to altitude improves performance at high levels but can altitude training improve an athlete's performance at sea-level?

The research is inconclusive. In theory, some adaptations that take place during prolonged exposure to the hypoxic conditions at 1500 m (4921 ft) or more above sea-level, should improve VO2 max and endurance performance at sea-level. Recall from the acclimatization to altitude article, that staying for a period of time at altitude increases the blood's oxygen carrying capacity.

However, maximal cardiac output is also decreased with exposure to altitude. Along with dehydration and a loss of lean muscle mass these detrimental effects may explain why living and training at altitude does not improve VO2 max or endurance performance on a return to sea-level.

Those few studies that have shown altitude training to have an ergogenic effect on sea-level performance are easy to criticize. Subjects have not usually reached a training peak so it becomes difficult to determine whether increases in aerobic power and / or endurance performance are the result of the adaptations to altitude or intensive training.

The major problem athletes living at altitude face is a significant reduction in training intensity. At 4000 m (13,122 ft) athletes can only exercise at 40% of their sea-level VO2 max compared to 80% at sea-level for example. Breathing hypoxic gases significantly reduces power output and this could lead to substantial detraining negating any of the ergogenic effects associated with acclimatization.

Live High - Train Low

Is it possible to induce the positive changes associated with altitude acclimatization without the associated negative effects? One banned and potentially dangerous tactic is blood doping and erythropoietin injections, which increase the blood's oxygen carrying capacity.

In an attempt to curb the detraining effect of reduced exercise intensity at altitude, Levine and Stray-Gundersen studied the effect of living high and training low on endurance performance. A group of 39 middle-distance runners were split into three altitude training groups - a "live high - train low" group, a "live high - train high" group and a "live low - train low" control group.

Unlike the control group, both "live high" groups increased their VO2 max on a return to sea-level by 5%. This was in direct proportion to the increase in red cell mass volume. However, only the "live high - train low" group improved their endurance performance as measured by a 5km time trial. Velocity at VO2 max and maximal steady state also improved in this group helping to shave an average of 13.4 seconds off their time.

The same researchers carried out a further altitude training study on elite male and female runners and found similar performance enhancing effects of living high and training low. The athletes' 3km time was measured before and after a period of 27 days living at altitude (2500m, 8200ft) interspersed with training sessions at sea-level. VO2 max increased an average of 3.2% and performance by an average of 1.1%. While this may seem like a negligible improvement, 1.1% at an elite level translates into a significant performance advantage.

Further altitude training studies, both at real altitude and simulated altitude, have shown that living high and training low can improve running economy, 800m, 1500m 3km performance, 400m performance, submaximal cycling performance and muscle buffer capacity.

These favorable results have stimulated interest in how athletes can "live high - train low" without having to actually move to high elevations. Several methods exist for artificially re-creating the hypoxic environment at altitude. These include hypobaric chambers, increasing the air's nitrogen content and altitude sleeping tents.

Sleeping tents are likely to be the most affordable and accessible option and don't seem to disrupt normal sleep quality. However, more research is needed to confirm whether these apartments do indeed improve performance.

16

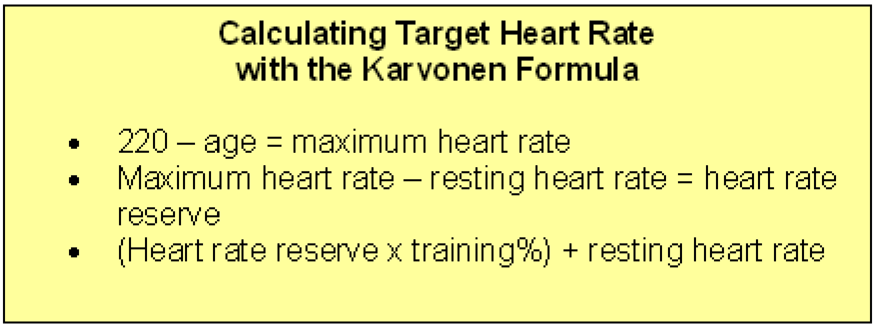
Heart Rate Reserve...
How to Determine Your Heart Rate Training Zone

Heart rate reserve is simply the difference between your maximum heart rate and your resting heart rate.

There is a relationship between heart rate and oxygen consumption - particularly at intensities ranging from 50-90% VO2 max . So traditionally, exercise intensity has been prescribed as a percentage of maximum heart rate (calculated as 220 - age). For example, a 30-year old with a maximum heart rate of 190bpm might train at 75% maximum or 143bpm.

One of the problems with the 220-age equation is that it makes no allowances for individual differences in resting heart rate. By incorporating the heart rate reserve into the equation, in theory a more accurate training zone can be determined.

The Karvonen formula uses the heart rate reserve to calculate training zones based on both maximum AND resting heart rate. Here's the actual formula:



Calculating Target Heart Rate
with the Karvonen Formula

- 220 – age = maximum heart rate
- Maximum heart rate – resting heart rate = heart rate reserve
- (Heart rate reserve x training%) + resting heart rate

Here's an example for a 50year old with a resting heart rate of 65bpm who wants to train at 70% maximum…

- 220 – 50 = 170bpm (maximum heart rate)
- 170 – 65 = 105bpm (heart rate reserve)
- (105 x 0.7) + 65 = 139bpm

Using the Karvonen formula this person's target heart rate works out as 139bpm. To create a 'zone' you might want to subtract i.e. 129 to 139bpm

Using the traditional 220 – age formula this same person would have a target heart rate of 119bpm, which is considerably lower (220 – 50 x 0.7). It's worth noting that the Karvonen formula nearly always calculates a higher target heart rate than 220 – age.

Here is a rough guide to different heart rate zones and the adaptations they elicit…

Recovery Zone - 60% to 70% Active recovery training should fall into this zone (ideally to the lower end). It's also useful for very early pre-season and closed season cross training when the body needs to recover and replenish.

Aerobic Zone - 70% to 80%

Exercising in this zone will help to develop your aerobic system and in particular your ability to transport and utilize oxygen. Continuous or long, slow distance endurance training should fall under in this heart rate zone.

Anaerobic Zone – 80% to 90%

Training in this zone will help to improve your body's ability to deal with lactic acid. It may also help to increase your lactate threshold.

It is important to remember that the heart rate reserve method of prescribing exercise intensity is by no means flawless. Firstly, estimating a person's maximal heart has been shown to have inaccuracies compared to laboratory testing - where exercise intensity is increased until a plateau in heart rate is found.

Secondly, the heart rate reserve tells us nothing about a person's lactate or anaerobic threshold. By recording heart rate data along side the point at which lactate threshold is thought to occur, a far more effective training plan can be devised.

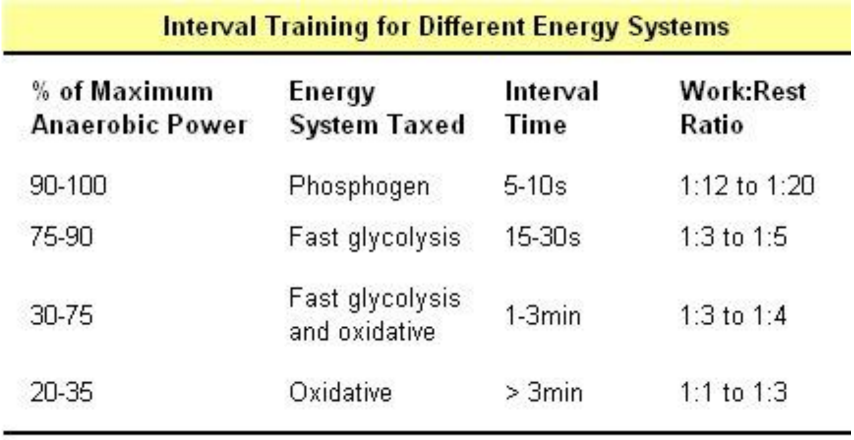
17

Interval Training For Sport Specific Endurance

Interval training can be best described as bouts of exercise interspersed with short rest intervals. It is based on the concept that more work can be completed at a higher relative intensity compared to continuous-type training.

The intensity and duration of the work intervals and the length of the rest periods dictates the training response. Very short, all-out bouts of work coupled with longer rest periods are used for speed and speed endurance development.

Short, very intense work intervals with short rest periods will predominantly tax the fast glycolytic energy system. Conversely, longer, lower intensity exercise bouts and short rest intervals can be used to develop aerobic endurance.



Interval Training for Different Energy Systems

% of Maximum Anaerobic Power	Energy System Taxed	Interval Time	Work:Rest Ratio
90-100	Phosphogen	5-10s	1:12 to 1:20
75-90	Fast glycolysis	15-30s	1:3 to 1:5
30-75	Fast glycolysis and oxidative	1-3min	1:3 to 1:4
20-35	Oxidative	> 3min	1:1 to 1:3

From Essentials of Strength Training and Conditioning, NSCA (2000)

Rest intervals are a critical component of the interval training program design. From the chart above, you can see that in order to stress the aerobic system efficiently, short rest periods are incorporated into the session. The opposite is true for speed development.

Research has shown that long rest periods (i.e. 1:12) result in low concentrations of lactic acid accumulation is low, increases in stroke volume are minimal and improvements in VO2 max are not seen. The opposite occurs when short rest intervals (i.e. 1:1 or less) are adopted .

Very short rest intervals are associated with high levels of blood lactate accumulation. This effects neuromuscular control and can negatively impact speed development. Because speed training requires maximal effort and a high quality of work, longer rest periods are more appropriate to allow the athlete to recover between work intervals. In order to enhance aerobic endurance and increase VO_2max towards its upper, genetic limit, interval training should consist of 3-5 minute work bouts with a 1:1 work to rest ratio or less. The intensity should equate to 90-100% VO_2max. This would be suitable for endurance events such as distance running, swimming, rowing or cycling for example. It could also be used for endurance development in multi-sprint sports such as rugby.

Interval Training is Suitable for Many Sports

Nearly all athletes require a basic level of cardiovascular endurance, if for no other reason than recovery between intense bouts of work. Traditionally, coaches have opted for long, slow, distance training at 70-80% maximum heart rate.

The problem with this approach is that is not specific to many sports such as the multi-sprint games and can actually be detrimental to strength and power performance. Research shows that long, slow continuous training can actually decrease anaerobic / glycolytic enzyme activity .

For sports such as basketball, soccer, hockey, tennis, rugby and so on, interval training may be more appropriate than continuous running because it can increase aerobic power and improve cardiorespiratory endurance without the associated detrimental effects on anaerobic power.

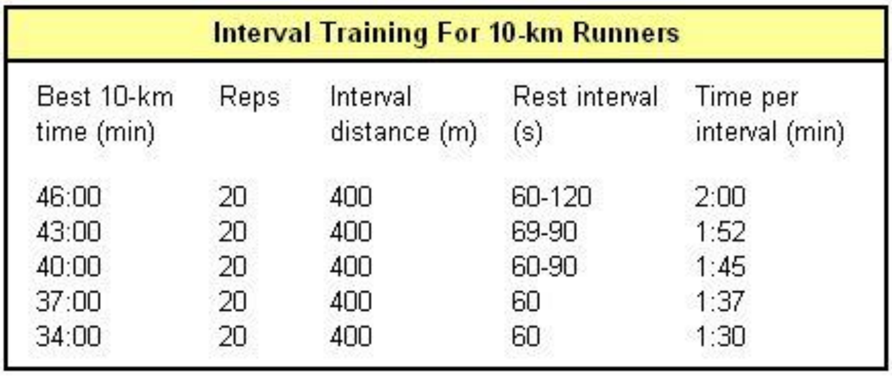
However, it’s not only multi-sprint sports that can benefit from interval training. Performance in the more classical endurance-based events such as the 10k run or distance swimming can improved by incorporating higher intensity interval training even if it’s at the expense of some volume. Below are some sample interval training sessions.

Interval Training Sessions

As mentioned earlier, interval training can be incorporated into a wide variety of sport-specific training programs. While the parameters in the table above provide a suitable program guideline, drills and sessions should be made as sport-specific as possible.

Interval Training Sessions For 10-km Runners

The training sessions in the table below are designed to improve the oxidative energy system – the most predominant pathway in this type of activity.



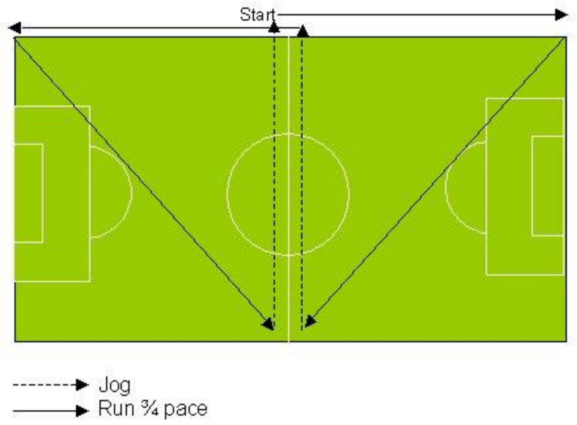
Interval Training For 10-km Runners

Best 10-km time (min)	Reps	Interval distance (m)	Rest interval (s)	Time per interval (min)
46:00	20	400	60-120	2:00
43:00	20	400	69-90	1:52
40:00	20	400	60-90	1:45
37:00	20	400	60	1:37
34:00	20	400	60	1:30

Interval Training Session For a Multi-Sprint Sport

The interval training session below is designed to improve cardiovascular endurance for a mutli-sprint sport such as soccer. Remember, that interval training describes only the format of training and is not only used for endurance development. Other sessions, using different work to rest ratios can be devised in order to develop speed or speed endurance.

Increasing Lap Run



Using the markings of a soccer pitch or similar size area, start on the touchline at the halfway point and run ¾ pace to the corner flag. Run ¾ pace diagonally to the opposite side of the pitch at the halfway point. Jog slowly along the halfway line back to the start. Continue for the other half of the pitch. This is one repetition. Repeat for 3 repetitions and rest for 2-3 minutes minutes. This is 1 set. Complete 3-5 sets in total for an interval endurance session.

Interval Training Sessions For a Tennis Player

Again, a sport like tennis requires elements of both aerobic endurance and anaerobic power. This interval training session below is designed to improve tennis-specific cardiovascular endurance.

Cross Court Drill

1. Holding a racket stand at one far corner of the court (where baseline and doubles sideline meet).
2. Side step along the baseline to the opposite far corner.
3. Run three quarter pace diagonally across the court to the corner of the net. Make an imaginary forehand shot with the racket.
4. Side step along the length if the net to the opposite corner.
5. Turn and run at three quarter pace diagonally across the court back to the start. Make an imaginary backhand shot.
6. Continue this sequence for 60 seconds then rest for 1-2 minutes. Perform a total of 5 runs to complete 1 set. Rest for 3 minutes and repeat for 2-3 sets.

18

The Cardiovascular System and Exercise

The cardiovascular system serves five important functions during exercise:

1. Delivers oxygen to working muscles
2. Oxygenates blood by returning it to the lungs
3. Transports heat (a by-product of activity) from the core to the skin
4. Delivers nutrients and fuel to active tissues
5. Transports hormones

Exercise places an increased demand on the cardiovascular system. Oxygen demand by the muscles increases sharply. Metabolic processes speed up and more waste is created. More nutrients are used and body temperature rises. To perform as efficiently as possible the cardiovascular system must regulate these changes and meet the body's increasing demands .

Below we will examine the acute or immediate response to exercise and also the long-term adaptations that take place in the cardiovascular system with repeated exercise. The most important aspects of the cardiovascular system to examine include:

- Heart rate
- Stroke volume
- Cardiac output
- Blood flow
- Blood pressure
- Blood

Immediate Response of the Cardiovascular System to Exercise

Heart Rate

Resting heart rate averages 60 to 80 beats/min in healthy adults. In sedentary, middle aged individuals it may be as high as 100 beats/min. In elite endurance athletes heart rates as low as 28 to 40 beats/min have been recorded.

Before exercise even begins heart rate increases in anticipation. This is known as the anticipatory response. It is mediated through the releases of a neurotransmitters called epinephrine and norepinephrine also known as adrenaline and noradrenaline .

After the initial anticipatory response, heart rate increases in direct proportion to exercise intensity until a maximum heart rate is reached. Maximum heart rate is estimated with the formula 220-age. But this is only an estimation, and not particularly accurate. The only direct method for determining maximum heart rate is to exercise at increasing intensities until a plateau in heart rate is found despite the increasing work rate.

Although heart rate increases rapidly with the onset of activity, providing exercise intensity remains constant, heart rate will level off. This is known as steady-state heart rate where the demands of the active tissues can be adequately met by the cardiovascular system. However, there is an exception to this…

During prolonged steady-state exercise, particularly in a hot climate, a steady-state heart rate will gradually increase. This phenomenon is known as cardiac drift and is thought to occur due to increasing body temperature .

Stroke Volume

Stroke volume is the amount of blood ejected per beat from left ventricle and measured in ml/beat.

Stroke volume increases proportionally with exercise intensity. In untrained individuals stroke volume at rest it averages 50-70ml/beat increasing up to 110-130ml/beat beat during intense, physical activity. In elite athletes resting stroke volume averages 90-110ml/beat increasing to as much as 150-220ml/beat .

Stroke volume may increase only up to 40-60% of maximal capacity after which it plateaus. Beyond this relative exercise intensity, stroke volume remains unchanged right up until the point of exhaustion . But this is not conclusive and other studies suggest stroke volume continues to rise until the pint of exhaustion .

Interestingly, swimmers see a smaller increase in stroke volume compared to runners or cyclists for example. It is believed that the supine position prevents blood from pooling in the lower extremities enhancing venous return.

Why does stroke volume increase with the onset of exercise? One explanation is that the left ventricle fills more completely, stretching it further, with the elastic recoil producing a more forceful contraction. This is known as the Frank-Starling mechanism. Other contributing factors include increased contractility of the ventricles and reduced peripheral resistance due to greater vasodilation of the blood vessels .

Cardiac Output

Cardiac output is the amount of blood pumped by the heart in 1 minute measured in L/min. It is a product of stroke volume and heart rate (SV x HR). If either heart rate or stroke volume increase, or both, cardiac output increases also.

Cardiac output increases proportionally with exercise intensity - which is predictable from understanding the response of heart rate and stroke volume to activity. At rest the cardiac output is about 5L/min. During intense exercise this can increase to 20-40L/min.

Blood Flow

The vascular system can redistribute blood to those tissues with the greatest immediate demand and away from areas that have less demand for oxygen.

At rest 15-20% of circulating blood supplies skeletal muscle. During vigorous exercise this increases to 80-85% of cardiac output. Blood is shunted away from major organs such as the kidneys, liver, stomach and intestines. It is then redirected to the skin to promote heat loss .

Athletes are often advised not to eat several hours before training or competition. This is advice worth adhering to, as food in the stomach will lead to competition for blood flow between the digestive system and muscles. It has been shown that gastrointestinal blood flow during exercise shortly after a meal is greater compared to exercising on an empty stomach .

Blood Pressure

At rest, a typical systolic blood pressure in a healthy individual ranges from 110-140mmHg and 60-90mmHg for diastolic blood pressure.

During exercise systolic pressure, the pressure during contraction of the heart (known as systole) can increase to over 200mmHg and levels as high as 250mmHg have been reported in highly trained, healthy athletes .

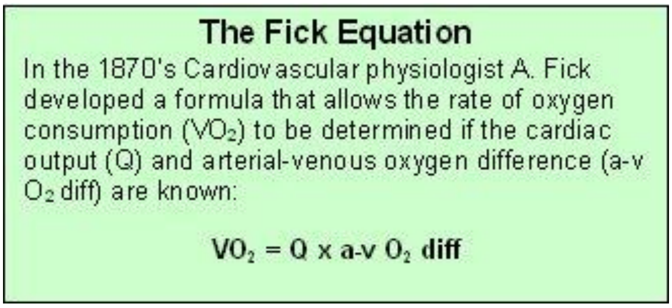
Diastolic pressure on the other hand remains relatively unchanged regardless of exercise intensity. In fact an increase of more than 15 mm Hg as exercise intensity increases can indicate coronary heart disease and is used as marker for cessing an exercise tolerance test.

Both systolic and diastolic blood pressure can rise to high, albeit brief, levels during resistance exercise. Values of 480/350mmHg have been reported to coincide with a Valsalva manoeuvre - i.e. trying to exhale against a closed mouth, nose and glottis.

Blood

During resting conditions the oxygen content of blood varies from about 20ml of oxygen per 100ml of arterial blood to 14ml of oxygen per 100ml of venous blood . The difference in oxygen content of arterial and venous blood is known as a-vO2 difference.

As exercise intensity increase the a-vO2 difference increase also and at maximal exertion the difference between arterial and venous blood oxygen concentration can be three times that at a resting level.



The Fick Equation

In the 1870's Cardiovascular physiologist A. Fick developed a formula that allows the rate of oxygen consumption (VO_2) to be determined if the cardiac output (Q) and arterial-venous oxygen difference (a-v O_2 diff) are known:

$$VO_2 = Q \times \text{a-v } O_2 \text{ diff}$$

Blood plasma volume decreases with the onset of exercise. The increase in blood pressure and changes in intramuscular osmotic pressures force water from the vascular compartment to the interstitial space. During prolonged exercise, plasma volume can decrease by 10-20% and by 15-20% in 1-minute bouts of exhaustive exercise. Resistance training with 40% and 70% one repetition maximum can cause a 7.7% and 13.9% reduction in blood plasma respectively .

A reduction in plasma increase the concentration of hemoglobin or hematocrit. Although no extra red blood cells have been produced, the greater concentration of hemoglobin per unit of blood significantly increases the blood’s oxygen carrying capacity. This is one of the main adaptations during immediate acclimatization to altitude.

Blood pH can change from a slightly alkaline 7.4 at rest to as low as 6.5 during all-out sprinting activity. This is primarily due to an increased reliance on anaerobic energy systems and the accumulation oh hydrogen ions.

Adaptations in the Cardiovascular System

Following training the cardiovascular system and its components go through various adaptations. Here are the most important:

Heart Size

The heart’s mass and volume increase and cardiac muscle undergoes hypertrophy.

It is the left ventricle that adapts to the greatest extent. As well as the chamber size increasing as a result of endurance training, more recent studies show that the myocardial wall thickness also increases.

Heart Rate

Resting heart rate can decrease significantly following training in a previously sedentary individual. During a 10-week exercise program, an individual with an initial resting heart rate of 80beats/min can reasonably expect to see a reduction of about 10beats/min in their resting heart rate. As mentioned earlier, highly conditioned athletes such as Lance Armstrong can have resting heart rates in the low 30’s.

During submaximal exercise, heart rate is lower at any given intensity compared to pre-training. This difference is more marked at higher relative exercise intensities. For example, at low work rates there may only be a marginal difference in heart rate pre and post training. As intensity reaches maximal levels, the difference can be as much as 30beats/min following training .

Maximum heart rate tends to remain unchanged by training and seems to be genetically limited. However, there are some reports that maximum heart rate is reduced in elite athletes compared to untrained individuals of the same age.

Following an exercise bout, heart rate remains elevated before slowly recovering to a resting level. After a period of training, the time it takes for heart rate to recover to its resting value is shortened . This can be a useful tool for tracking the effects of a training program. However, it is not so useful to compare to other people as various individual factors other than cardiorespiratory fitness play a role in how quickly heart rate returns to a resting level.

Stroke Volume

Stroke volume increases at rest, during submaximal exercise and maximal exercise following training. Stroke volume at rest averages 50-70 ml/beat in untrained individuals, 70-90ml/beat in trained individuals and 90-110ml/beat in world-class endurance athletes .

This all-round increase in stroke volume in attributable to greater end-diastolic filling. This greater filling of the left ventricle is due to a) an increase in blood plasma and so blood volume (see below) and b) reduced heart rate which increases the diastolic filling time .

According to the Frank-Starling mechanism, this increased filling on the left ventricle increases its elastic recoil thus producing a more forceful contraction. So not only is the heart filled with more blood to eject, it expels a greater percentage of the end-diastolic volume (referred to as the ejection fraction) compared to before training.

Cardiac Output

If heart rate decreases at rest and during submaximal exercise and stroke volume increases, what is the net effect on cardiac output?

In actual fact, cardiac output remains relatively unchanged or decreases only slightly following endurance training. During maximal exercise on the other hand, cardiac output increases significantly. This is a result of an increase in maximal stoke volume as maximal heart rate remains unchanged with training. In untrained individuals, maximal cardiac output may be 14-20L/min compared to 25-35L/min in trained subjects. In large, elite athletes, maximal cardiac output can be as high as 40L.min.

Blood Flow

Skeletal muscle receives a greater blood supply following training. This is due to:

- Increased number of capillaries
- Greater opening of existing capillaries
- More effective blood redistribution
- Increased blood volume

Blood Pressure

Blood pressure can decrease (both systolic and diastolic pressure) at rest and during submaximal exercise by as much as 10mmHg in people with hypertension. However, at a maximal exercise intensity systolic blood pressure is decreased compared to pre-training .

It is interesting to note that although resistance exercises can raise systolic and diastolic blood pressure significantly during the activity, it too can lead to a long-term reduction in blood pressure .

Blood Volume

Endurance training increase blood volume. While plasma volume accounts for the majority of the increase, a greater production of red blood cells can also a contributory factor. Recall that hematocrit is the concentration of hemoglobin per unit of blood. An increase in red blood cells should increase hematocrit but this is not the case. Because blood plasma increases to a greater extent than red blood cells, hematocrit actually reduces following training .

19

Hypertrophy in Human Muscle

As it relates to strength and muscle, hypertrophy is simply the enlargement of a muscle belly due to an increase in the size of muscle cells - particularly the muscle's fibres.

This differs from hyperplasia which would equate to an increase in the number of fibres.

Unlike hyperplasia, hypertrophy is a well-recognised and accepted physiological adaptation to skeletal muscle. But to really understand what happens we need to take a closer look at muscle anatomy...

Each muscle or muscle group (like the biceps) is made up of bundles of muscle fibres. Traditionally, researchers believed that the number of fibers we are born with doesn't change, regardless of any exposure to resistance training. This is contested by many proponents of muscle fibre hyperplasia, who suggest that training may induce a greater number of fibers to be formed.

According to the principle of hypertrophy, muscles become larger following a strength training routine, in part, because each fibre (usually fast twitch) becomes larger or thicker. One or more of the following adaptations cause the increase in fibre size :

- Increase in the number of contractile proteins (actin and myosin)
- Increase in the number and size of myofibrils per muscle fibre
- Increase in the amount of connective tissue
- Increased enzymes and stored nutrients

The long-term increase in muscle size is referred to as chronic hypertrophy. Short-term or transient hypertrophy refers to the pumpin-up of muscle that occurs during a resistance training session. This is predominantly due to fluid retention in the interstital and intracellular spaces of the muscle and is known as edema (1).

The increase in individual fiber size seems to be stimulated by an increase in muscle protein synthesis. During intense exercise, protein synthesis appears to decrease and then increase during the recovery period . The opposite is true for the breakdown or degradation of protein. This increases during and immediately following exercise and decreases in the recovery period. Taking a carbohydrate and protein supplement immediately after a resistance training sessions has been shown to reduce the rate of protein degradation

Interestingly, eccentric muscle action appears to induce a greater amount of muscular hypertrophy compared to concentric muscle action . Comparing training regimens of only concentric or eccentric exercises, one study found hypertrophy in fast twitch fibers was ten times greater in the eccentrically trained group.

20

Hyperplasia in Human Muscle

Hyperplasia can be defined as:

> *"the growth of an organ due to an increase in the number of cells."*

The breast tissue undergoes hyperplasia in a lactating mother. The tonsils grow by hyperplasia to enhance the immune response in a child with a throat infection. As it relates to skeletal muscle, hyperplasia defines muscle growth due to an increase in the number of muscle fibers.

In contrast, hypertrophy defines an increase in the size of existing cells or fibers rather than an increased number of cells.

Human skeletal muscle undergoes hypertrophy (i.e. it gets bigger) following a resistance training program. But is this whole-muscle hypertrophy the result of fiber hypertrophy or fibre hyperplasia. In other words, do muscles get bigger due to an increase in existing fibre size or an increase in the number of fibres?

It's a subject that had stirred much debate amongst researchers. While fibre hypertrophy is well accepted and documented, very few studies have measured fibre hyperplasia in humans. Studies on animals have shown conflicting results.

Studies on cats have found that hyperplasia occurs in response to heavy resistance training - cats were trained to move a heavy weight with their paw in order to get food . In contrast, other studies on chickens, rats and mice have found that overload resulted in muscle hypertrophy only and no change in the number of muscle fibres . The differences in results between the cat and other animal studies may be a result of the overload used. The cats were exposed to high resistances and low repetitions as opposed to more endurance-type activity used in the other studies.

A further study performed on birds reported an increase in the number of muscle fibres in the wing in response to chronic stretching by attaching a weight to it. Follow up studies using a similar model have both confirmed and contradicted these results.

Research into fibre hyperplasia in human muscle in scarce. Nygaard and Neilsen reported that fibre size remained unchanged in the shoulder muscles of swimmers despite the whole muscle belly becoming larger. It was argued that such muscle development must have resulted from hyperplasia.

Larsson and Tesch compared bodybuilders to active but untrained controls. They discovered that despite the significantly greater muscle cross-sectional area in bodybuilders, individual fiber size was not significantly different to the controls'. However, Schantz and co-workers found a significant difference in individual muscle fiber size between bodybuilders and male and female physical education students .

Proponents of hyperplasia suggest that it can take place through two mechanisms...

1. By the splitting up of pre-existing fibers
2. By the activation of satellite cells surrounding muscle fibers, which have the potential to mature into muscle fibers themselves.

One longitudinal study followed a group of recreational resistance trained subject. After 12 weeks of more intense resistance training, the number of muscle fibers in the biceps brachii in some of the subjects increased significantly. The fact that not all subjects responded in the same way suggests that if hyperplasia is possible in humans it may only occur in a few individuals under certain conditions.

21

How to Design a Resistance Training Program for Your Sport

Resistance training is now accepted as an integral and crucial part of any athlete's training plan...

Unlike the generic strength training routines found in fitness magazines, sport-specific strength conditioning involves a few more design variables and takes a little more planning. This guide outlines the seven steps to designing effective resistance training programs for sport...

Step 1 - Evaluation And Assessment

The first step, and perhaps the most important, is to evaluate the characteristics of the sport and to assess the athlete's physical profile.

Evaluating The Sport

Ultimately, a resistance training program should mirror the movement patterns of the sport as closely as is feasible.

While early stages of the program may focus on developing a general strength base, as the competitive season approaches, conditioning exercises should become more specifically tailored to the sport.

The same applies to the physiological demands of the sport - a cross country runner for example, requires high levels of muscular endurance. A volleyball player would benefit from explosive power and a football lineman from exceptional muscle mass. A hockey player would benefit from basic strength, explosive power and strength endurance.

Assessing The Athlete

A conditioning plan is only as successful as the individual's ability to commit to it. For most, training time is limited so the key is to prioritize. Although in an ideal scenario a soccer player would benefit from addressing explosive power and strength endurance needs, their lack of physical size and strength may be their greatest hindrance. A program to bulk the player up may have the greatest impact on their performance.

The only way to ascertain the most appropriate program design is through a battery of fitness tests. Again, selection of appropriate tests comes from an evaluation of the sport.

As a rule of thumb one repetition maximum testing for the upper and lower body is appropriate for most sports. The standing vertical jump is an obvious power test for a basketball player. The 60-second sit-up or push-up test would be suitable for many of the endurance sports.

Consider finally, the phases of the sport season. Generally, early pre-season or off-season training is reserved for maximum strength and hypertrophy. For athletes new to resistance training an extended period of time may be required for functional or anatomical training - preparing the body for a more strenuous lifting program.

Strength Training Priorities Over a Season

	Priority	Strength Training Goal
Off Season	High	Hypertrophy and maximal strength
Pre-Season	High >>> Medium	Sport-specific power and strength endurance
In-Season	Medium >>> Low	Maintenance of power and strength endurance
Transition	Low	Active rest (some athletes may start a hypertrophy program if weight gain is a priority)

Step 2 - Exercise Selection

Once a movement analysis of the sport has been considered and the strength objective for the program set (i.e. hypertrophy, maximum strength, power, strength endurance or a combination of several), the most appropriate exercises can be selected.

Core exercises (those that incorporate one or more large muscle groups) should form the basis of a maximal strength or hypertrophy resistance training program. Examples include back squats, bench presses, dead lifts and should presses. Core exercises suitable for power development include power cleans, push jerks and snatches.

When explosive power and strength endurance are more a priority (perhaps for a late pre-season strength program) more assistance exercises can be incorporated into the routine.

Assistance exercises recruit smaller muscle groups and are usually single joint exercises. They can be useful for maintaining a balance between agonists and antagonist muscle groups - especially if the sport places an uneven demand on the body. They can also closely match some of the movements in sport...

Kicking - leg extensions, hip abduction/adduction

Jumping - power cleans, calf presses, jump squats

Rowing - seated rows, hip sled, single arm rows

Swimming (front crawl) - lat pull downs, lateral raises, overhead pulls

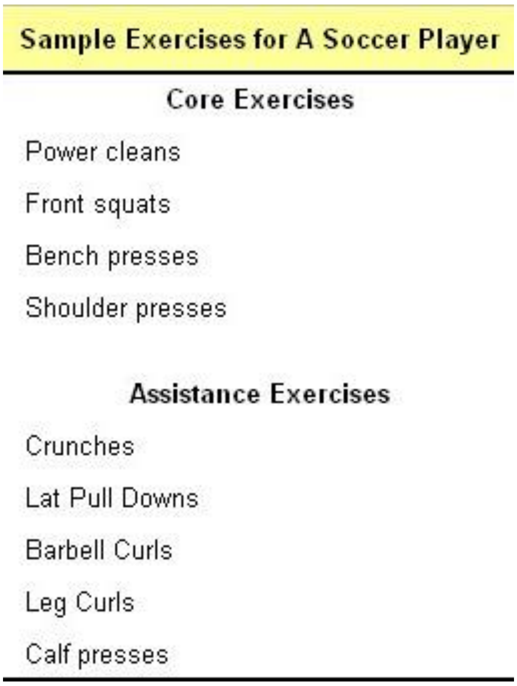
Sprinting - lunges, step-ups, calf raises

Throwing - overhead pullovers, triceps extensions, internal/external shoulder rotations

Even though mirroring sport specific movements is an important design variable, it should not be to the neglect of other major muscle groups.

A resistance training program should aim to develop balance throughout the body even if the sport has an upper or lower body emphasis. This is an important step in injury prevention.

Here is an example of the exercises selected for a soccer player. After completing a series of tests, they were assessed to be lacking in power and speed, although their basic strength and strength endurance was good:



Sample Exercises for A Soccer Player

Core Exercises

Power cleans
Front squats
Bench presses
Shoulder presses

Assistance Exercises

Crunches
Lat Pull Downs
Barbell Curls
Leg Curls
Calf presses

Step 3 covers how this collection of resistance exercises could be organized into structured sessions to achieve the desired conditioning outcome...

Step 3 - Frequency

Fequency

Many athletes choose to lift weights in three workouts a week. This often works well allowing sufficient recovery time and fits nicely into the 7-day week. More advanced lifters may benefit from a four, five or even six day a week program.

Beginners are recommended to start with two, total body sessions a week.

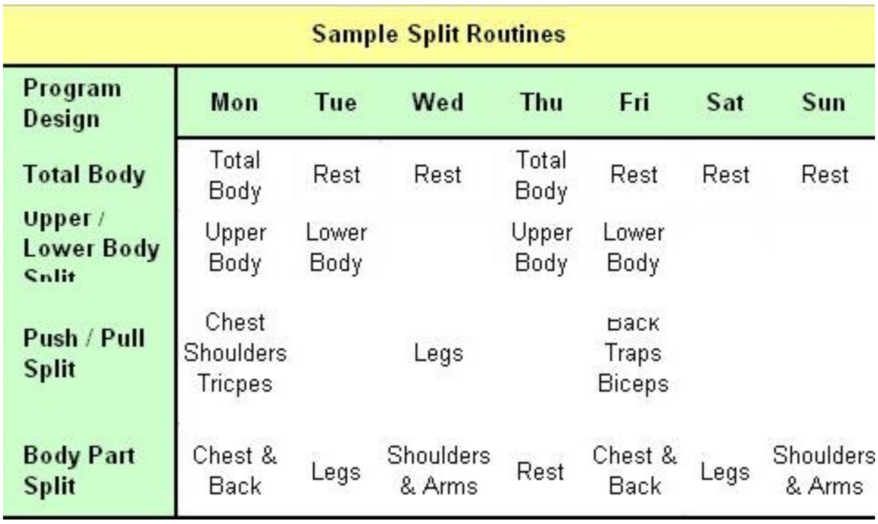
Guidelines from the National Strength and Conditioning Association suggest that there should be at least one rest day but not more than three between working each muscle group. At a minimum, a resistance training session that works the entire body could be completed Monday and Thursday or Tuesday and Saturday.

Alternatively, it may be more suitable to use the split routine design - training different muscle groups on different days.

It's also important to take the phases of season into consideration...

- Off Season - 4-6 sessions per week
- Pre Season - 3-4 sessions per week
- In Season - 1-2 sessions per week
- Transition - 0-3 sessions per week

Of course frequency design cannot be complete without taking other elements of training (such as speed and endurance sessions) into account. A resistance training program for a hockey player for example, might be coupled with plyometric training. In this scenario, only two resistance training sessions per week is feasible.



Sample Split Routines

Program Design	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Total Body	Total Body	Rest	Rest	Total Body	Rest	Rest	Rest
Upper / Lower Body Split	Upper Body	Lower Body		Upper Body	Lower Body		
Push / Pull Split	Chest Shoulders Tricpes		Legs		Back Traps Biceps		
Body Part Split	Chest & Back	Legs	Shoulders & Arms	Rest	Chest & Back	Legs	Shoulders & Arms

Step 4 - Exercise Order

The order in which exercises are performed in a session should not be overlooked. Sports conditioning is more demanding than general fitness training and with various forms of training often taking place in the week it's important to maximize overload to recovery ratio.

One method for structuring exercise order is power, core ,assistance exercises. So for example, power cleans (which involves the most complex movements) should start the session if they are included. A resistance training session that follows this structure might look as follows:

Hang cleans (power)
Back Squats (core)
Bench Presses (core)
Bent Over Rows (assistance)
Triceps Push Downs (assistance)

A second approach is to alternate upper and lower body exercises:

Lunges
Seated Rows
Leg Curls
Reverse Flies
Calf Presses
Barbell Curls

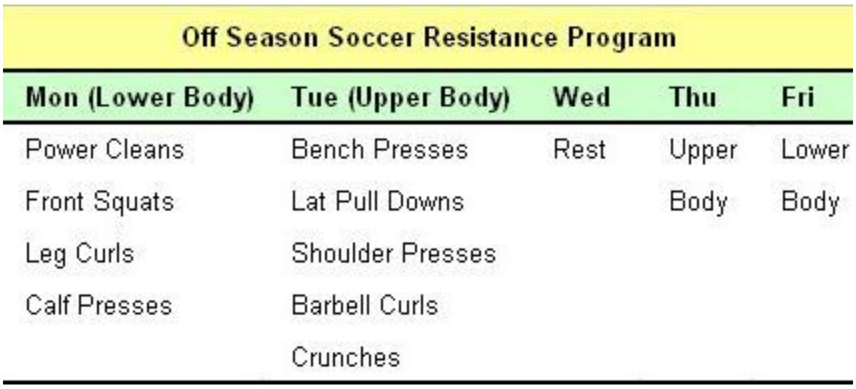
Finally, the push-pull format is an effective resistance training session structure. For the upper body:

Incline Bench Presses
Lat Pull Downs
Military Presses
Hammer Curls

And for the lower body:

Front Squats
Stiff Leg Deadlifts
Hip Sleds
Leg Curls

Sticking with the soccer training example from Step 2, here's how that selection of exercises could be structured into an Off-season weekly resistance training plan:



Off Season Soccer Resistance Program

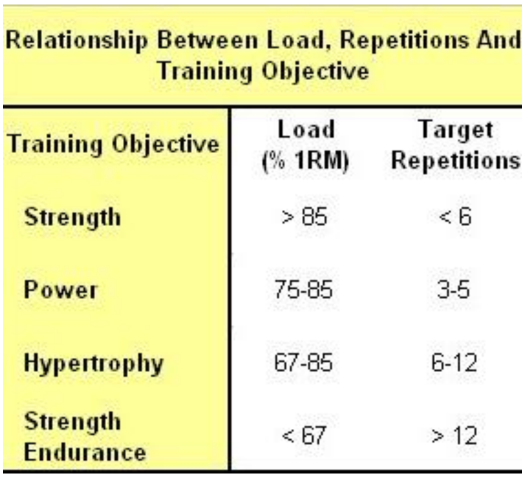
Mon (Lower Body)	Tue (Upper Body)	Wed	Thu	Fri
Power Cleans	Bench Presses	Rest	Upper	Lower
Front Squats	Lat Pull Downs		Body	Body
Leg Curls	Shoulder Presses			
Calf Presses	Barbell Curls			
	Crunches			

Notice how the sessions are split into the "upper body / lower body format" over the week. For the individual sessions exercises are ordered by a "push-pull" format.

Step 5 - Loading & Repetitions

Assigning the right intensity or load to the exercises depends on two main factors... the training objective and the athlete's current level of strength. Loads are usually assigned as a percentage of the athlete's one repetition maximum.

The chart below shows the relationship between loading patterns and the conditioning response:



Relationship Between Load, Repetitions And Training Objective

Training Objective	Load (% 1RM)	Target Repetitions
Strength	> 85	< 6
Power	75-85	3-5
Hypertrophy	67-85	6-12
Strength Endurance	< 67	> 12

Using the chart above, for an athlete to make the greatest gains in maximal strength they should perform sets of 6 repetitions or less. That means that failure to lift another, single repetition should occur within 6 repetitions - which typically correlates to a load of greater than 85% 1RM

Strength endurance, on the other hand, is developed when a greater number of repetitions are completed (more than 12) and loads usually correlate to less than 67% 1RM. It's important to remember that adequate overload, even when strength endurance is the primary objective, occurs when each set is performed to, or close to failure.

Explosive power development is a little different. From the chart above, power for multi-sprint sports (as opposed to single power events such as Olympic Weightlifting) is best developed in a repetition range of 3-5.

However, if exercises were performed to failure in this repetition range, loads of approximately 87-93% 1RM would be used. This is too heavy for substantial power production as it limits the athlete's ability to generate speed of movement. Instead, the 3-5 repetitions are completed with loads of 75-85% 1RM with emphasis on the quality of the lifts.

Step 6 - Volume

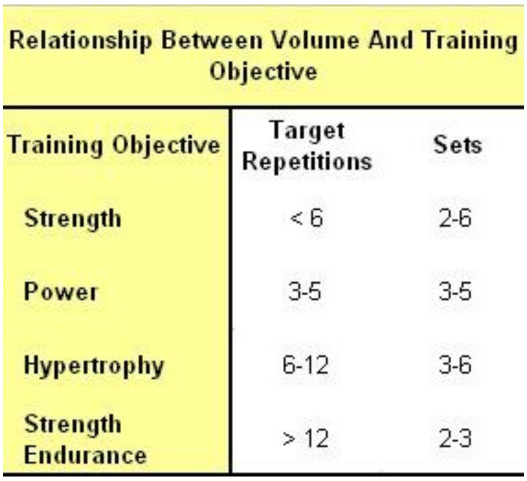
Volume can be classed as the total amount of weight lifted in a resistance training session. This is calculated by multiplying the weight used for each set for all exercises by the number of repetitions completed. So if 3 sets of bench presses are completed, each for 10 repetitions, using 175lbs (80kg) the total volume load equates as:

3sets x 10reps x 175lbs = 5250lbs

Research has shown that gain in both hypertrophy and maximal strength can be achieved with a single set per exercise.

However, many more studies suggest that while suitable for beginners, more advanced lifters require additional volume to make further gains in strength. It's also interesting to note that there is evidence that 3 sets of 10 repetitions completed without going to failure increase strength to a greater degree than 1 set of 10 repetitions completed to failure.

As with load, volume is dependant on the athlete's previous training history and the primary strength objective. One or two sets are suitable for beginners and up to 6 sets for experienced athletes. The chart below outlines the general relationship between volume and different aspects of strength:



Relationship Between Volume And Training Objective

Training Objective	Target Repetitions	Sets
Strength	< 6	2-6
Power	3-5	3-5
Hypertrophy	6-12	3-6
Strength Endurance	> 12	2-3

Rest Periods

Maximal strength training places the greatest demands on the neuromuscular system and requires the longest rest interval between sets and should last between 2-6 minutes.

Resistance training for power demands high quality of movement and the resulting fatigue from too short a rest interval compromises lifting technique. Rest periods of 2-5 minutes are also recommended for power training.

Rest interval of 30 seconds to 1.5minutes are suggested for hypertrophy and les than 30 seconds for improvements in strength endurance.

Step 7 - Progression

From phase to phase over the course of a season, resistance training usually progresses from general strength to sport-specific power and strength endurance. The in-season sees a reduction in training volume where the goal is to maintain the gains made in the off and pre-season phases.

From session to session loads and volume should increase gradually. The 2-for-2 rule is a useful guideline for increasing the resistance. For example, 3 sets of 8 repetitions may be prescribed for a particular exercise. When the athlete completes 2 more repetitions (i.e. 10 reps) on the final set for 2 consecutive sessions the weight should be increased. For smaller muscle groups an increase of 2.5-5lbs (1.25-2.5kg) is suggested and 5-10lbs (2.5-5kg) for larger muscle groups.

22

Strength Tests

Use these strength tests before you begin weight training and then periodically during your training program.

Maximal Strength Assessment (1-RM)

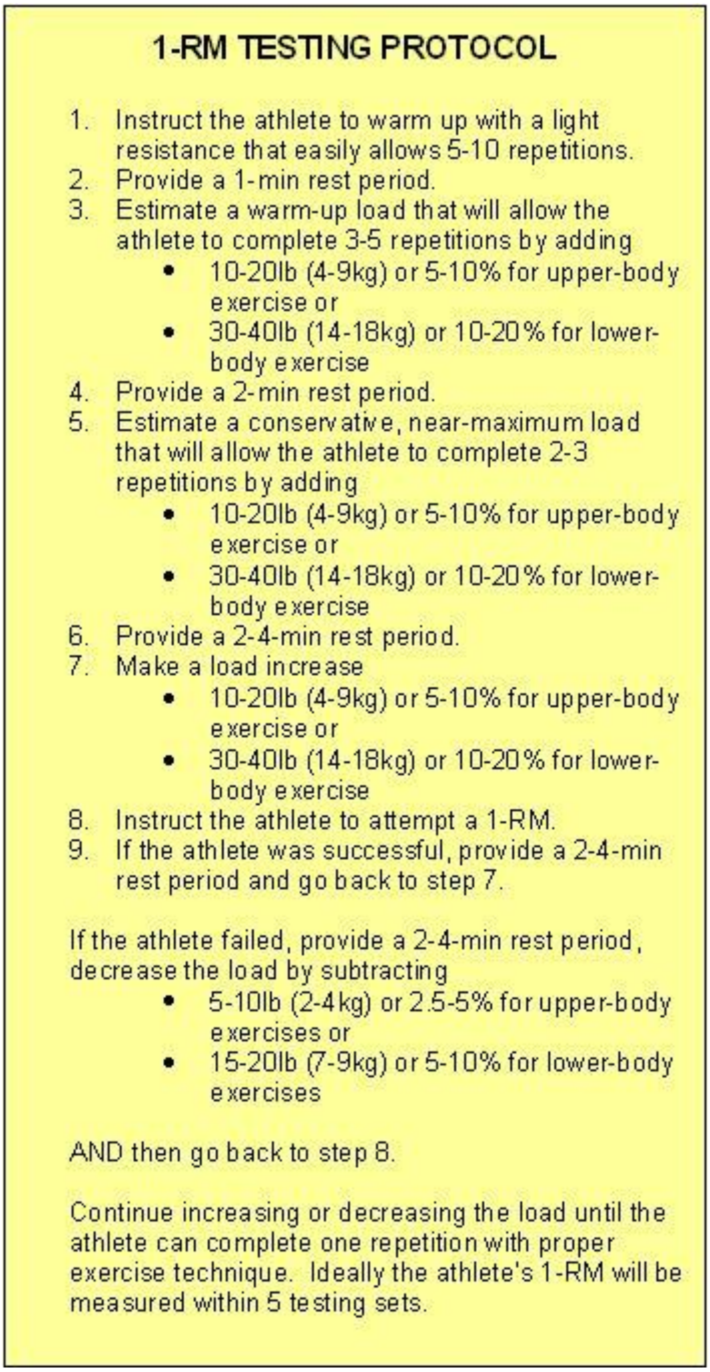
Strength tests to measure maximal strength are suitable for many athletes. For the reasons why maximal strength is important to athletic performance, see the strength training programs article.

The one repetition maximum (1-RM) is still considered the 'gold standard' of strength assessment by most coaches. The procedure usually consists of the bench press and back squat or leg press. These are compound movements incorporating most of the large muscle groups in the upper and lower body.

Either free weights or resistance machines can be used for the testing procedure but the choice should be determined by what the athlete intends to use during training. The specific adaptation to imposed demands means that a barbell back squat will more accurately determine the effectiveness of a free weights strength program than a machine leg press for example.

Testing Procedure

Here is the protocol for 1-RM testing as set out by the National Strength & Conditioning Association:



1-RM TESTING PROTOCOL

1. Instruct the athlete to warm up with a light resistance that easily allows 5-10 repetitions.
2. Provide a 1-min rest period.
3. Estimate a warm-up load that will allow the athlete to complete 3-5 repetitions by adding
    - 10-20lb (4-9kg) or 5-10% for upper-body exercise or
    - 30-40lb (14-18kg) or 10-20% for lower-body exercise
4. Provide a 2-min rest period.
5. Estimate a conservative, near-maximum load that will allow the athlete to complete 2-3 repetitions by adding
    - 10-20lb (4-9kg) or 5-10% for upper-body exercise or
    - 30-40lb (14-18kg) or 10-20% for lower-body exercise
6. Provide a 2-4-min rest period.
7. Make a load increase
    - 10-20lb (4-9kg) or 5-10% for upper-body exercise or
    - 30-40lb (14-18kg) or 10-20% for lower-body exercise
8. Instruct the athlete to attempt a 1-RM.
9. If the athlete was successful, provide a 2-4-min rest period and go back to step 7.

If the athlete failed, provide a 2-4-min rest period, decrease the load by subtracting

- 5-10lb (2-4kg) or 2.5-5% for upper-body exercises or
- 15-20lb (7-9kg) or 5-10% for lower-body exercises

AND then go back to step 8.

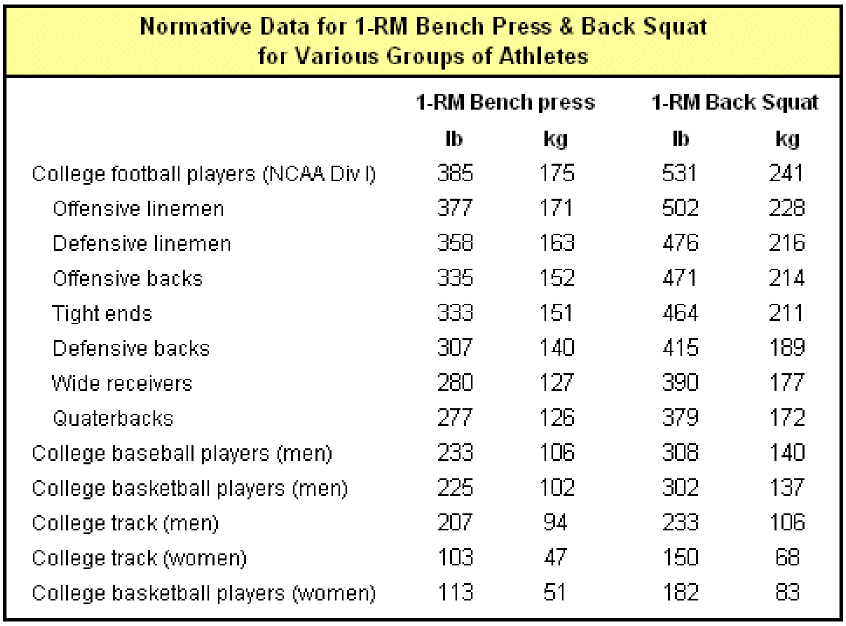
Continue increasing or decreasing the load until the athlete can complete one repetition with proper exercise technique. Ideally the athlete's 1-RM will be measured within 5 testing sets.

Results

Take your 1-RM weight for the bench press and leg press and divide it by your body weight. So for example, if you were able to lift 300lbs (136kg) on the leg press and you weigh 175lbs (80kg), that equates to a score of 1.7. Compare your score with the chart below...

1-RM Scores					
Bench Press	Poor	Fair	Good	Very good	Excellent
Men	0.6	0.8	1.0	1.2	1.4
Women	0.3	0.4	0.5	0.6	0.7
Leg Press	Poor	Fair	Good	Very good	Excellent
Men	1.4	1.8	2.0	2.4	2.8
Women	1.2	1.4	1.8	2.0	2.2

The table below gives typical 1-RM scores for various groups of athletes:



Normative Data for 1-RM Bench Press & Back Squat for Various Groups of Athletes

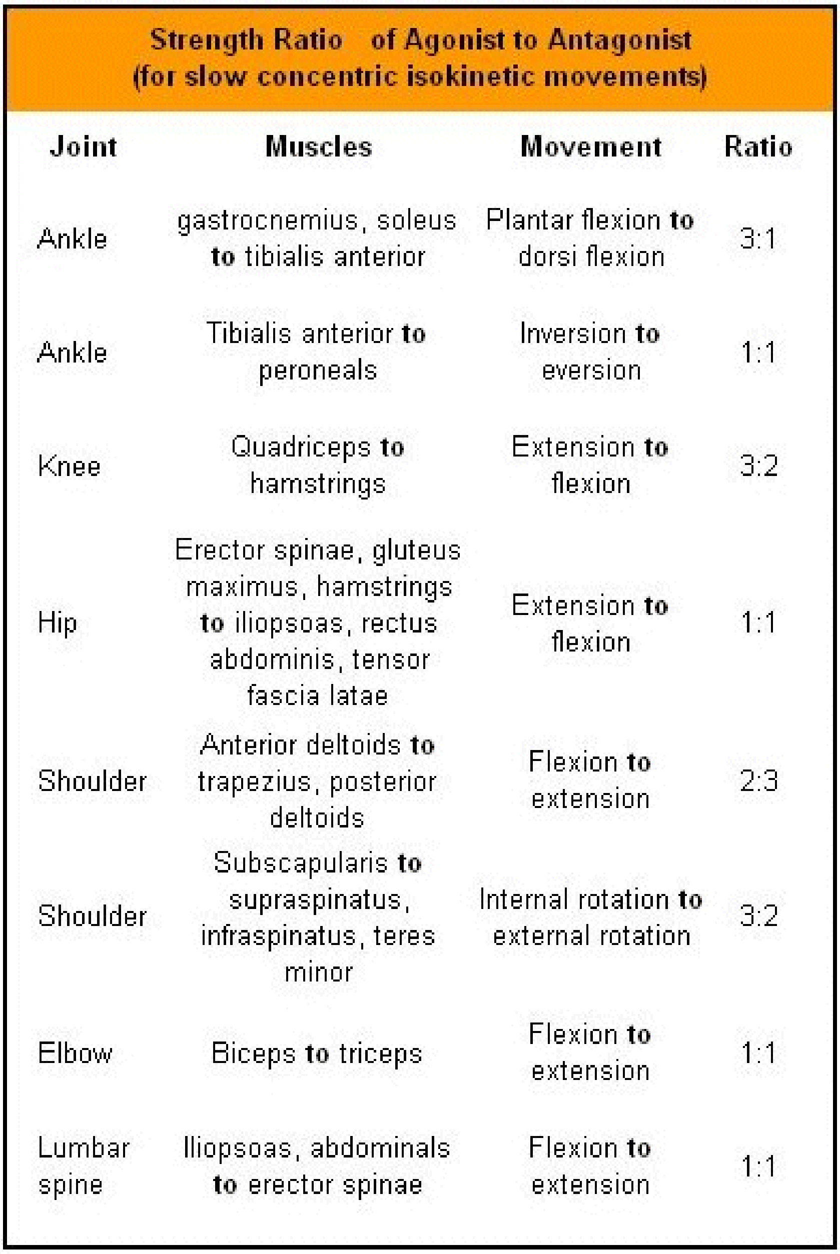
	1-RM Bench press		**1-RM Back Squat**	
	lb	**kg**	**lb**	**kg**
College football players (NCAA Div I)	385	175	531	241
Offensive linemen	377	171	502	228
Defensive linemen	358	163	476	216
Offensive backs	335	152	471	214
Tight ends	333	151	464	211
Defensive backs	307	140	415	189
Wide receivers	280	127	390	177
Quaterbacks	277	126	379	172
College baseball players (men)	233	106	308	140
College basketball players (men)	225	102	302	137
College track (men)	207	94	233	106
College track (women)	103	47	150	68
College basketball players (women)	113	51	182	83

Data from (1,2,3,4)

Alternative Strength Tests

Maximal strength tests do not have to consist of single lifts. A 10-repetition maximum may be more applicable and can be safer for weaker muscle groups such as the hamstrings.

Both sides of the body can be tested independently to compare muscular balance. For example a leg extension can be completed unilaterally for both the right and left quadriceps. The same principle can applied to compare agonists and antagonists - i.e. completing a leg extension and leg curl test and comparing the strength ration. The table below gives a guideline for strength ratios between opposing muscle groups:



Strength Ratio of Agonist to Antagonist
(for slow concentric isokinetic movements)

Joint	Muscles	Movement	Ratio
Ankle	gastrocnemius, soleus to tibialis anterior	Plantar flexion to dorsi flexion	3:1
Ankle	Tibialis anterior to peroneals	Inversion to eversion	1:1
Knee	Quadriceps to hamstrings	Extension to flexion	3:2
Hip	Erector spinae, gluteus maximus, hamstrings to iliopsoas, rectus abdominis, tensor fascia latae	Extension to flexion	1:1
Shoulder	Anterior deltoids to trapezius, posterior deltoids	Flexion to extension	2:3
Shoulder	Subscapularis to supraspinatus, infraspinatus, teres minor	Internal rotation to external rotation	3:2
Elbow	Biceps to triceps	Flexion to extension	1:1
Lumbar spine	Iliopsoas, abdominals to erector spinae	Flexion to extension	1:1

Data from (2)

Strength Endurance Assessment

The following two strength tests measure muscular endurance. The standard exercises used are push ups and sit ups. Again, these can be adapted. Seated rows may be more applicable for a rower for example.

The score is simply determined by the number of repetitions completed in one minute.

For a sit up to qualify you must place you hands to the side of you head, bend your knees and keep your feet flat on the floor. Your elbows must touch your knees and someone should hold your feet for support.

Results

Check your score with the table below:

Push Up & Sit Up Scores					
Sit Ups	Poor	Fair	Good	Very good	Excellent
Men	20	30	40	50	60
Women	20	30	40	50	60
Push Ups	Poor	Fair	Good	Very good	Excellent
Men	10	20	30	40	50
Women	10	20	30	40	50

*The scores for women's push ups are based on the modified push up - i.e. placing your weight on you knees instead of your toes.

23

Muscular Endurance Training

The combination of strength and endurance results in muscular endurance - the ability to perform many repetitions against a given resistance for a prolonged period of time .

It is a crucial element of fitness for athletes such as distance runners, swimmers, cyclists and rowers. It's also important for success in many team sports like soccer, field hockey and Australian rules football.

Traditionally, muscular endurance programs have used moderate loads lifted for 12-25 repetitions. However, this is completely inadequate for many sports such as boxing, canoeing, distance running, cycling, swimming, rowing, x-country skiing, triathlon and many others.

Any form of training must mirror the specific demands of the sport. In resistance training, this means that the load used should match the resistance that must be overcome while competing. The number of repetitions or the duration of exercise bouts in a session should approach that during the event.

Recall that muscular endurance training makes up only one part of the annual strength program - even for endurance athletes. It should follow a phase of maximal strength training. This makes sense because the greater an athlete's maximal strength, the greater their potential for strength endurance - i.e. the more force they will be able to apply over a prolonged period. Heavy strength training has also been shown to improve exercise economy in endurance athletes . For more information on the the annual strength program see the the sport specific approach to strength training programs.

The Different Types of Muscular Endurance

Different sports require different levels of muscular endurance. While each program will vary according to the athlete's needs, muscular endurance can be split into 3 groups:

Power Endurance

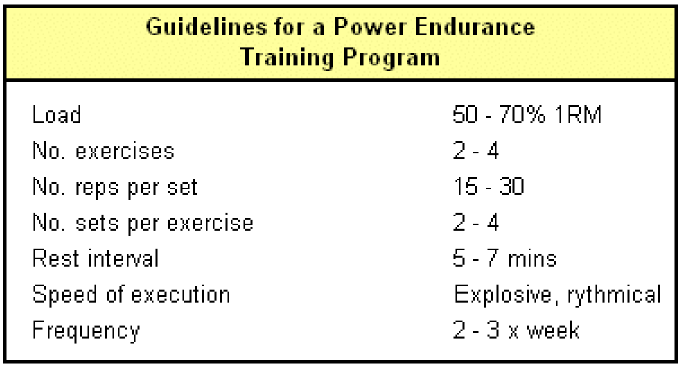
Athletes like baseball pitchers, sprinters, 50-m freestyle swimmers, martial artists, wrestlers, fencers, tennis players and so on must produce powerful movements and repeat them several times with little or no rest. In order to maintain the same amount of power with each effort, a certain level of power endurance is required.

Power endurance is typically characterized by intense, repeated efforts for a relatively short period of time (less than 30 seconds). A tennis player for example, has to produce several powerful shots in quick succession during a rally that may only last 10 seconds. A 100-m sprinter may take 48-54 powerful strides over a 10-12 second race and their success depends, in part, on maintaining a high power output in the last 20 meters.

Once maximal strength has been developed (earlier on in the annual strength program) it can be converted into explosive power through various methods of power training. Now power endurance training can be used to train the fast twitch fibres to resist fatgiue allowing explosive power to be maintained for longer.

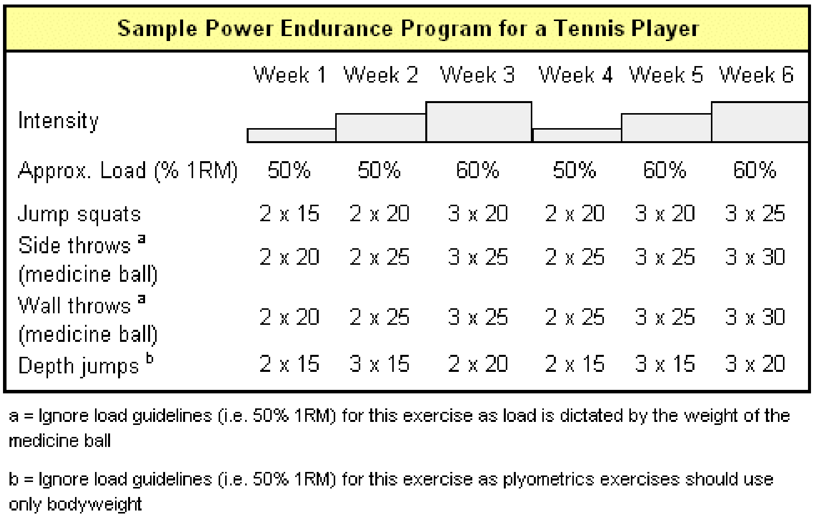
Power endurance training uses moderate loads of 50-70% 1RM lifted for 15 to 30 repetitions. Because this can lead to a significant build up of lactic acid, rest periods between sets are long (5-7 minutes) and a minimum number of sport-specific exercises are used (about 3-4). Exercises are also completed in a circuit training format i.e. one set of one exercise is completed, then one set of the next exercise and so on. Alternating exercises allows maximum recovery and sufficient time for lactic acid to disperse.

This is a critical rule to follow. If rest intervals are too short and sets are completed while the athlete is fatigued the result will be hypertrophy (increase muscle mass) rather than power endurance. Sets should not be completed to failure but should end when repetitions are no longer powerful and rhythmic.



Guidelines for a Power Endurance Training Program	
Load	50 - 70% 1RM
No. exercises	2 - 4
No. reps per set	15 - 30
No. sets per exercise	2 - 4
Rest interval	5 - 7 mins
Speed of execution	Explosive, rythmical
Frequency	2 - 3 x week

Here is a sample power endurance program for a tennis player:



Sample Power Endurance Program for a Tennis Player

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Intensity						
Approx. Load (% 1RM)	50%	50%	60%	50%	60%	60%
Jump squats	2 x 15	2 x 20	3 x 20	2 x 20	3 x 20	3 x 25
Side throws [a] (medicine ball)	2 x 20	2 x 25	3 x 25	2 x 25	3 x 25	3 x 30
Wall throws [a] (medicine ball)	2 x 20	2 x 25	3 x 25	2 x 25	3 x 25	3 x 30
Depth jumps [b]	2 x 15	3 x 15	2 x 20	2 x 15	3 x 15	3 x 20

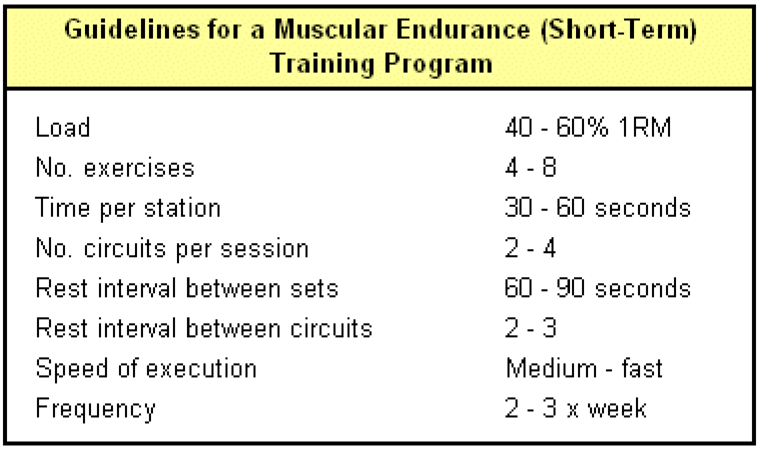
a = Ignore load guidelines (i.e. 50% 1RM) for this exercise as load is dictated by the weight of the medicine ball

b = Ignore load guidelines (i.e. 50% 1RM) for this exercise as plyometrics exercises should use only bodyweight

Muscular Endurance - Short Term

When sports and events consist predominantly of bouts of exercise lasting between 30 seconds and 2 minutes, "short-term" muscular endurance training is advantageous. These could be continuous events such as the 800-m or multi-sprint sports such as soccer.

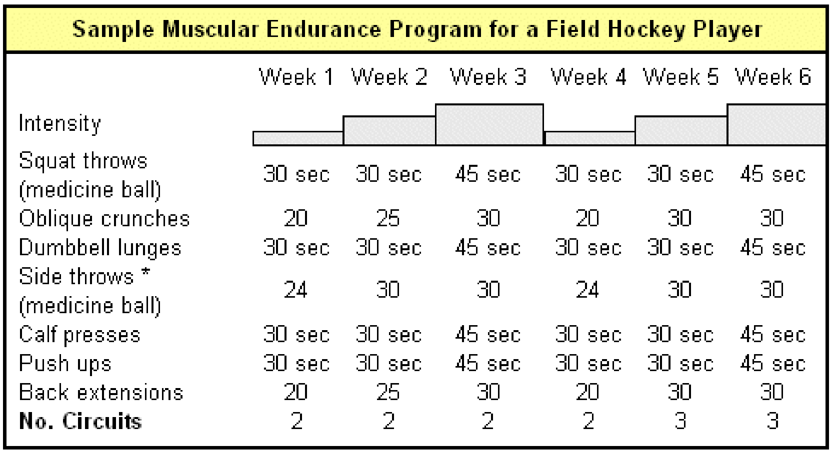
Muscular endurance training helps athletes to cope with fatigue and tolerate high levels of lactic acid. It uses relatively light loads of 40-60% 1RM and they can be lifted for a set period of time or a target number of repetitions. Again, a circuit training set up is suitable for this type of resistance training.



Guidelines for a Muscular Endurance (Short-Term) Training Program

Load	40 - 60% 1RM
No. exercises	4 - 8
Time per station	30 - 60 seconds
No. circuits per session	2 - 4
Rest interval between sets	60 - 90 seconds
Rest interval between circuits	2 - 3
Speed of execution	Medium - fast
Frequency	2 - 3 x week

Below is a sample muscular endurance program for a field hockey player:



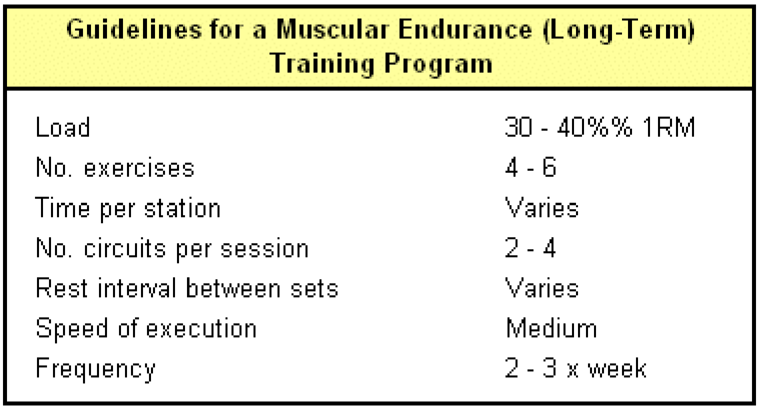
Sample Muscular Endurance Program for a Field Hockey Player

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Intensity						
Squat throws (medicine ball)	30 sec	30 sec	45 sec	30 sec	30 sec	45 sec
Oblique crunches	20	25	30	20	30	30
Dumbbell lunges	30 sec	30 sec	45 sec	30 sec	30 sec	45 sec
Side throws * (medicine ball)	24	30	30	24	30	30
Calf presses	30 sec	30 sec	45 sec	30 sec	30 sec	45 sec
Push ups	30 sec	30 sec	45 sec	30 sec	30 sec	45 sec
Back extensions	20	25	30	20	30	30
No. Circuits	2	2	2	2	3	3

* = The number of repetitions for side throws total number for both sides. Throws should be alternated from side to side i.e. right then left

Muscular Endurance - Long Term

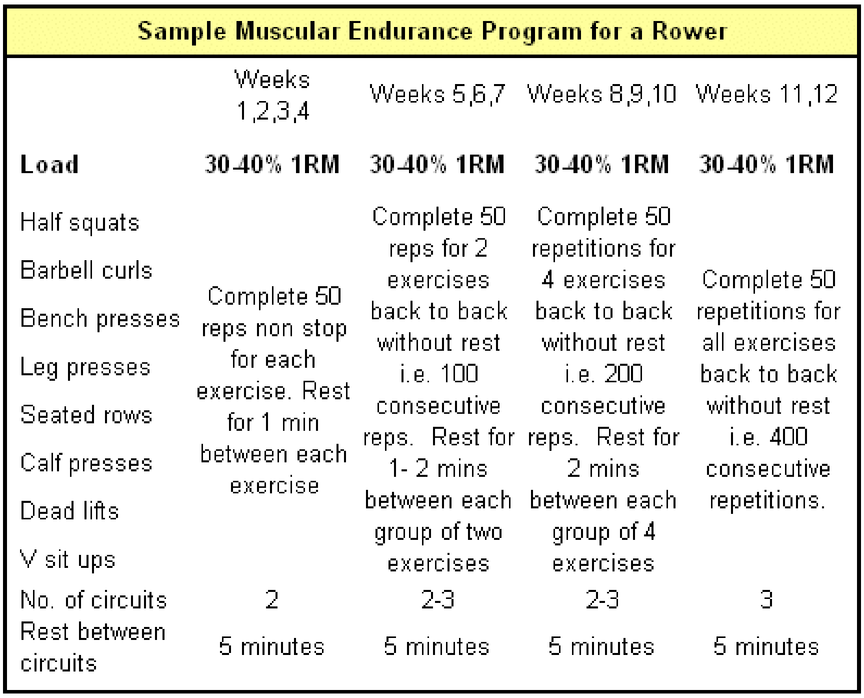
"Long term" muscular endurance is suitable for continuous, steady-state events such as the marathon, triathlon and rowing that last beyond 2 minutes. Light loads are used so that exercises can be sustained for a prolonged period. Rest periods are kept to a minimum and ideally the athlete should progress so that the only rest between exercises is the time it takes to move between equipment.



Guidelines for a Muscular Endurance (Long-Term) Training Program

Load	30 - 40%% 1RM
No. exercises	4 - 6
Time per station	Varies
No. circuits per session	2 - 4
Rest interval between sets	Varies
Speed of execution	Medium
Frequency	2 - 3 x week

The program below is designed for a rower and gradually progresses until the athlete performs all the exercises non-stop. By the final week the athlete would be completing 6-8 minutes of continuous work per circuit - a similar duration to a competitive race!



Sample Muscular Endurance Program for a Rower

	Weeks 1,2,3,4	Weeks 5,6,7	Weeks 8,9,10	Weeks 11,12
Load	**30-40% 1RM**	**30-40% 1RM**	**30-40% 1RM**	**30-40% 1RM**
Half squats	Complete 50 reps non stop for each exercise. Rest for 1 min between each exercise	Complete 50 reps for 2 exercises back to back without rest i.e. 100 consecutive reps. Rest for 1- 2 mins between each group of two exercises	Complete 50 repetitions for 4 exercises back to back without rest i.e. 200 consecutive reps. Rest for 2 mins between each group of 4 exercises	Complete 50 repetitions for all exercises back to back without rest i.e. 400 consecutive repetitions.
Barbell curls				
Bench presses				
Leg presses				
Seated rows				
Calf presses				
Dead lifts				
V sit ups				
No. of circuits	2	2-3	2-3	3
Rest between circuits	5 minutes	5 minutes	5 minutes	5 minutes

24

Weight Training Programs For Building Maximum Strength

These sample weight training programs are designed to develop maximal strength. Training for maximal strength is not the same as training for increased muscle size known as hypertrophy training.

Only relatively few athletes require significant muscle mass and bulk whereas maximal strength is an important fitness component even for classic endurance-type sports. The sport specific approach to strength training article outlines how various types of weight training programs fit together into an overall training plan.

The main objective of maximal strength training is to increase the highest level of force an athlete can generate. Most sports require either explosive power (i.e. sprinting, football, athletic field events) or muscular endurance (i.e. distance running, cycling, rowing) or a combination of the two (i.e. team sports). Explosive power is a combination of strength and speed. Muscular endurance is a combination of strength and endurance. It makes sense then that the greater an athlete's maximal strength is, the greater the potential for either of these fitness components.

Maximal Strength Training Over Bodybuilding

Maximal strength weight training programs are the only form of training that activates a large number of fast twitch motor units and improves muscle synchronization between the agonists and antagonists - so antagonists don't oppose the movement .

These neuromuscular adaptations plus increases in maximal strength can occur with little or no increase in muscle hypertrophy. This is important for most sports as a high strength to body mass ratio is beneficial . Although very large bodybuilders have exceptional muscle mass, their strength is not proportional to their size. Maximal strength training can result in strength gains that are up to 3x greater than the proportional gains in muscular hypertrophy.

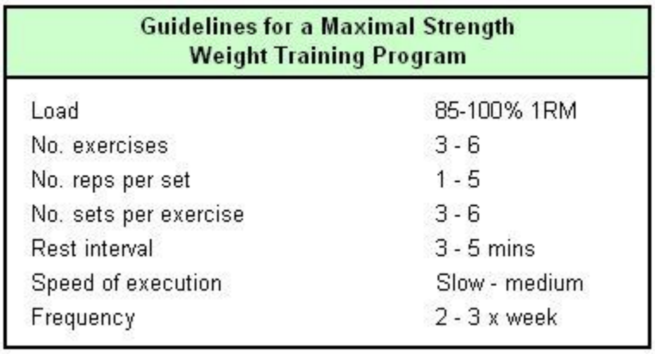
Hypertrophy is thought to result from a disturbance in the equilibrium between consumption and remanufacture of ATP. This is known as ATP deficiency theory. Maximal strength training, with its very high loads, permits only a small number of repetitions to be performed, and coupled with longer rest intervals this prevents ATP deficiency and significant hypertrophy occurring.

Designing Maximal Strength Weight Training Programs

In order to develop maximal strength, relatively heavy loads must be used - greater than 85% one repetition maximum (1RM). This permits only a small number of repetitions, between 1 and 5, per set. Maximal effort is required on each lift and as such this type of training is very taxing. Long rest intervals to allow recovery are required between sets and only a small number of exercises should make up the sessions .

To further aid recovery and allow maximal effort to be performed a vertical session design is preferable to a horizontal session design. In other words, one set of each exercise should be performed in sequence and repeated rather than completing all the sets for one exercise before moving on to the next .

Even though the bar will move slowly during maximal lifts, the athlete must focus on lifting as explosively as possible in order to recruit the highest number of fast twitch motor units as quickly as possible .

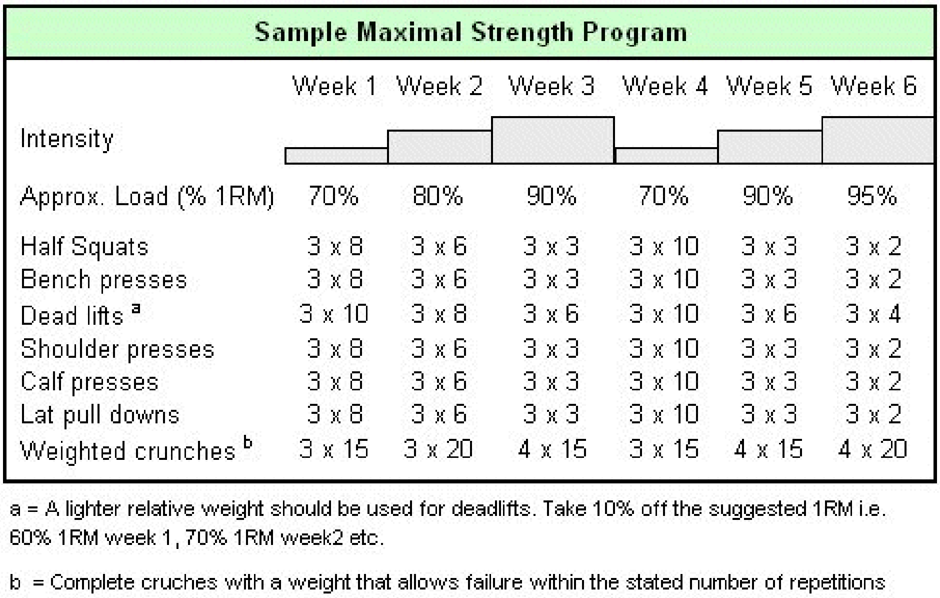


Guidelines for a Maximal Strength Weight Training Program	
Load	85-100% 1RM
No. exercises	3 - 6
No. reps per set	1 - 5
No. sets per exercise	3 - 6
Rest interval	3 - 5 mins
Speed of execution	Slow - medium
Frequency	2 - 3 x week

Weight training programs designed for maximal strength development should follow a suitable period of basic strength training. Two to three sessions per week is suitable for the pre-season phase and this is often reduced to one or two maintenance sessions during the in-season.

Sample Maximal Strength Weight Training Program

While weight training programs for maximal srength are not as sport-specific as later phases of training, they should still consist of exercises that work the prime movers in the sport or event. The following program is not specific to any sport in particular and works all the major muscle groups in the body. A volleyball player may want to omit bench presses while a badminton player could add barbell lunges for example.



Sample Maximal Strength Program

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Intensity						
Approx. Load (% 1RM)	70%	80%	90%	70%	90%	95%
Half Squats	3 x 8	3 x 6	3 x 3	3 x 10	3 x 3	3 x 2
Bench presses	3 x 8	3 x 6	3 x 3	3 x 10	3 x 3	3 x 2
Dead lifts [a]	3 x 10	3 x 8	3 x 6	3 x 10	3 x 6	3 x 4
Shoulder presses	3 x 8	3 x 6	3 x 3	3 x 10	3 x 3	3 x 2
Calf presses	3 x 8	3 x 6	3 x 3	3 x 10	3 x 3	3 x 2
Lat pull downs	3 x 8	3 x 6	3 x 3	3 x 10	3 x 3	3 x 2
Weighted crunches [b]	3 x 15	3 x 20	4 x 15	3 x 15	4 x 15	4 x 20

a = A lighter relative weight should be used for deadlifts. Take 10% off the suggested 1RM i.e. 60% 1RM week 1, 70% 1RM week2 etc.

b = Complete cruches with a weight that allows failure within the stated number of repetitions

Notice how even though the target load is +85% 1RM this is only achieved in 3 out of the 6 weeks. This stair-stepping approach of gradually increasing the load and then scheduling in a recovery week helps to prevent over-training and allows the athlete to reach a greater peak in performance.

25

Weight Training Programs For Increasing Muscle Mass

These sample weight training programs are designed to develop increased muscle mass and lean weight.

The enlargement of muscle size is known as hypertrophy and is the predominant aim of bodybuilding.

While bodybuilding may still dominate many sport-specific strength training programs, in reality it is only suitable for a small number of athletes and should only make up a portion of the overall conditioning program. See the sport specific approach to strength training article to see how these sample hypertrophy weight training programs are incorporated into the annual plan.

Athletes that can benefit from a phase of hypertrophy training include shot putters, rugby players, heavyweight wrestlers and linemen in football. For these individuals, an increase in active fat-free mass is beneficial. Other athletes such as boxers and wrestlers may want to move up a weight class and can use a bodybuilding approach to do so.

Traditional bodybuilding aims to increase the size of every muscle group making it a time consuming and enervating pursuit. Hypertrophy training for sport on the other hand aims only to increase the size of the prime movers, saving time and energy for other modes of training.

Whilst these hypertrophy weight training programs increase muscle and mass, they do not result in the nervous system adaptations that occur with maximal strength training - such as increased recruitment of fast twitch fibers and better synchronization of the muscles involved in the action .

To this end, a phase of hypertrophy training should be followed by a phase of maximal strength training before finally being converted into sport-specific power or muscular endurance. The table below is an example of how this may occur for a collegiate-level football lineman:

Annual Strength Program for a Football Linemen (Collegiate)

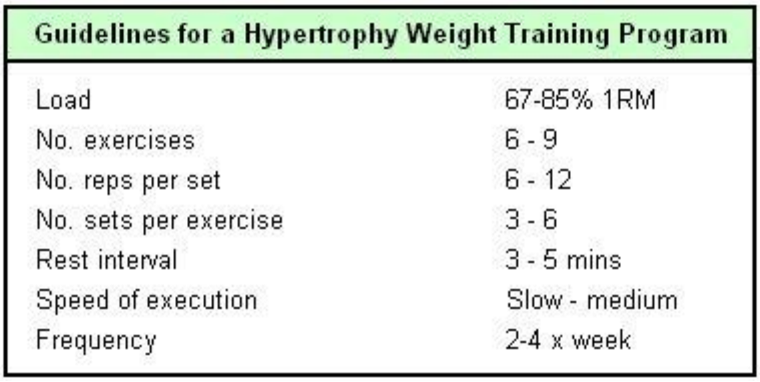
Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Pre-season					Competition					Transition	
BS	HYP	MXS		PW	Maintain MXS & PW					Recovery	

BS = Basic strength training, HYP = Hypertrophy training, MXS = Maximal strength training, PW = Power training

Designing Hypertrophy Weight Training Programs

Hypertrophy training employs moderate to heavy loads and moderate to high volume. It is generally accepted that higher volume is required to sufficiently overload the muscles to bring about substantial increases in fibre size. However, as mentioned earlier the athlete's overall training program must be taken into account - so a smaller number of exercises is used compared to traditional bodybuilding. Each session should consist of no more than 6 - 9 exercises focusing on the prime movers for 3-6 sets per exercise .

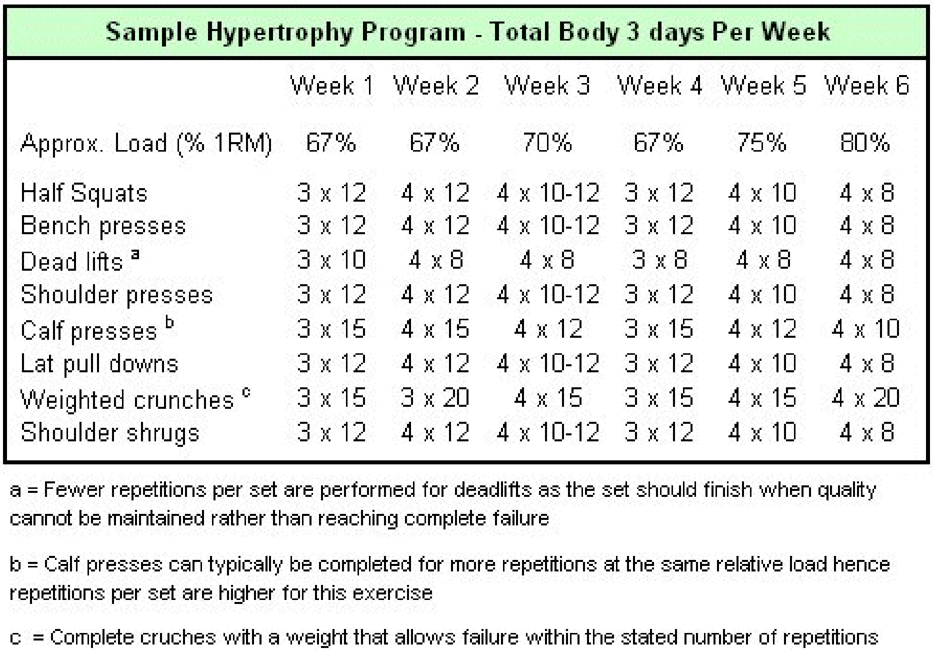
Loads should be in the 67% - 85% one repetition maximum (1RM) range so that failure in each set occurs between 6 - 12 repetitions . Sets must be performed to failure. The cumulative effect of exhaustion stimulates chemical reactions and protein metabolism so that optimal muscle growth can occur. Loads heavier than 85% 1RM, allowing less than 6 repetitions to be performed, develops maximal strength and not necessarily increased muscle mass.



Guidelines for a Hypertrophy Weight Training Program	
Load	67-85% 1RM
No. exercises	6 - 9
No. reps per set	6 - 12
No. sets per exercise	3 - 6
Rest interval	3 - 5 mins
Speed of execution	Slow - medium
Frequency	2-4 x week

Sample Hypertrophy Weight Training Programs

Hypertrophy weight training programs can follow several formats. One popular format is the total body routine where each session consists of exercises to target all the major muscle groups in the body. This would be performed 2-3 days per week with at least 24 hours rest between sessions:



Sample Hypertrophy Program - Total Body 3 days Per Week

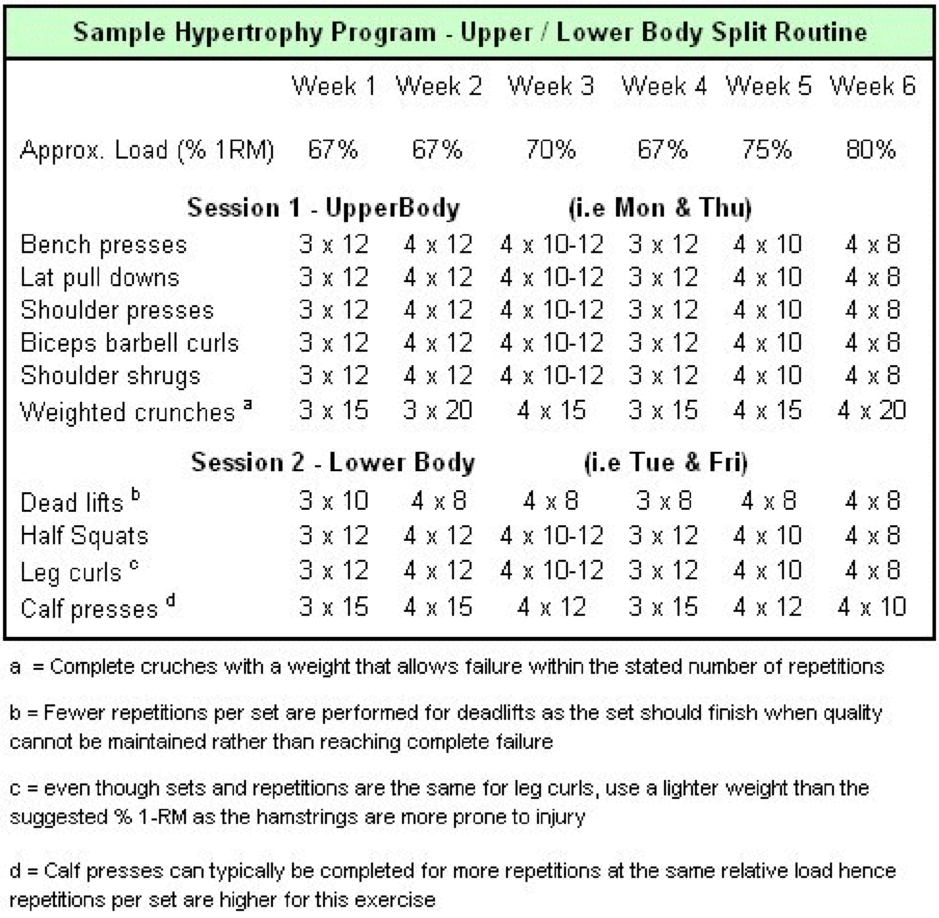
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Approx. Load (% 1RM)	67%	67%	70%	67%	75%	80%
Half Squats	3 x 12	4 x 12	4 x 10-12	3 x 12	4 x 10	4 x 8
Bench presses	3 x 12	4 x 12	4 x 10-12	3 x 12	4 x 10	4 x 8
Dead lifts [a]	3 x 10	4 x 8	4 x 8	3 x 8	4 x 8	4 x 8
Shoulder presses	3 x 12	4 x 12	4 x 10-12	3 x 12	4 x 10	4 x 8
Calf presses [b]	3 x 15	4 x 15	4 x 12	3 x 15	4 x 12	4 x 10
Lat pull downs	3 x 12	4 x 12	4 x 10-12	3 x 12	4 x 10	4 x 8
Weighted crunches [c]	3 x 15	3 x 20	4 x 15	3 x 15	4 x 15	4 x 20
Shoulder shrugs	3 x 12	4 x 12	4 x 10-12	3 x 12	4 x 10	4 x 8

a = Fewer repetitions per set are performed for deadlifts as the set should finish when quality cannot be maintained rather than reaching complete failure

b = Calf presses can typically be completed for more repetitions at the same relative load hence repetitions per set are higher for this exercise

c = Complete cruches with a weight that allows failure within the stated number of repetitions

A second format perhaps more suitable for advanced lifters is a split routine in which different muscle groups are trained on different days. The simplest split routine is upper body / lower body which could be performed 4 days per week. Upper and lower body sessions can also be performed on consecutive days:



Sample Hypertrophy Program - Upper / Lower Body Split Routine

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Approx. Load (% 1RM)	67%	67%	70%	67%	75%	80%
Session 1 - UpperBody			**(i.e Mon & Thu)**			
Bench presses	3 x 12	4 x 12	4 x 10-12	3 x 12	4 x 10	4 x 8
Lat pull downs	3 x 12	4 x 12	4 x 10-12	3 x 12	4 x 10	4 x 8
Shoulder presses	3 x 12	4 x 12	4 x 10-12	3 x 12	4 x 10	4 x 8
Biceps barbell curls	3 x 12	4 x 12	4 x 10-12	3 x 12	4 x 10	4 x 8
Shoulder shrugs	3 x 12	4 x 12	4 x 10-12	3 x 12	4 x 10	4 x 8
Weighted crunches [a]	3 x 15	3 x 20	4 x 15	3 x 15	4 x 15	4 x 20
Session 2 - Lower Body			**(i.e Tue & Fri)**			
Dead lifts [b]	3 x 10	4 x 8	4 x 8	3 x 8	4 x 8	4 x 8
Half Squats	3 x 12	4 x 12	4 x 10-12	3 x 12	4 x 10	4 x 8
Leg curls [c]	3 x 12	4 x 12	4 x 10-12	3 x 12	4 x 10	4 x 8
Calf presses [d]	3 x 15	4 x 15	4 x 12	3 x 15	4 x 12	4 x 10

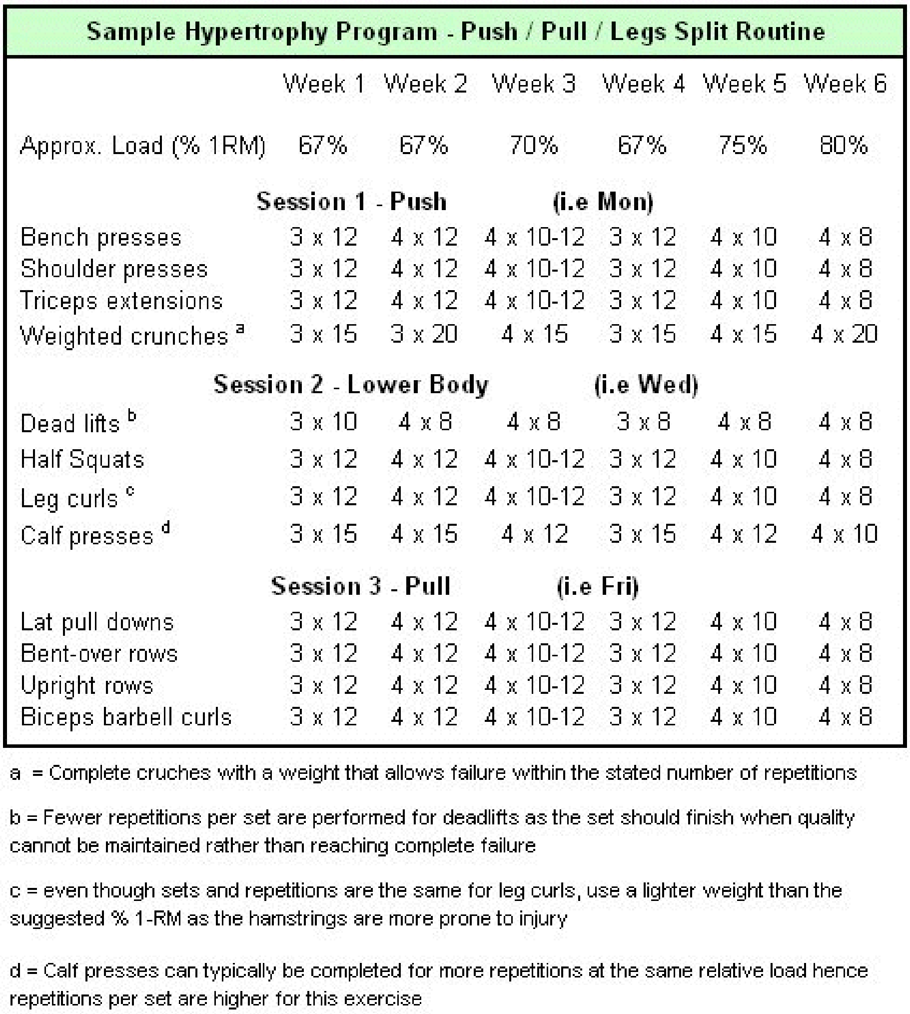
a = Complete cruches with a weight that allows failure within the stated number of repetitions

b = Fewer repetitions per set are performed for deadlifts as the set should finish when quality cannot be maintained rather than reaching complete failure

c = even though sets and repetitions are the same for leg curls, use a lighter weight than the suggested % 1-RM as the hamstrings are more prone to injury

d = Calf presses can typically be completed for more repetitions at the same relative load hence repetitions per set are higher for this exercise

A similar split routine that works well is the push / pull format. Pushing exercises such as chest, shoulder and triceps lifts are performed one day and pulling exercises such as back, trapezius and bicpes lifts on another. A third day is reserved for lower body:



Sample Hypertrophy Program - Push / Pull / Legs Split Routine

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Approx. Load (% 1RM)	67%	67%	70%	67%	75%	80%
Session 1 - Push			**(i.e Mon)**			
Bench presses	3 x 12	4 x 12	4 x 10-12	3 x 12	4 x 10	4 x 8
Shoulder presses	3 x 12	4 x 12	4 x 10-12	3 x 12	4 x 10	4 x 8
Triceps extensions	3 x 12	4 x 12	4 x 10-12	3 x 12	4 x 10	4 x 8
Weighted crunches [a]	3 x 15	3 x 20	4 x 15	3 x 15	4 x 15	4 x 20
Session 2 - Lower Body				**(i.e Wed)**		
Dead lifts [b]	3 x 10	4 x 8	4 x 8	3 x 8	4 x 8	4 x 8
Half Squats	3 x 12	4 x 12	4 x 10-12	3 x 12	4 x 10	4 x 8
Leg curls [c]	3 x 12	4 x 12	4 x 10-12	3 x 12	4 x 10	4 x 8
Calf presses [d]	3 x 15	4 x 15	4 x 12	3 x 15	4 x 12	4 x 10
Session 3 - Pull			**(i.e Fri)**			
Lat pull downs	3 x 12	4 x 12	4 x 10-12	3 x 12	4 x 10	4 x 8
Bent-over rows	3 x 12	4 x 12	4 x 10-12	3 x 12	4 x 10	4 x 8
Upright rows	3 x 12	4 x 12	4 x 10-12	3 x 12	4 x 10	4 x 8
Biceps barbell curls	3 x 12	4 x 12	4 x 10-12	3 x 12	4 x 10	4 x 8

a = Complete cruches with a weight that allows failure within the stated number of repetitions

b = Fewer repetitions per set are performed for deadlifts as the set should finish when quality cannot be maintained rather than reaching complete failure

c = even though sets and repetitions are the same for leg curls, use a lighter weight than the suggested % 1-RM as the hamstrings are more prone to injury

d = Calf presses can typically be completed for more repetitions at the same relative load hence repetitions per set are higher for this exercise

Which of these weight training programs is most preferable? The total body routine is usually preferred for beginners, while more advanced athletes, lifting weights at the upper end of the intensity and volume recommendations, favor one of the split routines.

A phase of hypertrophy training typically lasts 4-8 weeks. However, for exceptionally long pre-seasons and where hypertrophy is particularly important (such as in football linemen), phases of hypertrophy training can be alternated with phases of maximal strength training.

26

The Sport Specific Approach to Strength Training Programs

Sport-specific strength training programs are fundamental to an athlete's development and success. Long gone are the days when coaches shunned weight lifting for fear that it might hinder the performance of fine skill and correct technique. It's now accepted that high levels of strength are a prerequisite to superior speed, power, strength endurance and overall sporting performance.

Unfortunately, most strength training programs fall well short of what an athlete requires…

Bodybuilding and Olympic weightlifting programs still dominate many athletes' training regimes. While these types of training have their place, strength training for sport consists of a more refined approach than simply lifting heavy weights as many times as possible.

This article outlines the concept and the benefits of a periodized strength training plan. This is the most effective approach to strength training for sport. Not only does it help in the prevention of over training, it gives the athlete the best chance of peaking physically at the right time.

Exercise Selection

The principle of specificity states that training should mirror the demands of the sport as closely as possible. This applies not only to way the body's energy systems and neuromuscular system is taxed (through manipulation of intensity and rest intervals etc) but also to the movement patterns of each exercise.

Bodybuilders tend to isolate a muscle group and work it to exhaustion. Athletes on the other hand should train movements rather than muscles. A simple example is the vertical jump. The muscles involved in this action (calves, quadriceps, hamstrings, gluteals etc.) could be trained separately with exercise choices such as toe raises, leg extensions, leg curls, kickbacks and so on. A more appropriate exercise however is a barbell squat, which closely matches the movement pattern of the vertical jump. Taken a step further, jump squats are even more specific to jumping and it’s not surprising that they increase vertical jump performance to the greatest extent.

Athletes must divide their time and energy amongst various types of training – endurance, strength and power, speed and agility, tactical etc., and find the time to recover! By choosing only the most appropriate resistance exercises volume can be kept to a minimum saving energy for other types of training.

This has led many coaches to incorporate Olympic weight lifting into their strength training programs, almost without question. The rationale is that just a few Olympic lifts will build all-round strength and power. Whilst exercise such as power cleans can be beneficial to some athletes, for many there are more specific and more appropriate options .

Many of the sample strength training programs within this section of the website consist of relatively few exercises. This is deliberate and while it may seem unbalanced at first glance, it takes into account other training the athlete is expected to complete.

Different Types of Strength Training

Unlike bodybuilding, where the only aim is to increase the size and appearance of muscles, strength training programs for sport ultimately must develop either explosive power or muscular endurance . However, rather than immediately embarking on a program to improve either or both of these fitness components, a more effective approach is to first build a solid foundation…

Basic Strength

Basic strength training programs adapt the body for more strenuous resistance training later on. It’s objective is to prepare the body by targeting all of the major muscle groups, tendons, ligaments and joints helping to prevent injury.

The less experienced an athlete is, the more time they will need to spend developing foundational strength before progressing onto more advanced forms of resistance training. But even experienced athletes should set aside some time during the year to complete a phase of basic strength training. It can help to redress some of the muscle imbalances that inherently occur with competitive sport.

Hypertrophy

Some athletes will benefit from increasing their lean body mass by adding extra muscle bulk. However, the number of athletes that require hypertrophy training or a phase of bodybuilding is far fewer than most would expect. Larger muscles are not necessarily stronger and more weight – even lean, active weight – can be a hindrance in many sports.

Maximal Strength

Bodybuilders have exceptional muscle mass but they are typically bigger than they are strong. Maximal strength training programs do not necessarily increase the size of a muscle (hypertrophy) but they do lead to neuromuscular adaptations that are favourable to most athletes. Even endurance athletes can benefit from maximal strength training .

Explosive Power

Just as an athlete can be extremely muscular and lack an associated level of strength, they can also be exceptionally strong but lack significant power. Most athletic movements occur much more rapidly and demand significantly more power than lifting maximal loads. If maximal strength is not converted into sport-specific power, athletic performance will not improve – certainly not to the extent that it could.

Muscular Endurance

While many sports are dominated by powerful, explosive actions some athletes are required to overcome a relatively low resistance but for a prolonged period of time. Just as power athletes should convert maximal strength into explosive power, endurance athletes should aim to convert maximal strength into muscular endurance.

Of course, many team sports require a combination of the two – power and strength endurance – and developing both simultaneously without one negating the other requires careful consideration.

The Periodization of Strength

To promote long term training improvements and avoid over training, an overall training program can be split into specific periods, each with their own objectives and set of training parameters. This concept is called periodization and it is the most effective approach to planning strength training programs for sport.

The overall training program (usually taken as one year long) can be split into set periods and usually consist of the:

- Preparation Period (Pre-season)
- Competition Period (In-season)
- Transition Period (Off / closed-season)

By co-ordinating the different elements of a strength training program with the phases of a typical season, the athlete can reach a peak for the start of the competitive season and most important parts of year.

Just as an overall season is split into distinct periods or phases so is the development of sport-specific strength. As mentioned earlier, it makes sense to develop certain types of strength before others. Here are the phases, in order, of an overall strength training program (which also lasts a year) and how they should coincide with phases of a typical season above:

Phase 1 – Basic Strength

Training for many sports can have an unbalancing effect on the body’s musculoskeletal system. One side of the body may become stronger than the other, agonists may be overly strong compared to antagonists and smaller muscle groups are often neglected. Left unchecked these imbalances can compound and may lead to chronic and acute injury.

A period of basic strength training should occur at the start of the preparation period (early pre-season). For less experienced athletes it may be necessary to start during the transition period (closed season).

Phase 2 – Maximum Strength / Hypertrophy

Most athletes benefit from a period of maximal strength training. The length of this phase will vary depending on the sport. Strength and power athletes will spend more time in this phase compared to endurance athletes for example. If a period of hypertrophy training is required (i.e. football or rugby players) it usually occurs before maximal strength training .

Hypertrophy and maximal strength training programs usually occur midway through the preparation phase (pre-season).

Phase 3 – Conversion

Until this point strength training has been generic in nature. To be effective however, this general base of strength must converted into sport-specific power or muscular endurance or both. The conversion of maximal strength occurs late in the preparation phase and may continue into the start of the competitive season.

Phase 4 – Maintenance

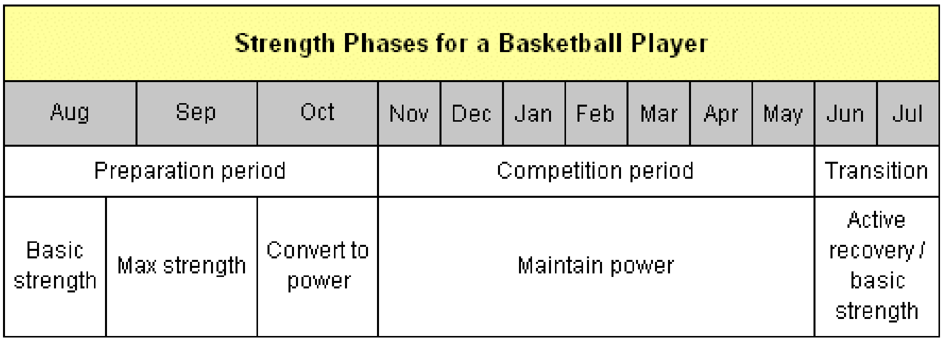
When strength training stops the benefits gained previously quickly diminish. In order to avoid this detraining effect a certain level of conditioning is required to maintain the gains made in the preparation phase.

Fortunately, the volume required to maintain strength is less than that required to build it. But with the onset of competitive matches and events, plus a greater emphasis on tactical and skill-based training, less time is available for strength conditioning and sufficient recovery. The maintenance phase occurs throughout the competitive season.

Phase 5 – Active Recovery

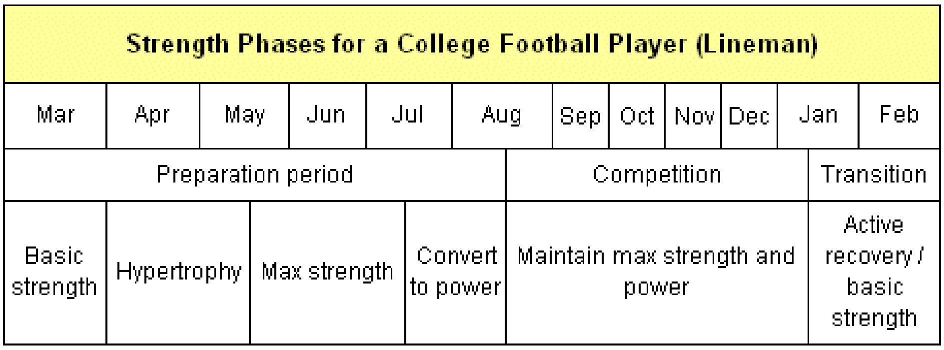
Following a strenuous season, a break from structured training and the rigours of competition is crucial for physical and mental respite. This can mean a complete break from all types of strength training programs for several weeks. Any longer than 3-4 weeks however, and fitness, particularly strength and power, diminishes rapidly. The active recovery phase occurs in the transition period (off / closed season).

Here are two sport-specific examples of how the various phases of strength training may occur in an annual plan:



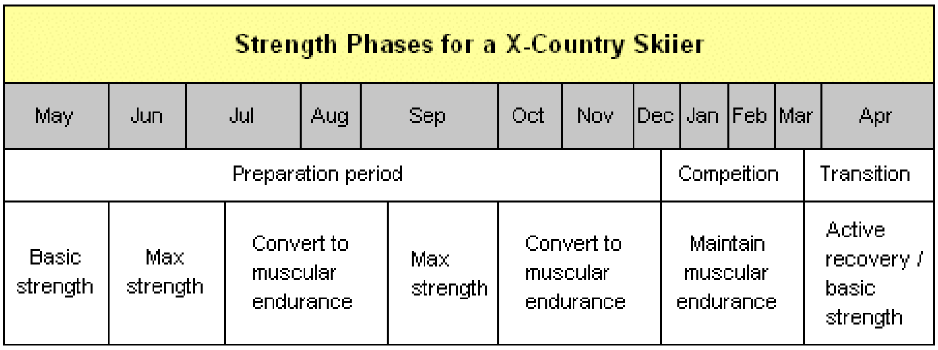
Strength Phases for a Basketball Player

Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
Preparation period			Competition period							Transition	
Basic strength	Max strength	Convert to power	Maintain power							Active recovery / basic strength	



Strength Phases for a College Football Player (Lineman)

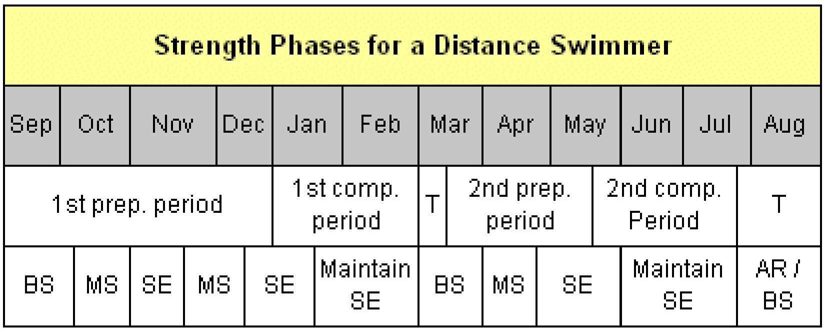
Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Preparation period					Competition					Transition	
Basic strength	Hypertrophy	Max strength		Convert to power	Maintain max strength and power					Active recovery / basic strength	



Strength Phases for a X-Country Skiier

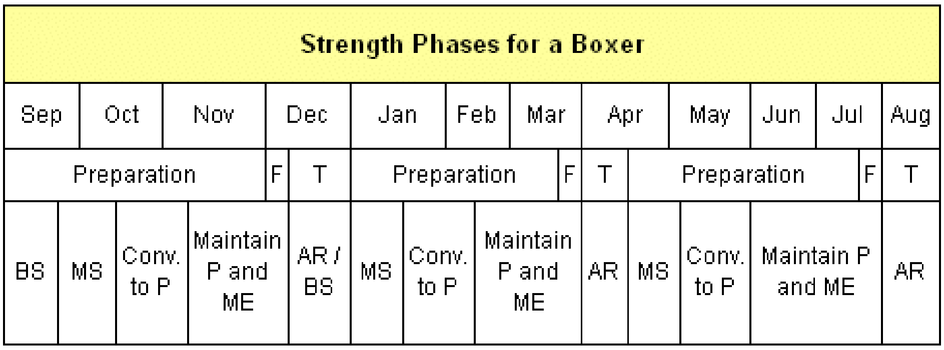
May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Preparation period							Compeition			Transition	
Basic strength	Max strength	Convert to muscular endurance		Max strength	Convert to muscular endurance		Maintain muscular endurance			Active recovery / basic strength	

Some sports do not have one continuous season. Swimmers for example, may have two competitive phases during the year. Boxers may need to prepare for several bouts in a year – each bout being the competitive phase.



<table>
<tr><th colspan="20">Strength Phases for a Distance Swimmer</th></tr>
<tr><td>Sep</td><td colspan="2">Oct</td><td colspan="2">Nov</td><td colspan="2">Dec</td><td colspan="2">Jan</td><td>Feb</td><td colspan="2">Mar</td><td colspan="2">Apr</td><td colspan="2">May</td><td>Jun</td><td colspan="2">Jul</td><td>Aug</td></tr>
<tr><td colspan="7">1st prep. period</td><td colspan="3">1st comp. period</td><td>T</td><td colspan="4">2nd prep. period</td><td colspan="3">2nd comp. Period</td><td colspan="2">T</td></tr>
<tr><td colspan="2">BS</td><td>MS</td><td>SE</td><td colspan="2">MS</td><td colspan="2">SE</td><td colspan="2">Maintain SE</td><td colspan="2">BS</td><td>MS</td><td colspan="3">SE</td><td colspan="2">Maintain SE</td><td colspan="2">AR / BS</td></tr>
</table>

BS = basic strength, MS = maximal strength, SE = strength endurance, AR = active recovery T = transition period



<table>
<tr><th colspan="22">Strength Phases for a Boxer</th></tr>
<tr><td colspan="2">Sep</td><td colspan="2">Oct</td><td colspan="2">Nov</td><td colspan="2">Dec</td><td colspan="2">Jan</td><td colspan="2">Feb</td><td colspan="2">Mar</td><td colspan="2">Apr</td><td colspan="2">May</td><td>Jun</td><td colspan="2">Jul</td><td>Aug</td></tr>
<tr><td colspan="6">Preparation</td><td>F</td><td>T</td><td colspan="5">Preparation</td><td>F</td><td>T</td><td colspan="5">Preparation</td><td>F</td><td>T</td></tr>
<tr><td>BS</td><td colspan="2">MS</td><td colspan="2">Conv. to P</td><td colspan="2">Maintain P and ME</td><td>AR / BS</td><td>MS</td><td colspan="2">Conv. to P</td><td colspan="3">Maintain P and ME</td><td>AR</td><td colspan="2">MS</td><td>Conv. to P</td><td colspan="3">Maintain P and ME</td><td>AR</td></tr>
</table>

BS = basic strength, MS = maximal strength, P = power, ME = muscular endurance, AR = active recovery, F - fight, T = transition phase

You will find more detailed strength training programs (covering the different types of strength) within this section of the site. See also the sport-specific sections for strength training programs designed specifically for that sport.

27

Power Training for Sport

Power training enables an athlete to apply the greatest amount of their maximal strength in the shortest period of time.

This is crucial for many sports men and women who will rarely be required nor have the time to produce maximal forces.

Most athletic activities involve far faster movements and far higher power outputs than are found in maximal strength exercises. An athlete can be exceptionally strong but lack significant explosive power if they are unable to apply their strength rapidly.

This article outlines the various methods of power training, their parameters and how they can be used to convert maximal strength into sport-specific power. But before examining how power training should fit into the overall strength program, it's important to have a basic understanding of the relationship between the force of movement and the velocity of movement...

The Force - Velocity Relationship

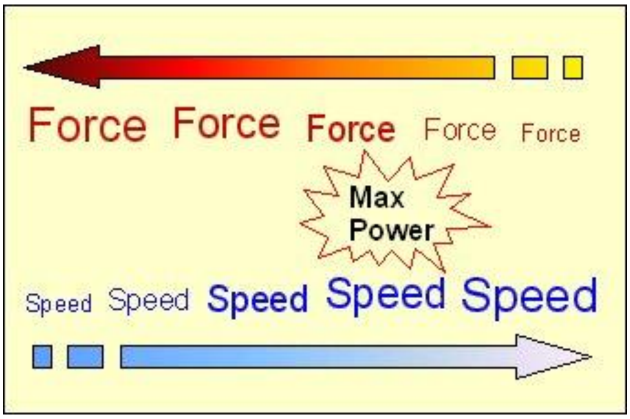
Power is intimately related to force and time, which can be expressed in the simple formula:

$$\text{Power} = \frac{\text{Force} \times \text{Distance}}{\text{Time}}$$

Traditional strength training typically alters the top half of this equation - increasing the ability to apply a maximum amount of force. But for power to be maximized the time component must also be altered. This is the aim of power training - to reduce the amount of time it takes to apply a set amount of force.

Maximum force production occurs when the speed of movement is very low (i.e. performing a one repetition maximum lift) or zero such as performing a static or isometric exercise.

Conversely, as the speed of movement increases, force decreases and at very high speeds force production is very low. Between these two extremes is an optimal point for power development. In fact, maximal power occurs at intermediate velocities when lifting moderate loads . Peak power output is typically seen when loads of 30% one repetition maximum (1-RM) are used.



This relationship between force and velocity and its affect on power explains why an athlete can be exceptionally strong but lack significant power if they are unable to apply much of their strength over a short period of time.

Assuming an athlete has maximized his or her ability to apply force (through maximal strength training), it would be beneficial if they could train to increase the rate of force production. Increasing the rate at which strength can be generated positively alters the time aspect of the power equation above.

The goal of power training is to increase the rate of force production and there are several methods that have been devised to do this...

The Different Types of Power Training

Below are four methods of power training. A prerequisite to starting one of these routines is the development of a solid base of functional strength. Power training, particularly plyometrics and ballistics, becomes less effective and the risk of injury is increased if a phase of anatomical adaptation has not already been completed.

Heavy Strength Training

Strength training alone can increase explosive power by positively affecting the top half of the power equation or the peak force production . Most athletic movements also start from a stationary position and it is this early phase of moving a resistance (be it a medicine ball or bodyweight) that requires the most effort. Therefore the greater an athlete's strength is, the more explosive this initial phase of motion will be. However, once this initial inertia has been overcome less force and more speed is required to continue the movement and heavy strength training becomes less suitable.

Additionally, lifting weights of 70-100% 1-RM has also been shown to reduce the rate of force production which is counter-productive to power development. This may explain why in strength trained individuals heavy resistance training is less effective at increasing vertical jump performance compared to ballistics or plyometrics for example .

For an athlete who already has a solid base of strength training (+6 months) gains in power are minimal with further weight training. Of course, untrained individuals can significantly improve their power with weight training and this is a safer and more favorable mode of training than some of the advanced techniques that follow.

Explosive Strength Training

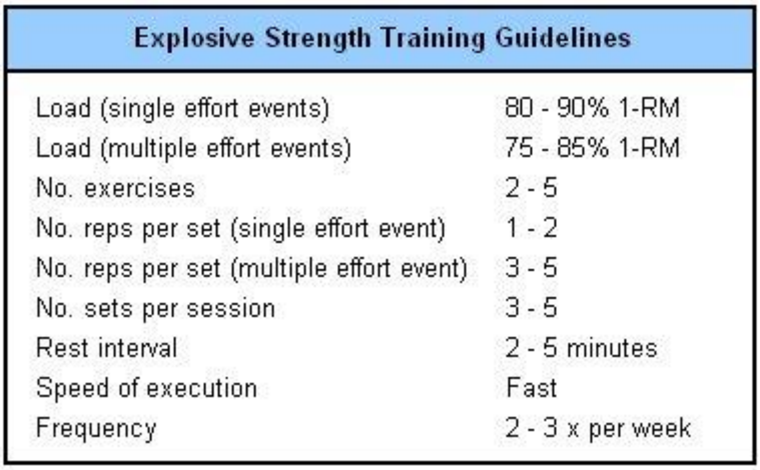
Once a plateau in strength has been reached, more sport-specific types of power training are required. One of these training methods is a variation of traditional resistance training. As mentioned earlier, maximal power production occurs when moderate loads of about 30% 1-RM are used.

Completing traditional weight lifting exercises as fast as possible with relatively light loads produces in theory, the greatest power output. Unfortunately there is a problem with this approach...

Lifting a bar rapidly loaded with 30% 1-RM is difficult to execute, particularly in the final phase of the movement. The athlete must decelerate and stop the bar in order to keep it under control . This deceleration activates the antagonist muscles negatively affecting power output and hinders the required adaptations .

Ballistics and plyometrics avoid this problem, as there is no deceleration. The athlete is free to jump as high as possible or throw an object as far as possible without restricting the movement.

If free weights exercises are used for power training, loads of 75-85% are recommended for sets of 3-5 repetitions. The parameters for explosive strength training can be seen in the table below:



Explosive Strength Training Guidelines	
Load (single effort events)	80 - 90% 1-RM
Load (multiple effort events)	75 - 85% 1-RM
No. exercises	2 - 5
No. reps per set (single effort event)	1 - 2
No. reps per set (multiple effort event)	3 - 5
No. sets per session	3 - 5
Rest interval	2 - 5 minutes
Speed of execution	Fast
Frequency	2 - 3 x per week

Data from (1,2,3)

For single power efforts such as the throwing events in athletics, a higher load (80-90% 1-RM) can be used for a smaller number of repetitions . A multiple power effort sport includes sprinting,team sports or any event that requires repeated efforts.

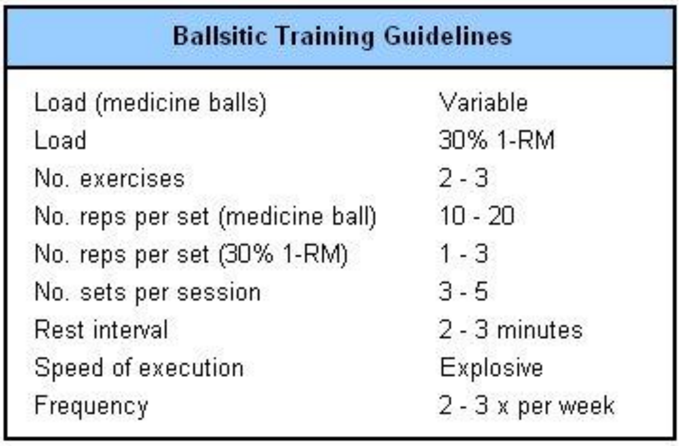
Sets are not performed to exhaustion as the quality and speed of each lift is the most important factor. Rest intervals are also kept high for the same reason.

Ballistics

During a ballistic action, the force far outweighs the resistance so movement is of a high velocity. The resistance is accelerated and projected. Examples include a medicine ball throw and a jump squat. The aim is to reach peak acceleration at the moment of release projecting the object or body as far as possible.

While there is no definitive guidelines for the resistance used with ballistics, Fleck and Kraemer suggest a load of 30-35% 1-RM should be used for exercises that include free weights such as jump squats. For many ballistic exercises the weight of the objects themselves dictate the load i.e. medicine balls ranging from 2-6kg (4.4-13lbs) and kettlebells ranging from 10-32kg (22-70lbs).

Parameters for ballistic power training are summarized in the table below:



Ballsitic Training Guidelines	
Load (medicine balls)	Variable
Load	30% 1-RM
No. exercises	2 - 3
No. reps per set (medicine ball)	10 - 20
No. reps per set (30% 1-RM)	1 - 3
No. sets per session	3 - 5
Rest interval	2 - 3 minutes
Speed of execution	Explosive
Frequency	2 - 3 x per week

Data from (1,2,3)

Repetitions can be reasonably high as the nature of some exercises means there can be up to 20 seconds between efforts - for example when a medicine ball has to be retrieved. A set should stop however, the moment the speed and quality of movement can no longer be maintained.

For exercises such as jump squats that use 30% 1-RM loads, Fleck and Kraemer recommend up to 5 sets of 3 repetitions with 3 minutes rest between sets.

Ballistics can place considerable eccentric forces on joints, ligaments and tendons when landing from a jump squat for example. Athletes should always progress gradually from unloaded to loaded exercises and must not be fatigued before starting a ballistic power training session.

Plyometrics

Plyometric drills involve a quick, powerful movement using a pre-stretch or counter-movement that involves the stretch shortening cycle . Classical plyometric exercises include various types of jump training and upper body drills using medicine balls.

Plyometrics is a suitable form of power training for many team and individual sports. While many might see it simply as jumping up and down, there are important guidelines and program design protocols that need to be followed if plyometrics is to be as safe and effective as possible. For this reason, and due to its popularity plyometrics has its own section of the website...

For full plyometric guidelines and sample sessions see the plyometric training section of the website.

Which is The Best Form of Power Training?

The type of power training employed must be the most specific to the sport or event. Olympic lifts, such as power cleans, may be suitable for sports such as football and rugby. Some plyometric exercises are suitable for soccer and hockey. Ballistic exercises with medicine balls fit well with basketball and volleyball.

But many sports would benefit from a combination of power training methods. Take basketball for example - explosive strength training such as power cleans, plyometric exercises such as depth jumps and ballistics such as jump squats and overhead medicine ball throws would all be suitable choices.

Interestingly, a study measuring the effects of three types of power training found that all of them increased vertical jump performance. However, while traditional weight training lead to a 5% increase and plyometrics a 10% increase, the most effective was ballistic jump squats, which lead to an 18% improvement in jump height. This confirmed the findings of a similar earlier study .

Does this mean ballistics is superior to other forms of power training? Not necessarily. In this case it may be that jump squats was the most specific to the performance outcome.

28

Isometric Exercises & Static Strength Training

Isometric exercises, also known as static strength training, involve muscular actions in which the length of the muscle does not change and there is no visible movement at the joint .

The term 'static contraction training' is sometimes used to describe isometrics. However, 'contraction' signifies a change in length (shortening) of the muscle belly, which does not occur during static strength training. The term 'static action' is preferred to static contraction.

Isometric exercises can be used for general strength conditioning and for rehabilitation where strengthening the muscles without placing undue stress on the joint is warranted.

Some actions within a wide variety of sports require isometric or static strength. Examples include climbing, mountain biking and motocross (grip and upper body strength), Judo, wrestling, alpine skiing (static strength required to stabilize the upper and lower body), shooting, gymnastics and horseback riding.

Isometric exercises can be completed with submaximal muscle action - such as holding a weight steady, out to the side. The force used to hold the weight still is not maximal as this would lift the weight further causing movement and a change in the muscle length and joint angle. Static strength training can also involve maximal muscle actions and examples here include pushing against an immoveable object such as a wall or heavy weight.

Both submaximal and maximal isometric muscle actions can increase isometric strength and induce muscular hypertrophy . In practice, maximal isometric exercises are used for strength and conditioning and submaximal exercises are used for rehabilitation .

Although isometric exercises can increase strength they are not the most suitable form of resistance training for dynamic actions such as sprinting and jumping. Most sports and athletic movements are dynamic in nature, performed at maximal speed against little or no external resistance. Isometric exercises do not increase the limb's maximal velocity and only strengthen the muscle at the angle at which it is trained (see below).

Guidelines For Isometric Exercises

Isometric exercises can raise blood pressure significantly for the duration of the exercise. While it will return to a resting level soon after, this can be dangerous for people with hypertension or any form of cardiovascular disease. Even if you don't suffer from high blood pressure it is important to breath continuously throughout the exercises. Breath holding will only compound any increases in blood pressure.

As with all forms of exercise you should warm up thoroughly first. Muscles are under tension for a longer period of time and although that tension is more constant compared to a dynamic contraction, tears can still occur. Finally, try to maintain some degree of tension in the abdominal region during all exercises. This will help to maintain a correct posture and will help to develop core stability.

Number & Duration of Muscle Actions

Volume for a classic strength training routine is prescribed based on the number of sets and repetitions. The equivalent in isometric exercises is the length of time each action is held for and the number actions in total. Research has measured both longer duration actions (i.e. 10 seconds or above) and fewer repetitions, and shorter duration actions (i.e. 2-3 seconds) with more repetitions . Both approaches seem to increase static strength.

The general consensus is that in healthy individuals training to improve strength (as opposed to rehabilitation of an injury), the most efficient use of isometric exercises is 15-20 maximal voluntary actions held for 3 to 5 seconds. Three sessions per week is required and results can be seen in as little as 2 weeks. However, when submaximal loads are used (such as bodyweight) it may be more suitable to increase the duration and reduce the number of repetitions.

This number and duration of contractions is required for each muscle group. As with traditional dynamic strength training, exercise selection should be based on a needs analysis of the athlete. Multi joint isometric exercises such as static leg presses may be more suitable then isolating the quadriceps, hamstrings and other hip flexors / extensors.

Joint Angles

Isometric exercises strengthen the muscle at or near to the joint angle at which the exercise is performed. For example a static bicep exercise held with the joint at 25^o only increases the athlete's strength at that specific angle and there is no gain in strength when the elbow is held at other angles. However, at particular joint angles (and it varies from muscle group to muscle group) there is some cross-transference of strength to other joint angles. An isometric bicep curl performed at 80^o for example also increases strength at other angles to a lesser extent. The same phenomenon is true for the knee and plantar flexors .

Essentially, training at only one joint angle does not increase strength throughout the full range of motion . In order to improve dynamic power, isometric exercises would have to be performed at multiple joint angles for the same muscle group. This becomes time consuming and enervating for an athlete who may already be spending considerable time on other training modalities.

If static strength training is used to increase strength throughout the entire range of motion, isometric exercises should be performed at every 10 to 30 degree increments. If this is too time consuming, it is better to perform exercises at an extended joint angle (rather than a flexed joint angle) as this leads to greater cross-transference of strength at other angles.

Example Full Body Isometric Exercises

The following isometric exercises use submaximal contractions i.e. bodyweight or a light free weights.

Plank Bridge

1. Start by lying face down on the ground. Place your elbows and forearms underneath your chest.
2. Prop yourself up to form a bridge using your toes and forearms.
3. Maintain a flat back and do not allow your hips to sag towards the ground.
4. Hold for 10-30 seconds or until you can no longer maintain a flat bridge. Repeat 2-3 times.

Side Bridge

1. 1.Start on your side and press up with your right arm.
2. 2.Form a bridge with your arm extended and hold for 10-30 seconds. Repeat 2-3 times.

Hundred Breaths Exercise

This isometric exercise is taken from Pilates and is excellent for developing static strength in the core region.

1. Lie face up on a mat with arms by your sides. Bend legs to 90 degrees. Lift your head and shoulders off mat and take 5 short, consecutive inhales, followed by 5 short, consecutive exhales.
2. At the same time, lift arms off mat and pulse them in unison with the breath - palms face up on inhale and down on exhale.
3. Repeat 10 times for a total of 100 breaths.

Example Upper & Lower Body Isometric Exercises

Isometric Push Ups

1. Starting in the push up position with arms fully extended, lower yourself to about half way to the floor.
2. Hold this position for 10-30 seconds remembering to breathe. Repeat 2-3 times.

Isometric Shoulder Raises

1. Standing with feet shoulder width apart raise a dumbbell (or light weight) directly out to your side.
2. When your arm is parallel to the ground hold for 10-30 seconds or until your arm begins to drop.
3. Repeat 2-3 times and change arms. Alternatively you can work both arms at once, which can be a little better for posture.

Isometric Squats

1. Place your back against a wall and lower yourself until your upper legs are parallel to the floor
2. Shuffle your feet until your lower legs are parallel to the wall behind you. Your knees should be bent to 90 degrees.
3. Hold your arms out in front of you and hold the position for 10-30 seconds. Repeat 2-3 times.

Isometric Calf Raises

1. Standing next to a sturdy chair (or any fixed objective) stand on just your right leg.
2. Rest your left foot on the back of your right calf and stand up on to your toes holding on to the chair for balance.
3. Hold the position for 10-30 seconds and repeat 2-3 times. Now repeat for the left leg.

Isometric Leg Extensions

1. Stand next to a bed (should be about 18 inches high). You should be facing away from the bed with the backs of your legs against the side of the bed.
2. Bend your right leg and rest it on the bed behind you. Your upper leg should be pointing straight down and your knee bent to roughly 90 degrees with your lower leg resting on the bed parallel to the floor.
3. Push your right leg into the bed as forcefully as possible and hold for 10-30 seconds.
4. Repeat 2-3 times and change legs. Remember to breathe!

Isometric Hip Extensions

1. Stand next to a table or sturdy chair for support. You should be facing towards the table.
2. Raise your right leg directly behind you keeping it as straight as possible as you hold onto the table in front of your for balance.
3. You will need to bend forward slightly at the waist and also bend your standing, left leg slightly to take the strain off your left hamstrings.
4. Try to get your leg parallel to the ground. You should feel your right hamstrings, glutes and lower back contracting.
5. Hold for 10-30 seconds, repeat 2-3 times and change legs. Remember to breathe!

Isometric Hip Abductions

1. Stand to the side of a sturdy chair or table for support. Your left leg should be next to the back of the chair.
2. Holding on to the chair with your left arm only, raise your right leg directly out to the side as high as you can.
3. Hold your leg as close to parallel to the floor as your can and keep that position for 10-30 seconds.
4. Repeat 2-3 times and change legs.

29

Medicine Ball Exercises

Medicine ball exercises are an important tool for developing sport-specific power. They can be used as part of a circuit training format or plyometrics program. In fact, upper body plyometric exercises are limited without their use.

Strength training for sport, for the most part, is very different from bodybuilding. While a phase of the strength training program should focus on maximal strength development and occasionally hypertrophy, it is explosive power and/or strength endurance that should be the end-goal for most athletes. While there are various methods to increase power, a common element is speed of contraction. Medicine balls are relatively light allowing exercises to be performed explosively.

Medicine ball exercises allow the athlete and coach to devise drills that closely match the movements within a particular sport. Take tennis training for example. Mirroring the movement patterns of a forehand or backhand stroke with traditional free weights is difficult. Torso twists, where the ball is released to a partner incorporate many of the same muscle groups in the same firing pattern as a tennis forehand or backhand stroke. And of course medicine ball exercises are not limited to tennis. They have obvious application to sports such as:

- Athletics (field events)
- Baseball
- Basketball
- Football
- Netball
- Rugby
- Squash and Racket ball

- Soccer (goalkeepers)
- Volleyball

Incorporating Medicine Ball Exercises into A Program

Medicine ball exercises have their place in an overall strength program. That doesn't mean to say they should replace all forms of strength training however. Rather than following a medicine ball 'routine' as such, a more appropriate approach is to select a few exercises and incorporate them into a circuit or session designed to increase power and/or strength endurance.

Remember also, that medicine ball exercises are effective and should only be selected if the closely mirror the movements within the sport. Athletes spend a great deal of time and energy training and all exercises should be chosen with care to ensure they make the very most if the training time available.

The very best to incorporate medicine ball exercises into the overall conditioning program is to use the principle of periodization. By splitting the annual strength program into several phases, different elements of strength can be developed that will enhance the next phase of training. Medicine ball exercises used to develop explosive power will be more effective if they are performed after a phase of maximal strength training. The idea is that the more strength you have to work with, the more of it you can convert into sport-specific power.

See the various sport sections on this site for more specific examples of how medicine ball exercises can be built into the conditioning program.

General Guidelines

- Warm up thoroughly before starting a medicine ball routine.
- Ensure you have plenty of space and a competent training partner when performing these drills.
- Medicine ball exercises, as with other forms of power training, should be completed when you are fresh before heavy aerobic or anaerobic training if completed in the same day.
- Focus on speed of movement but not at the sacrifice of technique.
- Do not choose a ball that is so heavy it slows the movement of the exercise down.

- Complete 1-3 sets of 8-10 repetitions for each exercise. (This can vary however depending on the format of the session).
- When standing and throwing from behind the head, be careful not to hyperextend the spine too far.

Sample Medicine Ball Exercises

Kneel to Push Ups

1. Start Position: Your body will be in an upright position sitting on your knees.
2. Hold medicine ball at chest level. Keeping your torso erect fall forward and chest press the medicine ball to a partner or a wall.
3. Upon releasing the ball drop your hands to the floor and immediately complete a push-up.
4. Advanced athletes: To make this more challenging have a partner throw the ball back to you. You will have to explode up with the push-up so that you are back in the seated upright position on your knees. Your partner will throw the ball back to you and then repeat the exercise until the desired repetitions are met.

Single Leg Chops

1. Starting Position: Stand on right leg and your arms are extended holding the medicine ball up and to your right.
2. Bring medicine ball down in a wood chopping motion towards your left foot.
3. During this place motion switch feet so your left foot is now on the ground and your right foot is in the air. Repeat this motion for the desired repetitions and then repeat in the opposite direction.

Slams

1. Stand with feet parallel and knees slightly bent.
2. Pull medicine ball back behind head and forcefully throw ball down on the ground as hard as possible.
3. Catch the ball on the bounce from the ground and repeat according to prescribed repetitions.

Figure of Eights

1. Start Position: Hold medicine ball with your arms extended over your right shoulder.
2. In one continuous motion bring the ball down in front of you like you are chopping wood and the ball should end towards your left foot.
3. Stand back up and raise the ball straight up over your left shoulder and now bring the ball down towards your right foot.
4. You will have to bend at your knees to complete this.
5. Return to starting position and repeat.

Medicine Ball Lunge Crossovers

1. Stand with feet hip width apart. Take left leg and step back approximately 2 feet standing on the ball of the foot.
2. Start position: Feet should be positioned at a staggered stance with head and back erect and straight in a neutral position. Hold medicine ball in front of your chest.
3. Lower body by bending at hip and knee until thigh is parallel to floor. Body should follow a straight line down towards the floor. As you are lunging reach to one side of the leg with the ball.
4. Return to start position and repeat by reaching to the opposite side with the ball. Alternate or switch to other leg after prescribed reps.

Russian Twists

1. Stand with feet hip-width apart.
2. Hold medicine ball with both hands and arms only slightly bent.
3. Swing ball over to the right hip and forcefully swing ball forward and around towards the left side. Reverse back in the opposite direction. Keep the stomach drawn in to maximize proper usage of muscle.

Single Leg V-Ups

1. Start position: Lie back onto floor or bench with knees bent, both hands behind head. Keep elbow back and out of sight. Head should be in a neutral position with a space between chin and chest.
2. Leading with the chin and chest towards the ceiling, contract the abdominal and raise shoulders off floor or bench. Extend arms and

also raise one leg up toward ceiling.

3. Return to start position.
4. Remember to keep head and back in a neutral position. Hyperextension or flexion may cause injury. To increase resistance, hold medicine ball in hands. To decrease resistance, position hand closer towards body

Medicine Ball Obliques

1. Starting Position: Lie on your back and raise your legs with your knees bent.
2. Holding a medicine ball between your knees rotate your legs to the side and then return to the starting position. Repeat to the other side.

Lateral Flexion w/ Stability Ball

1. Starting Position: Lie on your side over the stability ball and spread your legs for balance.
2. Hold a medicine ball over your head and curl up towards the ceiling. Lay back down across the ball and repeat the movement.
3. Repeat with the other side.

Reverse Curls

1. Start position: Lie with back on floor or bench with hips flexed at 90° and feet in air holding onto a medicine ball. Position arms at sides with palms down on floor.
2. Leading with the heels towards the ceiling, raise glutes (butt) off floor or bench.
3. Return to start position.
4. Remember keep legs from swinging to prevent momentum throughout the exercise.

30

Circuit Training Section

Circuit training is an efficient and challenging form of conditioning. It works well for developing strength, endurance (both aerobic and anaerobic), flexibility and coordination.

Its versatility has made it popular with the general public right through to elite athletes. For sports men and women, it can be used during the closed season and early pre-season to help develop a solid base of fitness and prepare the body for more stressful subsequent training.

A well-designed circuit can help to correct the imbalances that occur in any sport played to a high level. It can also be one of the best types of training for improving strength endurance – be it for a sport such as soccer or a classic endurance event like the triathlon.

If you haven't quite reached "elite athlete" status yet, circuit training is superb for general fitness and caters for a wide variety of fitness levels. A great time saver, it can be a refreshing and fun change from the more monotonous types of exercise.

The articles in this section of the website cover a wide variety of circuits for different performance outcomes. Circuit training in itself is not a form of exercise per se, but the way an exercise session is structured. Routines can be developed purely for strength development or for improving endurance or some combination of the two.

Circuit classes often seen in gyms and boot camps typically consist of about ten exercises stations completed for 60 seconds in sequence with 30-60 seconds rest between. While this is a great structure for some individuals it’s only one of many potential circuit programs and may not be the best approach for endurance athletes for example.

Circuit Training Articles

How to Design a Circuit Training Program

Circuit training can be used for different performance outcomes. Changing the time spent at each station and the rest intervals significantly alters the way the body will adapt to training. This articles covers all the basic guidelines to develop the most suitable circuit training routine for your particular needs…

Circuits for General, All-Round Fitness

These sample circuits are an effective, time-efficient way to develop all-round fitness. Additionally, they require little or no expensive exercise equipment...

Circuits for Strength Endurance (Short-Term)

Many athletes require good strength endurance to perform well in their sport. These circuits are designed for “short-term” strength endurance i.e. prolonged games such as soccer and filed hockey that consist of repetitive bursts of high intensity activity…

Circuits for Strength Endurance (Long-Term)

Athletes such as distance runners, cyclists and swimmers can also benefit from circuit training. Here are some sample programs...

Twenty Circuit Training Exercises

Why not use these exercises to develop your own circuit based on your own needs and the equipment you have available?

31

Plyometric Training

Athletes from a wide range of sports use plyometric training to help them reach peak physical condition. Used correctly, it can be a highly effective form of power training, especially when combined with a suitable strength training program.

Unfortunately, there is little research to define the optimal guidelines for plyometric training. While many coaches use their experience to determine the quantity and intensity of sessions, several objective guidelines have been proposed by bodies such as the National Strength & Conditioning Association and other experts in the field

32

Kettlebell Exercises

Here are the kettlebell exercises and images.

If you missed the kettleball training article you can see an example of how these exercises can make up a routine.

Do kettlebell exercises offer any performance advantages over regular freeweights and dumbbells? Not necessarily. An athlete must be very selective over the training they choose to integrate into their program. They have a limited amount of time and energy and each element of conditioning must take the whole into account. Unless you are a Girevik (Girevoy Sport is made up exclusively of kettlebell exercises), think seriously before replacing proven training methods for kettlebell routines.

Kettlebell Exercises

It goes without saying that should perform a throrough warm up before any exercise session. And with these kettlebell exercises it's doubly important. Do 5-10 minutes of light aerobic activity followed by stretching exercises to all the major muscle groups.

Kettlebell Cleans

1. Keep torso straight but bent forward at the hips slightly.
2. Explosively raise the kettleballs by extending the hips, knee and ankle in a “jumping action”.
3. Keep your elbows out and shoulders directly above the kettleballs as long as possible. Keep the kettleballs close to the body.
4. Once you have extended the lower leg shrug your shoulders and at maximum elevation of the shoulders start pulling with the arms. Keep

the elbows high during the pull until the highest point.

5. Rotate elbows around and underneath the kettleballs. Rack your hands across the front of the shoulders. Slightly flex the hips and knees to absorb the weight.
6. This should be a fluid motion where all the steps flow together.

Single Arm Kettlebell Row

1. Stand with feet hip width and knees slightly bent. Bend at hips with back straight and knees bent.
2. 2.Take one hand and place on stationary object that is approximately waist height to support upper body.
3. Hold kettleball in other hand with a neutral grip and let arm hang straight down (perpendicular to floor).
4. Keeping elbows close to body, pull kettleball up to body and squeeze shoulder blades together at top of movement.
5. Return to start position. Remember to keep back and head straight - hyperextension, flexion, or trunk rotation may cause injury.

Alternating Floor Press

1. Lie on your back holding a kettleball in each hand.
2. Alternating with your arms push up one kettleball at a time.
3. Slightly rotate your trunk when pressing the kettleball up. Repeat with the other arm.

Kettlebell Front Squat

1. Grasp kettleballs and hold them at chest level in front of you.
2. Stand with feet slightly wider than hip width apart. Knees should be slightly bent.
3. Lower body by flexing at the hips and knees. Upper body can flex forward at the hips slightly (~5°) during movement. Be sure to “sit back” so that knees stay over the feet.
4. Once thighs are parallel to floor, return to start position.

Single Arm Kettlebell Jerk

1. Stand with feet shoulder width apart and knees slightly bent. Position kettleball to ear level with an overhand grip (palms facing forward).
2. Go into a quick ¼ squat. Immediately extend legs and stand up and at the same time press hands up above head keeping wrists over the elbow and arm moving parallel to body at all times.
3. Return to start position. This is an explosive exercise and the legs are used to be able to lift more weight overhead

Kettlebell Swing

1. Hold one kettleball between your legs and your body is in a bentover stance with your back flat.
2. Swing the kettleball backwards and then forcefully swing the kettleball forward to a chest level. Keep your arm straight and forcefully extend your hips, knees, and ankles.

Kettlebell Windmill

1. Place one arm overhead full extended with a kettleball. Bend forward at the hips keeping back flat to grab the other kettleball with the free hand.
2. While holding one kettleball overhead continue to raise and lower the other kettleball.
3. Continue for the desired repetitions and repeat with the other arm.

There are literally dozens of kettlebell exercises you can perform. Just as with other free weights, the combinations and variations are endless. However, athletes should remember the principle of specificity. Pick kettlebell exercises that most closely match the movement patterns of your sport.

Kettlebell exercises may not be as effective as more traditional free weights for developing maximal strength - an important phase in the athlete's overall program. The movement patterns and loads they incorporate makes them better suited to converting maximal strength into explosive power and / or strength endurance.

33

Static Stretching Exercises & Flexibility Program

Stretching exercises should form an integral part of any conditioning program. Performed consistnetly, the stretching exercises below can help to do the following...

- Increase the range of motion about a joint reducing the risk of muscle and tendon tears during competitive activity.
- Relieve muscle tightness and stiffness.
- Improve postural imbalances and help to reduce chronic back pain.
- Increase localized blood flow to the muscles being stretched.
- Possibly relieve muscle soreness after intense physical activity and help to reduce the severity of DOMS (dleayed Onset Muscle Sorness).

Often seen as secondary to strength and endurance, flexibility training is neglected by many athletes. Yet stretching, both through shorter term performance enhancement and longer term injury prevention, is well worth the small amount of effort it requires.

Stretching exercises can easily be integrated into a cool down following a training session. It saves the athlete time and range of motion is increased more readily when the body is warm.

Key Points For Effective Stretching

The stretching exercise below are classed as static stretches. Evidence suggests that static stretching should be avoided immediately before competition in favor of a general warm up and dynamic stretching.

1. To increase flexibility and range of motion, perform stretching exercises when the body is warm. This can be at the end of a training session or following 10 minutes of light aerobic exercise.

2. Complete a range of stretching exercises for different muscle groups. Pay particular attention to the muscle groups that are involved most in your sport.
3. Hold each stretch for 10-20 seconds. Initial tightness should gradually diminish as you hold the stretch.
4. Repeat each of the stretching exercises 2-3 times in succession.
5. Perform stretching exercises at least 3 times a week and ideally 5 times per week.
6. Ease slowly in and out of the stretch. Do not bounce! Breathe out as you stretch and continue to breathe as you hold it.
7. If you feel any pain, release the stretch immediately.

Upper And Lower Body Stretching Exercises

Shoulder Stretch

Interlock your fingers and reach above your head. Your lower back should be flat or slightly arched inwards. You can perform this exercise sitting or standing.

Triceps Stretch

Place your left hand behind your head and reach as far down your back as possible. With your right hand grasp your left elbow and gently pull it behind the back of your head. You can perform this exercise sitting or standing. Repeat for the other arm.

Chest Stretch

Clasp your hands behind your back. Gently straighten your elbows and raise your arms as high as comfortably possible. You can perform this exercise sitting or standing.

Lower Back Stretch

Lying flat on your back place the sole of your right foot on your left thigh. Grasp your right knee with your left hand and gently roll it to the left. Try to get your knee as close to the floor as possible without your right shoulder leaving the floor.

Groin Stretch

Stand with your feet about 2 meters apart, toes pointing forward. Gradually shift all your weight to your right leg by bending your right knee. Your left leg stays straight. Place both your hands on your right knee for support. You can increase the starting distance between your feet for a greater stretch.

Groin Stretch

Sit down and place the soles of your feet together. Clasp your ankles with your hands so that your elbows rest on your knees. Gently push your knees down with your elbows until your fell the stretch.

Quadriceps Stretch

Standing upright hold onto a support with one hand (i.e. a chair) for balance. With your other hand clasp your ankle and pull your heel into your butt. Repeat for the other leg.

Hamstring Stretch

Sitting down, stretch your legs out in front of you while keeping your back flat and upright. Bend your left leg keeping your left foot flat on the floor. Slowly reach forward and try to touch your right toe with both hands. Bend from your waist keeping your lower back flat and your head up. Repeat for the other leg.

Calf Stretch

Stand arms length away from a wall and with feet shoulder width apart. Place your right foot about 2 feet in front of your left. Keeping both heels flat on the ground lean towards the wall by bending your right knee. Your left leg should stay straight. Push gently against the wall for a deeper stretch. Repeat for the left leg.

Achilles Stretch

This is exactly the same procedure as above except as you lean towards the wall let both knees bend. Rather than leaning forward you should feel like you are lowering yourself straight down. Remember to keep both heels flat on the floor. Repeat for the other leg.

34

Static Stretching

Static passive stretching (more commonly referred to as just static stretching) has been used by coaches and athletes for years without question.

You may be aware of the current debate that started some years ago now, questioning whether static stretching prior to exercise really deserved the credence it has...

Static Stretches Before Performance

Once a staple part of the warm up, many strength and conditioning coaches are now suggesting that static stretches should be avoided just prior to competition. Their advice is based on a number of studies that have linked detrimental performance in power, maximal voluntary contraction, balance and reaction time tests with a static stretching routine shortly before .

However, before disregarding static stretching entirely (as a component of the warm up), it's important to take a closer look at the research. By no means have all studies found static stretches to have a negative effect on power performance. And in many studies that have found a negative association, the effects are often minimal.

Remember that this debate relates to an acute bout of static stretching prior to exercise. It is still considered important and benefical to athletes away from competition to to bring about a long-term increase in range of motion...

Long-Term Static Stretching Programs

While dynamic stretches may be more suitable as part of a warm up, static stretching is more effective at increasing range of motion.

Static stretching is slow and constant and held at an end position for up to 30 seconds . Static *passive* stretching uses an external force to hold the stretch in position. No muscle groups are statically contracted to hold the limb in position - as they are with static active stretching.

An example is holding one leg outstretched with the heel on the floor to stretch the hamstrings. Both floor and bodyweight act as the external forces to bring about the stretch in this muscle group. Lying supine (i.e. flat on the back face up) with one leg held extended at right angles to the body (hamstring stretch) is a static active stretch. If a partner holds the leg in that position it becomes a static passive stretch.

A static stretching program effectively increases range of motion over time (7). This chronic adaptation may reduce the risk of injury as it increase the safe range through which a joint can be taken without injury occurring to surrounding muscles and ligaments.

Perhaps most importantly, from the athlete's persepctive, regular stretching improves force production, speed and jumping ability.

35

Dynamic Stretches & Stretching Routine

Dynamic stretches are best incorporated into your warm up routine before training or a competition.

More recently, clinical studies have shown that traditional static stretching exercise may be detrimental to sports involving powerful movements. Dynamic stretches seem to be more effective at reducing muscle stiffness, which is thought to increase the likelihood of muscle tears. For this reason, many coaches now advocate static stretching away from competition to increase range of motion, and dynamic stretching prior to performing for injury prevention and preparation.

Some of the exercises below incorporate a stability ball. Stability balls are great for developing functional strength and core stability. They inexpensive and extremely versatile. You will find them at any store that sells exercise equipment.

Dynamic Stretches

Arm Swings

1. Stand tall and hold arms out to your side.
2. Slowly swing your arms back and forth across the front of your body.
3. Repeat this continuous motion for 30 seconds.

Side Bends

1. Stand with a shoulder width stance. Place a toning bar on your shoulders (optional).
2. Lean to one side keeping your torso straight. Do not bend forward or backwards.
3. Hold for a count of 2 and then repeat to the other side.
4. Complete 10 stretches each side.

Trunk Rotations

1. Stand with a shoulder width stance. Place hands on hips.
2. With knees slightly bent, turn from side to side keeping feet firmly on the floor.
3. Complete a total of 15-20 full swings.

Full Back Stretch

1. Lie on your back and bring both your knees to your chest with hands clasped under back of knees.
2. Roll forwards until your feet touch the floor and then immediately roll back until just before your head touches the floor.
3. Continue until you complete 10-15 full rolls.

Abdominal Stretch

1. Start by lying on your back on the stability ball holding a toning bar at your chest (the toning bar is optional).
2. Push back with your feet and simultaneously push the bar over and behind your head.
3. Your legs should be straight and your arms outstretched.
4. Return to the starting position and repeat for 10-15 reps.

Hamstring Stretch

1. Lie on your back and place a piece of exercise tubing (or rolled up towel) around the bottom of one of your feet.
2. Pull the tubing and raise your leg at the same time until a comfortable stretch is felt. Return to the starting position and repeat for 10-15 repetitions.
3. Repeat with other leg.

Groin Stretch

1. Start by placing your right knee on top of a stability ball and maintain your balance.
2. Slowly spread your leg out to the side until you feel a stretch on the inside of your thigh.
3. Return to the start and repeat for 10-12 repetitions before changing to the other leg.

Alternate Toe Touches

1. Start by standing with your feet spread as far apart as comfortably possible.
2. Lean forward toward one leg and try to reach your foot or until a comfortable stretch is felt in your low back and hamstrings.
3. Now try to touch the other foot with the opposite arm. This motion should be continuous alternately touching each foot (as close as possible) with the opposite hand.

Important: skip this stretch you are prone to low back pain or if it causes you any discomfort.

Leg Swings

1. Start by standing with your feet shoulder width apart.
2. Keeping your upper body perpendicular to the ground swing one leg forward and backward.
3. Do not swing your leg so hard that you cannot keep your upper body from moving.
4. Repeat for 10 full swings and repeat on other leg. 5. You can also swing your leg across your body stretching the abductors and adductors.

Use these dynamic stretches as part of your warm up. Start with 10-15 minutes of light aerobic exercise to make sure the body is thoroughly warm. While they are not as effective as static stretching for increasing flexibility they can help to prevent injury and do not negatively effect strength and power immediately afterwards. Static stretches can be performed after training or competition to increase flexibility.

36

Static Active Stretching

Static stretching is simply the opposite of dynamic stretching. The muscle groups are stretched without moving the limb itself and the end position is held for up to 30 seconds

Static *active* stretching requires the strength of the opposing muscle groups to hold the limb in position for the stretch. For example, standing on one leg and holding the opposite leg out directly in front of you is classed as a static active stretch. The quadriceps actively hold the stretched limb.

Static active stretching is an effective way to increase active flexibility. A martial artist raising her leg up to an opponent's head and holding it there, is a good demonstration of static active flexibility. Being able to simply kick to head height is an example of dynamic flexibility.

A static active stretch should be held for 10-30 seconds for 1-2 stretches per muscle group. As with other forms of stretching, static active stretching is not recommended before a sporting event. It may impair balance and reaction time and reduce power output and without any of the benefits of injury prevention .

As part of a warm up routine, incorporate dynamic stretches, which can help reduce muscle tightness and reduce the risk of injury.

37

Weight Training Programs For Basic Strength

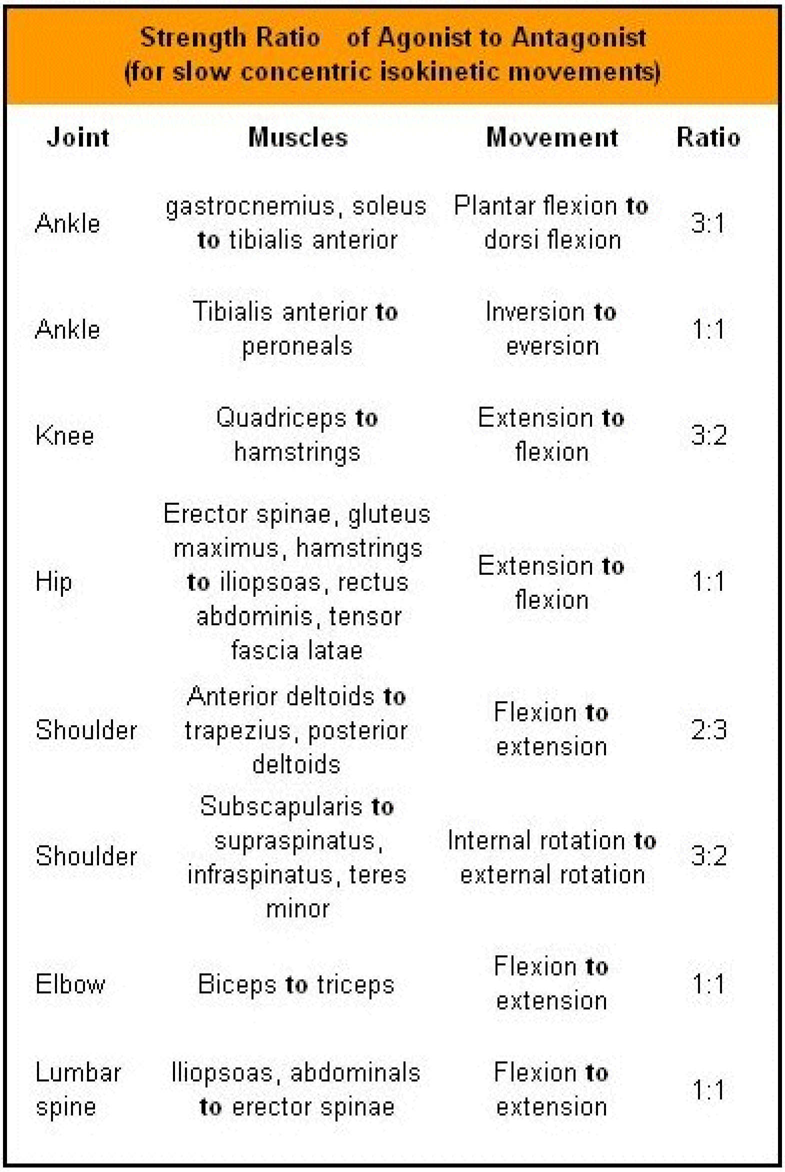
These sample weight training programs are designed to develop basic, functional strength. For more sample weight training programs designed to meet other objectives (such as increased muscles mass, maximal strength, explosive power or strength endurance) see the main strength training section.

A phase of basic strength training is important for adapting the body for more strenuous, subsequent weight training. It aims to balance the body's musculature by working most or all of the major muscle groups and prepares tendons, ligaments and joints helping to reduce the risk of injury later on .

Recall from the sport-specific approach to weight training programs that this basic strength phase should precede maximal strength training, hypertrophy training and explosive power training . This is important even for experienced strength-trained athletes as the nature of competitive sport places uneven stresses on the body...

The basic strength phase aims to balance strength between the two sides of the body . Racket sports for example, place greater strain on the shoulder and arm muscles of one side of the body for example. Soccer players usually have a predominant kicking foot.

It also aims to restore correct balance between the flexors and extensors (such as the hamstrings and quadriceps for example). The table below gives an approximate guideline to the balance of strength between various muscle groups.



Strength Ratio of Agonist to Antagonist
(for slow concentric isokinetic movements)

Joint	Muscles	Movement	Ratio
Ankle	gastrocnemius, soleus **to** tibialis anterior	Plantar flexion **to** dorsi flexion	3:1
Ankle	Tibialis anterior **to** peroneals	Inversion **to** eversion	1:1
Knee	Quadriceps **to** hamstrings	Extension **to** flexion	3:2
Hip	Erector spinae, gluteus maximus, hamstrings **to** iliopsoas, rectus abdominis, tensor fascia latae	Extension **to** flexion	1:1
Shoulder	Anterior deltoids **to** trapezius, posterior deltoids	Flexion **to** extension	2:3
Shoulder	Subscapularis **to** supraspinatus, infraspinatus, teres minor	Internal rotation **to** external rotation	3:2
Elbow	Biceps **to** triceps	Flexion **to** extension	1:1
Lumbar spine	Iliopsoas, abdominals **to** erector spinae	Flexion **to** extension	1:1

Data from (2)

Core strength training should be a major focus of "basic strength" weight training programs. This involves working the abdominal muscles, lower back muscles and other muscle groups supporting the spinal column and hip girdle. Weak core muscles may be associated with injury, and are more likely to occur when training becomes more demanding.

Designing Weight Training Programs for Basic Strength

The length of basic strength weight training programs depends on the experience of the athlete and also the importance of strength to their particular sport. Inexperienced athletes should follow a program such as the samples below for 8-10 weeks . This helps to ensure their bodies are fully prepared for more intense training.

Experienced athletes require only 3-5 weeks of basic strength training and any longer may lead to an undesirable detraining effect. However, as short as this phase may be it should not be skipped for the reasons outlined above.

Weight training programs for basic strength should be completed in the early part of the preparatory phase, often called early pre-season. However, for athletes with little or no strength training experience this basic strength phase may need to start in the off season or transition period.

Because basic strength training should work most major muscle groups, a circuit training format is ideal. It alternates between muscle groups allowing a quicker recovery and a greater number of exercises to be completed. Circuit training does not have to incorporate an aerobic or cardiovascular element. It simply refers to the organization of exercises and in fact, for our purposes, a circuit training program should consist only of resistance exercises.

A wide range of equipment can be used for these circuit-style weight training programs, including bodyweight resistance bands, medicine balls, dumbbells and barbells.

The parameters for resistance, sets and repetitions are covered in the table below:

Guidelines for Basic Strength Training

Training Parameter	Beginner	Experienced
Length of phase	8-10 weeks	3-5 weeks
Time of year	Off-Season	Off-Season
Load (free weights)	30-40% -RM	40-60% 1-RM
No. Repetitions	12-15	12-15
No. Stations per circuit	9-15	6-9
No. Circuits	2-3	3-5
Duration of circuit	20-30min	30-40min
Rest Between Exercises	90sec	60sec
Rest Between Circuits	2-3min	1-2min
Frequency Per Week	2-3	3-4

Data from (2)

Exercises should be set up so that a muscle group is not worked on two consecutive exercises. A simple format to follow is to alternate between the upper body and lower body or total body / upper body / lower body / core exercise for example.

Inexperienced lifters should start with body weight exercises and progress to free weights. If free weights are used the resistances should start off low to moderate (see the table above) and gradually progress towards the end of the program.

Most athletes will move on to one of the maximal strength training programs following this basic strength phase. It's important that there isn't too big a jump in resistance from the end of basic strength training to the start of maximal strength training.

Sample Weight Training Programs for Basic Strength

The following sample weight training programs should follow the parameters in the table above. Exercises should be completed in the sequences set out.

Program 1 – Bodyweight Exercises

- Burpees
- Push ups
- Lunges
- Crunches
- Box step up with knee drive
- Pull ups
- Alternating split squats
- Supermans

See the circuit training exercises article and abdominal exercises article for exercise descriptions.

Program 2 – Medicine Balls & Resistance Bands

- Medicine ball lunge cross over
- Resistance band lateral rows
- Medicine ball oblique crunches
- Resistance band squats
- Medicine ball kneel to push ups
- Resistance band lunges
- Medicine ball reverse curls
- Resistance band bent over rows
- Medicine ball single leg chops
- Resistance band biceps curls

See the medicine ball exercises article and resistance band exercises article for exercise descriptions.

Program 3 – Free weights

- Dumbbell squats
- Bench presses
- V sit ups
- Deadlifts (light weight)
- Bent over rows
- Back extensions
- Lunges

- Seated dumbbell shoulder presses
- Russian twists with dumbbell
- Calf raises

The weight training programs could also be combined taking various exercises from each.

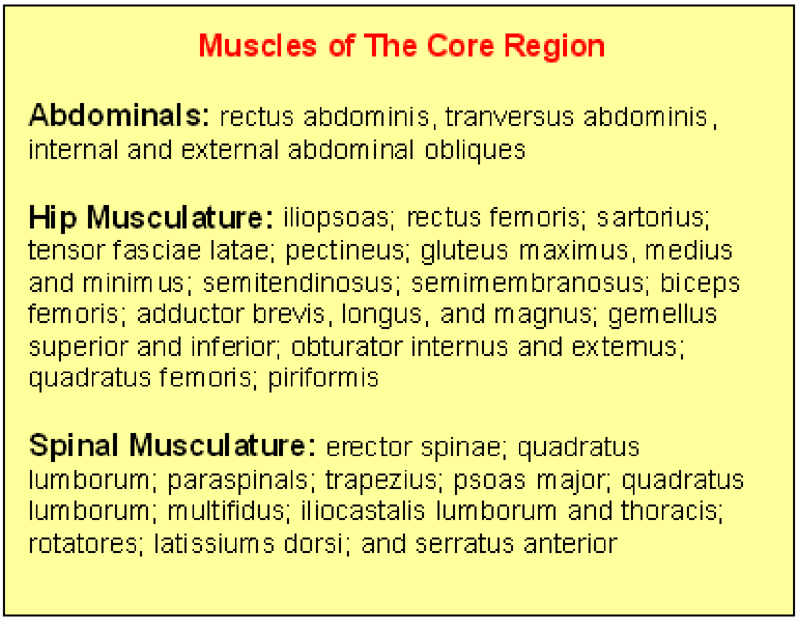
38

Core Strength Training for Athletes

Core strength training may be a relatively new, buzz term in the fitness industry but coaches and athletes have understood its value for many years.

The core region consists of far more than just the abdominal muscles. In fact core strength training aims to target all the muscles groups that stabilize the spine and pelvis.

It's these muscle groups that are critical for the transfer of energy from large to small body parts during many sporting activities.



Muscles of The Core Region

Abdominals: rectus abdominis, tranversus abdominis, internal and external abdominal obliques

Hip Musculature: iliopsoas; rectus femoris; sartorius; tensor fasciae latae; pectineus; gluteus maximus, medius and minimus; semitendinosus; semimembranosus; biceps femoris; adductor brevis, longus, and magnus; gemellus superior and inferior; obturator internus and externus; quadratus femoris; piriformis

Spinal Musculature: erector spinae; quadratus lumborum; paraspinals; trapezius; psoas major; quadratus lumborum; multifidus; iliocastalis lumborum and thoracis; rotatores; latissiums dorsi; and serratus anterior

Core Strength Training For Athletic Performance

The muscles of the trunk and torso act to stabilize the spine, pelvis and shoulder girdle. From this solid, balanced base the limbs can be moved powerfully and under control. In fact before rapid movements of the extremities can take place, the central nervous system stabilizes the spine in anticipation. The rate at which the core muscles stabilize the spine may have a direct effect on the power of limb movement.

Core strength training differs from many traditional weight training routines by working both the lower back and abdominals in unison. The same is true for the upper and lower body. All athletic movements incorporate the core in some way. Very few muscle groups are isolated. Instead the whole body works as a unit and core strength training endeavours to replicate this.

What are the benefits of core strength training to the athlete?

- Greater efficiency of movement
- Improved body control and balance
- Increased power output from both the core musculature and peripheral muscles such as the shoulders, arms and legs
- Reduced risk of injury (the core muscles act as shock absorbers for jumps and rebounds etc.)
- Improved balance and stability
- Improved athletic performance!

Core Strength Training for Reducing Back Problems

Weak or poorly controlled core muscles have been associated with low back pain. The back muscles are responsible for movements such as extension and flexion of the spine and rotation of the trunk.

Excessive or uneven shock on the spine may lead to back problems. This may be exaggerated because weak core muscles lead to improper positioning or a forward tilt. In many exercises that use the back muscles, the abdominal muscles contract isometrically stabilizing the body.

The stronger and more correctly balanced the core muscles are, the less the uneven strain on the spine.

Equipment Used For Core Strength Training

While there are no doubt countless gimmicks on the market purporting to strengthen the core region most are useless to the athlete.

There are however, several pieces of exercise equipment that are genuinely useful for strengthening the core region. They include...

- Medicine Balls
- Stability Balls
- Balance Boards

These simple pieces of equipment allow the coach or athlete to devise resisted sport-specific movements. Medicine balls are particular helpful for mimicking rotation movements for example that would be unpractical with free weights.

Of course even these pieces of equipment are not essential. There are many exercises that use bodyweight or partner resistance that strengthen the core effectively. The use of free weights can adapted to cater for the majority of athletic movements.

Popular Core Strength Training Exercises

Prone Bridge

In a face down position, balance on the tips of your toes and elbows while attempting to maintain a straight line from heels to head. This exercise focuses on both the anterior and posterior muscle groups of the trunk and pelvis.

Lateral Bridge

Start on your side and press up with your right arm. Form a bridge maintaining a straight line from your hand to your foot. Rest on your elbow to increase the difficulty. This exercise focuses on the abdominal obliques and transversus abdominus

Supine Bridge

Lying on your back, raise your hips so that only your head, shoulders, and feet are touching the floor. The supine bridge focuses on the gluteal muscles. Stronger gluteals help maintain pelvic control

Pelvic Thrusts

Lie on your back with your legs bent 90 degrees at the hip. Slowly lift your hips off the floor and towards the ceiling. Lower your hips to the floor and repeat for the prescribed number of repetitions.

Russian Twists

1. Start by sitting on the floor with hips and knees flexed to approximately 90 degree angles.
2. Grasp a medicine ball or small dumbbell and swing it to the right and left as you keep the hips from rotating with the shoulders.
3. The arms are not perpendicular to the torso, but instead, kept low, near the thighs, as the medicine ball is swung to each side.

Good Mornings

1. Stand with feet shoulder width apart with knees slightly bent (at 20°).
2. Start position: Grasp bar with overhand grip shoulder width apart. Back should be straight in a neutral position.
3. Bending at the hips, lower bar to approximately knee height. Keep knees bent at 20° throughout movement.
4. Return to start position.
5. Remember to keep back straight - movement should occur at the hip. To facilitate this, shift glutes back as if ready to sit down. Knees should not move forward beyond the toes.

Dumbell Lunges with Crossover

1. Start position: Stand with feet hip width apart. Grasp DB's and hold out in front of body.
2. Step forward 2-3 feet forming a 90° bend at the front hip and knee. DO NOT allow front knee to extend past the big toe - may cause injury. As you are lunging swing dumbbells across body towards the hip.
3. Pushing off front foot, return to start position with legs and dumbbells.
4. Remember to keep head and back upright in a neutral position. Shoulders and hips should remain squared at all times.
5. Watch for proper knee alignment - do not let front knee extend past big toe or deviate laterally or medially. Back knee should not come in contact with floor.

Other excellent core stability exercises include:

- Lat Pull Downs
- Leg Presses/Squats
- Crunches and crunch variations
- Regular lunges
- Back extensions
- Deadlifts
- Chin-ups
- Medicine ball exercises

39

Speed Endurance Training

These speed endurance drills will help you to maintain a higher work rate for longer.

They are excellent for improving performance in sports such as football, soccer, hockey and basketball. Any athlete that is required to repeat high intensity sprints in quick succession can benefit from this type of training.

The accumulation of blood lactate disturbs the excitation-contraction coupling and cross-bridge formation. In other words, the muscle's mechanical properties are disturbed. The result? A decrease in force production, peak force and velocity.

Training can improve the clearance rate of lactate and reduce early lactate formation.

Both submaximal aerobic exercise and interval training can improve the body's ability to buffer and tolerate lactate. However, only intense interval training can increase various important components of anaerobic power and capacity. Submaximal aerobic exercise does not and may even decrease anaerobic enzyme activity (not good for speed development!).

Speed endurance training is similar to speed or sprint training, however there are two important distinctions:

1. Repetitions should last from 30 seconds up to 2-3 minutes as opposed to 5-10 seconds for speed drills.
2. Rest intervals between repetitions is reduced to prevent complete recovery.

Speed Endurance Drills

Speed endurance training should form the later part of pre-season training and in-season training. It is important to develop a solid fitness base beforehand, which includes strength and endurance conditioning.

No more than two speed endurance sessions are required. This may be reduced to once a week during the competitive season. Because speed endurance training can be so demanding, keep session duration to 20-30 minutes maximum. Rest intervals should consist of active recovery exercises such as walking or jogging slowly on the spot.

High Intensity Shuttle Run

- Pace out 30 meters on grass or a running track. Place a cone at the start and at 5 meter intervals (7 cones in total).
- Sprint from the starting cone to 5 meter cone and back. Turn and sprint to 10 meter cone and back to start. Sprint to 15meter cone and back to start and so on until you sprint the full 30 meters and back.
- Rest for 90 seconds and repeat. Complete a total of 6 sets keeping rest periods to 90 seconds.

Pyramids

- Pace out 50 meters placing a cone at the start and then at 10 meter intervals (6 cones in total).
- Starting at the first cone sprint all out for 10 meters and walk the remaining 40 meters.
- Turn and sprint 20 meters and walk for 30 meters.
- Turn and sprint 30 meters and walk for 20 meters.
- Turn and sprint 40 meters and walk for 10 meters. Finally...
- Turn and sprint 50 meters and then turn and sprint 50 meters again back to the start.
- This is classed as one set. Rest for 90 seconds and repeat for a total of 4 sets. Rest for a full 3 minutes and repeat.

Cruise And Sprint

- Mark out a distance of 100 meters. From the start gradually accelerate to reach full speed at about 60 meters. Sprint all out for the final 40 meters.
- Slow down gradually, turn and repeat.
- Continue for 2 minutes and then rest for 2 minutes. This is one set. Repeat for a total of 6 sets.

Hollow sprint

- Set 5 cones out in 30 meters intervals. Sprint 30 meters, jog 30 meters, sprint 30 meters and jog 30 meters to the final cone.
- Turn around and repeat always alternating jogging and sprinting. Work for 2 minutes and then rest for 2 minutes.
- This is one set. Try to complete a total of 6 sets.

Cross Drill

- Using 4 cones mark a box 30 meters by 30 meters. Place another cone in the center of the box.
- Starting at the center cone sprint to each corner and back in a clockwise direction. Once you have completed a circuit rest for 60 seconds.
- Perform a total of 6 circuits to complete one set. A session could contain up to 4 sets with a 3 minute rest interval between sets.

40

How to Design Fartlek Training Sessions for Your Sport

Fartlek training offers a wide range of athletes an effective ad efficient form of endurance conditioning...

But just like every other form of sports training you must structure the session to meet the demands of your sport..

Fartlek training allows the athlete to run freely over varying distances and at varying speeds. A single session might consist of walking, cruising and sprinting. It might last for 20 minutes or 5 miles. The variations are unlimited. And that means some specific guidelines are in order so each session can be made as effective as possible.

If you’ve read some of the other articles on the site you’ll appreciate the importance of specificity. It's one the most important principles of training and one that is often overlooked.

In most fartlek training sessions intervals are kept relatively short and frequent. Anything too long simply becomes more like interval training. Each interval might range from 10 seconds up to 5 minutes for example.

For long distance runners (anything from 1500m to 10k) more structured sessions are beneficial. For example, you might run hard for 5 minutes (above race pace) then jog slowly for 1 minute to recover, and repeat that five or six times.

For multi-sprint sports such as soccer, basketball, racket sports, hockey and so on, shorter and more random intervals will be more appropriate. Consider tennis for example...

Plenty of stop-starting, movement patterns are unpredictable and very few rallies last longer than a minute at most.

A more effective fartlek training session then, would be a jog for 60 seconds, followed by a hard run for 30 seconds, followed by a jog for 30 seconds, followed by all-out sprint for 10 seconds, followed by a walk for 30 seconds. This would then be repeated for a total of 20-30 minutes.

In theory you could make the session up as you go along, throwing in some jogs, runs, sprints, backward running etc. as and when. But in practise this becomes hard for athletes to a) push themselves and b) measure progression over time.

Here are some example fartlek training sessions for different sports and events:

Sample Fartlek Training Sessions

Session 1 – Long Distance Events (10k, 5k, 3k, Cycling)

- Warm up with a steady jog for 10 minutes
- Run hard, above race pace for 4-5 minutes
- Jog slowly for 1 minute
- Repeat 6-8 times
- Cool down at a steady pace for 10 minutes

Session 2 – Middle Distance Events (1500m, 3k, 5k)

- Warm up with a steady jog for 10 minutes
- Run hard, above race pace for 3 minutes
- Jog slowly for 1 minute
- Repeat 6-8 times
- Cool down at a steady pace for 10 minutes

Session 3 – Astrand Fartlek (800m)

- Warm up with a steady jog for 10 minutes
- Run hard, above race pace for 75 seconds
- Jog for 150 seconds
- Run hard, above race pace for 60 seconds
- Jog for 120 seconds
- Repeat 3-4 times
- Cool down at a steady pace for 10 minutes

Session 4 – Mulit-Sprint Sports (Soccer, basketball tennis etc.)

- Warm up with a steady jog for 10 minutes
- Jog for 60 seconds
- Run hard (3/4 pace) for 90 seconds
- Jog for 45 seconds
- Sprint for 10 seconds
- Jog for 30 seconds
- Run backwards for 30 seconds
- Walk for 30 seconds
- Run hard for 60 seconds
- Repeat 3-4 times
- Cool down at a steady pace for 10 minutes

Fartlek training is good in the early pre-season. It's an ideal session to re-introduce athletes to more demanding endurance work after the summer or winter layoff. One or two sessions per week combined with interval training is ample.

41

Plyometric Training For Sport Specific Power

Plyometric training has been shown to be one of the most effective methods for improving explosive power. A wide variety of athletes can benefit from power training, particularly if it follows or coincides with a strength training program.

This article outlines how to set up a plyometric program covering the parameters for sets, repetitions and exercise selection. The guidelines on this page can be used in conjunction with the various animated lower body plyometric exercises and upper body plyometric drills in this section of the website.

If you are interested in how plyometric training works and the physiology behind it, see the the physiology of plyometrics article.

Plyometrics & The Strength Training Program

In order for plyometric training to be at its most effective it should follow a phase of maximal strength training. The purpose of plyometrics is to improve the athlete’s capacity to apply more force more rapidly. Logically then, the greater the athlete’s ability to generate maximal force or strength to begin with, the more of it can be converted into sport-specific power. See the sport specific approach to strength training programs for the ‘big picture’ and how plyometrics fits in to the overall strength program.

Plyometric Exercise Selection

There are many plyometric exercises for both the upper and lower body. As with other forms of sports training, exercise selection should mimic the movement patterns of the sport as closely as possible.

Lower Body Plyometric Exercises

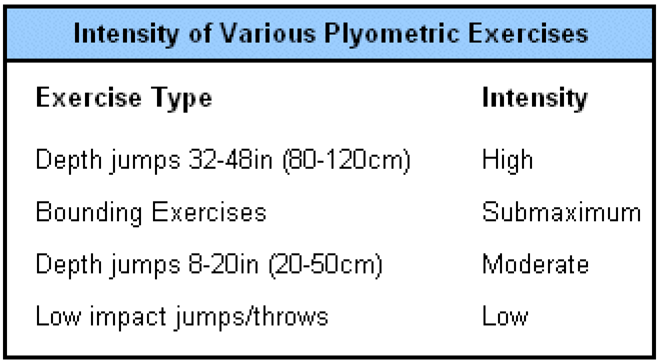
lower body plyometric exercises are suitable for many sports such as basketball, track & filed athletics, sprinting, soccer, hockey, rugby, football, baseball and so on. In fact, performance in any sport that involves jumping, sprinting or kicking can be improved with lower body plyometric exercises.

Upper Body Plyometric Drills

Performance in sports such as basketball, volleyball, softball, baseball, tennis, badminton, golf and the throwing events in athletics can benefit with upper body plyometric exercises. Also, certain position players such as goal keepers in soccer will find these drills useful. Most upper body plyometric drills requires the use of a medicine ball.

Exercise Intensity

The intensity of plyometric exercises varies greatly. Skipping exercises are classed as low intensity, while reactive drop jumps from 32in (80cm) and above are the highest intensity of the plyometric exercises. See the table below for further intensity classifications:



Intensity of Various Plyometric Exercises

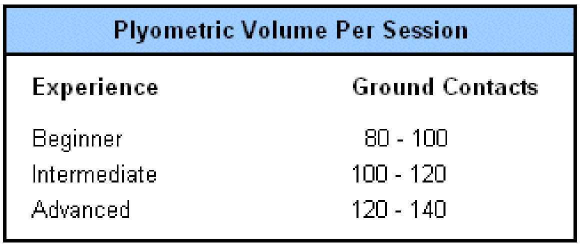
Exercise Type	Intensity
Depth jumps 32-48in (80-120cm)	High
Bounding Exercises	Submaximum
Depth jumps 8-20in (20-50cm)	Moderate
Low impact jumps/throws	Low

Plyometric training should progress gradually from lower intensity to higher intensity drills, especially for individuals who lack a significant strength training background.

Increasing the load by adding additional weight thought weighted vests of ankle weights for example, is not recommended. Too great a load can reduce the speed and quality of movement negating the effects of plyometrics.

Volume

Plyometric volume relates to the number of repetitions per session. For lower body exercises a repetition is a ground contact. See the table below for the number of repetitions recommended for a plyometric training session:



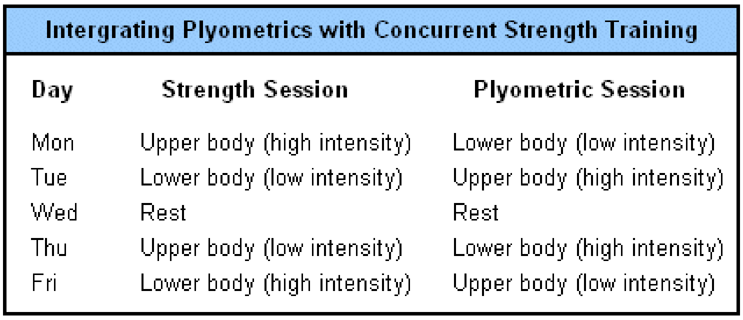
Plyometric Volume Per Session

Experience	Ground Contacts
Beginner	80 - 100
Intermediate	100 - 120
Advanced	120 - 140

Frequency

Typically, 2-3 sessions of plyometrics can be completed in a week. Alternatively, recovery time between sessions can be used to prescribe frequency and is recommended at 48-72 hours .

It is not recommended that plyometric training be scheduled for the day after a heavy weight training session when muscles may still be sore. This poses a planning problem for athletes that may need to strength train 3-4 times per week. The table below offers a solution to this problem by alternating upper and lower body strength training with upper and lower body plyometrics:



Intergrating Plyometrics with Concurrent Strength Training

Day	Strength Session	Plyometric Session
Mon	Upper body (high intensity)	Lower body (low intensity)
Tue	Lower body (low intensity)	Upper body (high intensity)
Wed	Rest	Rest
Thu	Upper body (low intensity)	Lower body (high intensity)
Fri	Lower body (high intensity)	Upper body (low intensity)

The phase of the training program will also determine how many plyometric training sessions are suitable per week. For example, a track and filed athlete may require 3-4 sessions during the preparation phase reducing to 2-3 session in-season. A football player on the other hand may require only 2-3 sessions pre-season reducing to 1-2 sessions during the competitive season.

Rest Intervals

The effectiveness of a plyometric training session depends on maximal effort and a high speed of movement for each repetition. Rest intervals between repetitions and sets should be long enough to allow almost complete recovery. As much as 5-10 seconds may be required between depth jumps and a work to rest ratio of 1:10 is recommended. For example, if a set of bounds takes 30 seconds to complete, the rest interval between sets would be 300 seconds or 5 minutes.

Warming Up

As with any training an adequate warm up is required before completing a plyometric training session. The Nation Strength & Conditioning Association recommends that toe jogging and straight leg jogging be included as part of the warm up to prepare for the shock impact of plyometric drills. Plyometrics should be completed at the start of a combined session when the athlete is fresh.

Safety Considerations

Limited data exists as to whether there is any increased risk of injury through plyometric training. However, due to the stress that repeated shock-tension exercises can place on joints and connective tissue, several safety guidelines have been proposed.

It has been suggested that athletes should be able to complete a one repetition maximum squat a weight 1.5 times that of their bodyweight and bench press a weight 1-1.5 times bodyweight .

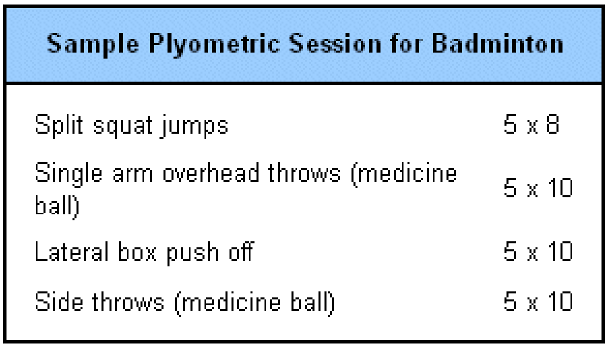
Balance is also an important factor in the safe performance of plyometric exercises. Again, it has been recommended that athletes can stand on one leg for 30 seconds in order to complete less intense exercises. For more advanced exercises they should be able to stand on one leg for 30 seconds in a semi-squat position.

Plyometric training is contraindicated in prepubescent children as it may cause damage to the epithyseal plates that have yet to close . Some strength and conditioning professionals have questioned this as children routinely perform jumping movements as part of unstructured play. However, to be effective, plyometric training requires numerous, repeated maximal efforts. It is the structured nature of training that may pose an over-training risk to younger individuals.

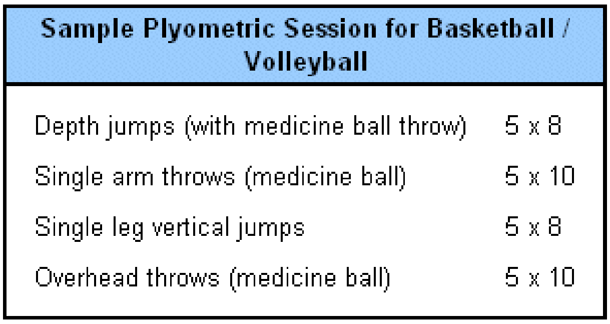
Finally, the landing surface must posses adequate shock absorbing qualities. Good choices include grass, a suspended floor and an exercise mats (not crash mats).

Sample Plyometric Training Sessions

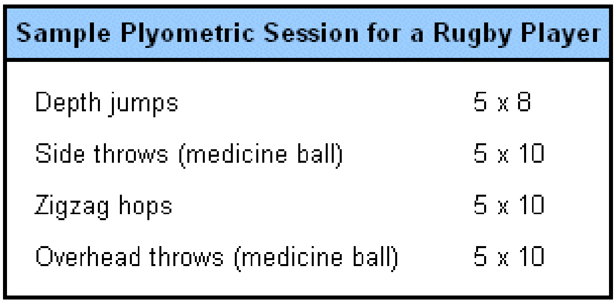
Below are sample plyometric training sessions for badminton, basketball/ volleyball and rugby. You will find more examples in the sport-specific sections of the site.



Sample Plyometric Session for Badminton	
Split squat jumps	5 x 8
Single arm overhead throws (medicine ball)	5 x 10
Lateral box push off	5 x 10
Side throws (medicine ball)	5 x 10



Sample Plyometric Session for Basketball / Volleyball	
Depth jumps (with medicine ball throw)	5 x 8
Single arm throws (medicine ball)	5 x 10
Single leg vertical jumps	5 x 8
Overhead throws (medicine ball)	5 x 10



Sample Plyometric Session for a Rugby Player	
Depth jumps	5 x 8
Side throws (medicine ball)	5 x 10
Zigzag hops	5 x 10
Overhead throws (medicine ball)	5 x 10

You will find animated diagrams for these exercises in the main plyometrics section.

Plyometric training is one of the best ways to create incredible sport-specific power. But it must follow a well-designed program structure that will meet the demands of your sport...

How To Literally DOUBLE Your Vertical Jump (Or Increase By 12 Inches Or More!)

Does this sound impossible? It's a big claim and just imagine what it do to your performance as an athlete - especially if you're a basketball player or volleyball player. Slam dunking and spiking suddenly become effortless!

A special jump program, created by athlete Luke Lowrey, is achieving remarkable results just like these. Based on a combination of proven sports science and Luke's unique training methods, it's helped hundreds of athletes add anything from 6 to 14 inches to their vertical leap (6 inches is the guaranteed minimum)...

42

Lower Body Plyometric Exercises

These animated lower body plyometric exercises can be used to develop power in any sport that involves sprinting, jumping, quick changes of direction and kicking etc. They are most effective when completed in conjunction with a suitable strength training program or following a phase of maximal strength training...

For more details on how to develop a sport-specific strength and power program, and where plyometrics fits into the overall plan, see the sport specific approach to strength training programs.

There is no evidence to suggest the risk of injury is increased during plyometric training in adults. However, as a precaution several safety guidelines have been recommended to keep plyometric exercises as safe as possible. Because plyometrics has received little scientific study compared to conventional strength training, there are no definitive guidelines regarding sets, repetitions and frequency etc. The National Strength & Conditioning Association and several leading experts in the field have proposed parameters that will help coaches and athletes design an effective training plan.

Plyometric Exercise Intensity

Not all plyometric exercises are equal in intensity. Skipping exercises for example, are relatively light while single leg bounds and depth jumps are the most intense. A program should progress gradually from lower intensity drills to more advanced plyometric exercises – particularly in an individual with less strength training experience.

The number of plyometric exercises is typically kept to a minimum also. A typical session may contain only two or three lower body plyometric exercises interspersed with upper body plyometric drills if they're appropriate for that sport.

Correct exercise selection is essential! While there are many plyometric exercises below only a few will be suitable for any one particular sport or event. Again, for all the details on exercise selection, sets, repetitions, rest intervals and so on, see this plyometric training article.

Lower Body Plyometric Exercises (Low Intensity)

Squat Jumps

1. Stand with feet shoulder-width apart, trunk flexed forward slightly with back straight in a neutral position.
2. Arms should be in the "ready" position with elbows flexed at approximately 90°.
3. Lower body where thighs are parallel to ground and immediately explode upwards vertically and drive arms up. Do not hold a squat position before jumping up – keep the time between dipping down and jumping up to a minimum.
4. Land on both feet. Rest for 1-2 seconds and repeat

Prior to takeoff extend the ankles to their maximum range (full plantar flexion) to ensure proper mechanics.

Jump to Box

1. 1.Stand facing box with feet slightly wider than hip-width apart.
2. 2.Lower body into a semi-squat position and immediately jump up onto box. Do not hold a squat position before jumping up – keep the time between dipping down and jumping up to a minimum.
3. Feet should land softly on box. Step back down (not jump back down) and repeat.

Lateral Jump to Box

1. Stand side on to box with feet slightly wider than hip-width apart.
2. Lower body into a semi-squat position and jump up onto box. Do not hold a squat position before jumping up – keep the time between dipping down and jumping up to a minimum.

3. Feet should land softly on box. Step back down (not jump back down) and repeat.

Lower Body Plyometric Exercises (Moderate Intensity)

Split Squat Jumps

1. Stand with feet hip width apart. Take left leg and step back approximately 2 feet standing on the ball of back foot.
2. Feet should be positioned at a staggered stance with head and back erect and straight in a neutral position.
3. Lower body by bending at right hip and knee until thigh is parallel to floor then immediately explode vertically.
4. Switch feet in the air so that the back foot lands forward and vice versa.

Prior to takeoff extend the ankles to their maximum range (full plantar flexion) ensure proper mechanics.

Tuck Jumps

1. Stand with feet shoulder-width apart, knees slightly bent, with arms at sides.
2. Jump up bringing knees up to chest.
3. Land on balls of feet and repeat immediately.
4. Remember to reduce ground contact time by landing soft on feet and springing into air.

Lateral Box Push Offs

1. Stand to side of box and place the left foot on top of box.
2. as high as possible. Drive the arms forward and up for maximum height.
3. Land with right foot on the box and left foot on the ground to the other side of the box.
4. Repeat from this side.

Bounding

1. Jog into the start of the drill for forward momentum.
2. After a few feet, forcefully push off with the left foot and bring the leg forward. At same time drive your right arm forward.
3. Repeat with other leg and arm
4. This exercise is an exaggerated running motion focusing on foot push-off and air time.

Bounding with Rings

1. Jog into the start of the drill for forward momentum.
2. After a few feet, forcefully push off with the left foot and bring the right leg forward. At same time swing left arm forward and land into the first ring, which is 3-4 feet out and to the left, with the right foot.
3. Continue and repeat with other leg and arm into the second ring, which is now 3-4 feet up and to the right.
4. This exercise is an exaggerated running motion focusing on foot push-off and air time.

Box Drill with Rings

1. Stand with feet slightly wider than hip-width apart with your body facing the first ring.
2. Hop forward using both feet and land in first ring.
3. Now hop to the left and land in the ring to the side. Now jump backwards to land in ring behind you. Finish by jumping to your right to land in final ring.
4. Rest and repeat. Remember to keep ground contact time between bounds to a minimum.Hurdle Jumps

Lateral Hurdle Jumps

1. Stand beside object to be cleared.
2. Bring knees up and jump vertically but also laterally off ground and over the barrier.
3. Land on both feet and immediately jump the other direction over barrier.

4. Try not to pause between jumps or sink down into a squat position.

Lower Body Plyometric Exercises (High Intensity)

Zigzag Hops

1. Stand to the left of an agility ladder or similar object approximately 1-2 feet away.
2. Forcefully push off both feet and land the on the other side of the ladder.
3. Repeat and land feet back on the other side, continue repeating and so on down the ladder.4. Do not "double hop" upon each landing and keep ground contact time to a minimum.

Single Leg Tuck Jump

This is the same as the tuck jump exercise above only one leg is used. Upon landing another jump is performed immediately with minimal ground contact time and with the same leg for the desired number of repetitions. This is repeated for the other leg after a rest period. Single leg plyometric exercises are typically more advanced and require greater strength and balance. They are suitable for sports were a takeoff is completed on one leg.

Single Leg Lateral Hops

1. Start by standing on one leg with your hands on your waist or at your sides.
2. Proceed to hop to the side while maintaining your balance and hop back to the starting position.
3. You can place a rope on the ground or any object on the ground. The object can be small in size and height or large to increase difficulty.
4. Repeat continuously.

Depth Jumps

1. Stand on box with toes close to edge, feet shoulder width apart.
2. Step off (do not jump off) box and land on both feet. Immediately jump up as high as possible and reach up with both hands towards. The jump should be vertical with no horizontal movement.

3. Ground contact time should be short unlike in the diagram. Landing should be soft.Note: Start with a box height of 30cm (12in). Intensity can be increased by gradually increasing the box height to a maximum of 107cm (42in) but this is only for experienced athletes with a substantial strength training background.

43

Upper Body Plyometric Drills

These animated plyometric drills are used to develop explosive power in the upper body. Lower body plyometric exercises can be found on a separate page.

There are several different methods of power training. The simplest is to perform classic weight lifting exercises, such as bench presses, as explosively as possible. The problem with this method is that the barbell has to be decelerated at the end of the movement so the lifter can keep control of it. This inevitable slowing down causes a loss of power. These upper body plyometric drills allow maximum power to be generated because, unlike barbells or dumbbells, the medicine ball can be released into the air.

Racket sports such as tennis, badminton and squash, the throwing events in athletics, basketball, volleyball, rugby, and football, the martial arts and wrestling all require upper body power. Plyometric drills can be used to convert an athlete’s maximal strength training into sport-specific power helping to further improve performance.

See the sport specific approach to strength training programs article for more details about how plyometric drills fit into the annual strength and conditioning plan.

Plyometrics has not had the same level of scientific study compared to traditional strength training. As yet there are no definitive guidelines regarding volume, intensity and frequency etc. However, guidelines have been set out by leading authorities in the field. See the plyometric training article for more details.

Upper Body Plyometric Drills

Overhead Throws

1. Stand with one foot in front (staggered stance) with knees slightly bent.
2. Pull medicine ball back behind head and forcefully throw ball forward as far as possible into the wall.
3. Catch ball on the bounce from the wall and repeat according to prescribed repetitions. Keep the time between pulling the ball back and starting the throw (transition phase) to a minimum. Can also be completed with a partner instead of a wall.

Side Throws

1. Stand with feet hip-width apart; place left foot approximately one foot in front of right foot.
2. Hold medicine ball with both hands and arms only slightly bent.
3. Swing ball over to the right hip and forcefully underhand toss ball forward to a partner or wall. Keep the stomach drawn in to maximize proper usage of muscle.
4. Catch ball on the bounce from your partner or wall and repeat.

Over Back Toss

1. Stand with feet slightly wider than hip-width apart. Have a partner or trainer stand approximately 10-15 yards behind you.
2. Grasp ball and lower body into a semi-squat position. Explode up extending the entire body and throwing medicine ball up and over the body.
3. The goal is to throw the ball behind you as far as you and generating most of the power in the legs.
4. Catch ball on the bounce from your partner and repeat according to prescribed repetitions.

Slams

1. Stand with feet parallel, shoulder-width apart and knees slightly bent.
2. Pull medicine ball back behind head and forcefully throw ball down on the ground as hard as possible.
3. Catch the ball on the bounce from the ground and repeat according to prescribed repetitions.

Explosive Start Throws

1. Stand with feet slightly wider than hip-width apart. Knees should be slightly bent.
2. Pick medicine ball up to chest level.
3. Quickly explode up and press the ball straight out as far and fast as you can.
4. As you press the ball forward explode with either leg so that you actually sprint forward a couple of steps.

Single Arm Overhead Throws

1. Stand with feet slightly wider than hip-width apart.
2. Grasp medicine and lower body into a semi-squat position. Explode up extending the entire body and throwing the medicine ball up into the air.
3. The aim is to throw the ball as high as you can and generating most of the power in the legs.
4. Catch ball on the bounce and repeat.

Squat Throws

1. Stand with feet slightly wider than hip-width apart. Knees should be slightly bent.
2. Hold medicine ball at chest level and squat down to a parallel position.
3. Quickly explode up and jump as high as you can. As you start your jump you should start to shoulder press the ball up and reach full extensions with the arms when you are at the peak of your jump. Push ball as high as possible into the air. Try to minimize the time spent in

the squatted position. It should be a quick squat and jump.

4. Catch ball on the bounce and repeat according to prescribed repetitions.

Plyometric Push-Ups

1. Start by getting into a push-up position.
2. Lower yourself to the ground and then explosively push up so that your hands leave the ground.
3. Catch your fall with your hands and immediately lower yourself into a push-up again and repeat.

Plyometrics drills are a superb way to increase your sport-specific power. But they must follow a suitable program structure designed to meet the demands of your sport...

44

The Physiology of Plyometrics

Plyometrics refers to exercise that enables a muscle to reach maximum force in the shortest possible time . The muscle is loaded with an eccentric (lengthening) action, followed immediately by a concentric (shortening) action.

This article outlines the physiology behind how and why plyometrics works. It also examines the research that demonstrates why, as a form of power training, plyometric training is very effective.

Practical guidelines for designing a plyometric training program along with animated drills can be found in the main plyometric training section

How Plyometric Exercises Work

A muscle that is stretched before a concentric contraction, will contract more forcefully and more rapidly. A classic example is a “dip" just prior to a vertical jump. By lowering the center of gravity quickly, the muscles involved in the jump are momentarily stretched producing a more powerful movement. But why does this occur? Two models have been proposed to explain this phenomenon. The first is the…

Mechanical Model

In this model, elastic energy is created in the muscles and tendons and stored as a result of a rapid stretch . This stored energy is then released when the stretch is followed immediately by a concentric muscle action. According to Hill (9) the effect is like that of stretching a spring, which wants to return to its natural length. The spring is this case a component of the muscles and tendons called the series elastic component. The second model is the…

Neurophysical Model

When a quick stretch is detected in the muscles, an involuntary, protective response occurs to prevent overstretching and injury. This response is known as the stretch reflex. The stretch reflex increases the activity in the muscles undergoing the stretch or eccentric muscle action, allowing it to act much more forcefully. The result is a powerful braking effect and the potential for a powerful concentric muscle action .

If the concentric muscle action does not occur immediately after the pre-stretch, the potential energy produced by the stretch reflex response is lost. (i.e. if there is a delay between dipping down and then jumping up, the effect of the counter-dip is lost).

It is thought that both the mechanical model (series elastic component) and the neurophysical model (stretch reflex) increase the rate of force production during plyometrics exercises.

The Stretch-Shortening Cycle

All plyometric movements involve three phases. The first phase is the pre-stretch or eccentric muscle action. Here, elastic energy is generated and stored.

The second phase is the time between the end of the pre-stretch and the start of the concentric muscle action. This brief transition period from stretching to contracting is known as the amortization phase. The shorter this phase is, the more powerful the subsequent muscle contraction will be.

The third and final phase is the actual muscle contraction. In practice, this is the movement the athlete desires – the powerful jump or throw.

This sequence of three phases is called the stretch-shortening cycle. In fact, plyometrics could also be called stretch-shortening cycle exercises.

How to Increase Your Vertical Jump

One very quick and simple way to demonstrate the effect of the stretch-shortening cycle is to perform two vertical jumps. During the first vertical jump the athlete bends the knees and hips (eccentric muscle action or pre-stretch) and holds the semi-squat position for 3-5 seconds before jumping up vertically (concentric contraction) as high as possible. The 3-5 second delay increases the amortization phase.

On the second jump the athlete bends the knees and hips to the same degree but immediately jumps up without a delay. This keeps the amortization phase to a minimum and makes best use of the stored elastic energy. The second jump will be higher.

Is Plyometric Training Really That Effective?

By making use of the stretch-shortening cycle, movements can be made more powerful and explosive. Plyometrics is simply a set of drills designed to stimulate the series elastic component over and over again – preferably during movements that mimic those is the athlete's sport. But what long-term effect does practising plyometrics have on the body and performance?

A wide variety of training studies shows that plyometrics can improve performance in vertical jumping, long jumping, sprinting and sprint cycling. It appears also that a relatively small amount of plyometric training is required to improve performance in these tasks. Just one or two types of plyometric exercise completed 1-3 times a week for 6-12 weeks can significantly improve motor performance. Additionally, only a small amount of volume is required to bring about these positive changes i.e. 2-4 sets of 10 repetitions per session or 4 sets of 8 repetitions.

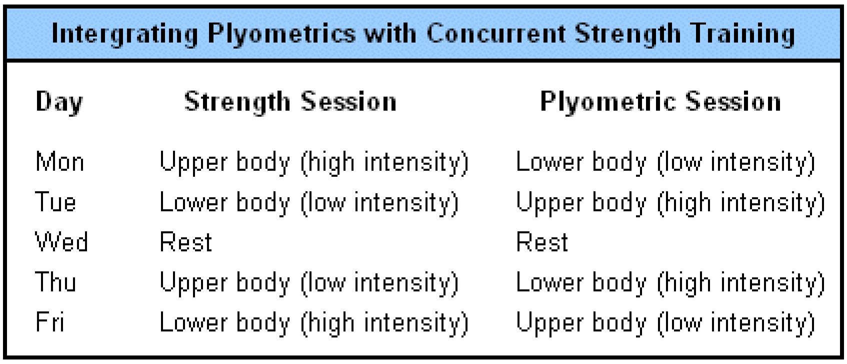
While upper body plyometrics has received less attention, three sessions of plyometric push ups a week has been shown to increase upper body power as measured by medicine ball throws.

Using a variety of plyometric exercises such as depth jumps, counter-movement jumps, leg bounding and hopping etc., can improve motor performance. While the majority of studies have focused on untrained subjects, trained athletes such as soccer and basketball players have improved their performance with plyometrics.

Plyometrics & Concurrent Strength Training

A conditioning program consisting of both plyometric training and resistance training can improve power performance in the vertical jump and 40yard sprint time.

It appears that concurrent resistance and plyometrics training can actually improve power to a greater extent than either one alone. However, the overall program should be carefully planned as heavy weight training and plyometric training are not recommended on the same day. One way around this is to alternate upper body and lower body exercises as follows:



Intergrating Plyometrics with Concurrent Strength Training

Day	Strength Session	Plyometric Session
Mon	Upper body (high intensity)	Lower body (low intensity)
Tue	Lower body (low intensity)	Upper body (high intensity)
Wed	Rest	Rest
Thu	Upper body (low intensity)	Lower body (high intensity)
Fri	Lower body (high intensity)	Upper body (low intensity)

Plyometrics & Injury

Strength and conditioning specialists are often cautious in their prescription of plyometrics due to what they believe is an inherent risk of injury. However, there is limited data to either confirm or reject this claim.

Several researchers have explicitly stated that no injuries occurred during their plyometric studies . Most do not mention whether injuries occurred or not or to what extent.

As a precaution it has been suggested that athletes have a substantial strength training background. The criteria often cited is that the athlete should be able to back squat 1.5-2x bodyweight for lower body plyometrics and bench press 1x bodyweight for upper body plyometrics .

If injuries are more likely to occur with this form of training it may be due to improper landing, landing surface or depth jumps from too great a height . Several studies have measured the height of depth jumps on vertical jump performance. Depth jumps from both 50cm (19.7) and 80cm (31.5in) both improved power to the same extent . The same results were found between jumps of 75cm and 110cm and between jumps of 50cm and 100cm. This suggests that there may be little or no added benefits of jumping from heights above 50cm (19.7in) even though the risk of injury is likely to rise.

Finally, landing surface is an important component of the plyometrics session. It should posses adequate shock absorbing properties such as grass, rubber mats and a suspended floor. Concrete, tiles, hardwood and crash mats are not suitable .

Plyometrics is one of the best ways to develop sport-specific power. But you must have a well-designed program structure for them to be truely effective...

45

Flexibility Exercises

This compilation of flexibility exercises targets all the major muscle groups.

Stretching should form a fundamental part of any exercise program and not just as part of the warm up...

In fact recent research suggests that static stretching may not be beneficial before training or athletic performance. Dynamic stretching seems to be more appropriate as part of the warm up.

If you're not sure what the difference is between various types of stretching see the main flexibility training section for more details.

The flexibility exercises on this page are classed as static stretches. When is static stretching best performed? Ideally, after an exercise session when the body is fully warm. Many athletes perform a series of flexibility exercises like those below at the end of a training session or even after competition.

While you don't have to be an athlete to benefit from stretching, you should be thoroughly warmed up before you begin to stretch.

Here are some general guidelines to bear in mind when following a flexibility program...

- You should be thoroughly warmed up before performing these exercises
- Stretch to just before the point of discomfort
- The feeling of tightness should diminish as you hold the stretch
- Breath out into the stretch. Avoid breath holding
- Hold each stretch for 10-30 seconds
- If tightness intensifies or you feel pain stop the stretch
- Shake out limbs between stretches
- Complete 2-3 stretches before moving onto the next exercise

Upper Body Flexibility Exercises

Stretch #1 – Shoulder & Chest

This can be performed kneeling or standing. Clasp hands behind back and straighten arms. Raise hands as high as possible and bend forward from the waist and hold.

Stretch #2 – Arm Across Chest

Place one arm straight across chest. place hand on elbow and pull arm towards chest and hold. Repeat with other arm.

Stretch #3 – Triceps Stretch

Place one hand behind back with elbow in air. Place other hand on elbow and gently pull towards head. Hold and repeat with other arm.

Lower Body Flexibility Exercises

Stretch #4 – Glute Stretch

Sitting on floor with right leg bent, place right foot over left leg. Place left arm over right leg so elbow can be used to push right knee. Hold and repeat for other side.

Stretch #5 – Adductor Stretch

Stand with feet as wide apart as is comfortable. Shift weight to one side as knee bends. Reach towards extended foot and hold. Repeat for other side.

Stretch #6 – Single Leg Hamstring

Place leg out straight and bend the other so your foot is flat into your thigh. Bend forward from the waist keeping your back flat. Hold and repeat with the other leg.

Stretch #7 – Standing Quadriceps

Standing on one leg grab the bottom of one leg (just above ankle). Pull heel into buttocks and push the hips out. Your thigh should be perpendicular to the ground. Hold and repeat with the other leg.

Stretch #8 – Standing Calf

Place feet in front of each other about 18 inches apart. Keep back leg straight and heel on the floor. Push against a wall to increase the stretch. Hold and repeat with other leg.

46

Flexibility Training Section

Flexibility training is perhaps the most undervalued component of conditioning. While recent and ongoing debate questions its role in injury prevention, athletes can still gain much from a stretching regime.

From a volleyball spike to a rugby drop kick, flexibility of the body’s muscles and joints play an integral part in many athletic movements.

In general terms, flexibility has been defined as the range of motion about a joint and its surrounding muscles during a passive movement . Passive in this context simple means no active muscle involvement is required to hold the stretch. Instead gravity or a partner provides the force for the stretch.

The Benefits of Flexibility Training

By increasing this joint range of motion, performance may be enhanced and the risk of injury reduced . The rationale for this is that a limb can move further before an injury occurs.

Tight neck muscles for example, may restrict how far you can turn your head. If, during a tackle, your head is forced beyond this range of movement it places strain on the neck muscles and tendons.

Ironically, static stretching just prior an event may actually be detrimental to performance and offer no protection from injury. The emphasis is on "may" however, as a closer examination of the scientific literature shows that effects are often minimal and by no means conclusive.

Muscle tightness, which has been associated with an increased risk of muscle tears, can be reduced before training or competing with dynamic stretching. For this reason many coaches now favor dynamic stretches over static stretches as part of the warm up.

Competitive sport can have quite an unbalancing effect on the body. Take racket sports for example. The same arm is used to hit thousands of shots over and over again. One side of the body is placed under different types and levels of stress compared to the other. The same is true for sports like soccer and Australian rules football where one kicking foot usually predominates. A flexibility training program can help to correct these disparities preventing chronic, over-use injury.

Of course, a more flexible athlete is a more mobile athlete. It allows enhanced movement around the court or field with greater ease and dexterity. Some other benefits may include an increase in body awareness and a promotion of relaxation in the muscle groups stretched - both of which may have positive implications for skill acquisition and performance.

Types of Flexibility and Stretching

1. Dynamic flexibility -- the ability to perform dynamic movements within the full range of motion in the joint. Common examples include twisting from side to side or kicking an imaginary ball. Dynamic flexibility is generally more sport-specific than other forms of mobility.
2. Static Active flexibility -- this refers to the ability to stretch an antagonist muscle using only the tension in the agonist muscle. An example is holding one leg out in front of you as high as possible. The hamstring (antagonist) is being stretched while the quadriceps and hip flexors (agonists) are holding the leg up.
3. Static Passive flexibility -- the ability to hold a stretch using body weight or some other external force. Using the example above, holding your leg out in font of you and resting it on a chair. The quadriceps are not required to hold the extended position.

A flexibility training program can be made up of different types of stretching:

1. Dynamic stretching
2. Ballistic stretching
3. Static Active stretching
4. Static Passive stretching
5. Isometric stretching
6. PNF stretching

Which type of flexibility training is best?

It depends on the sport and the athlete's outcomes - something which will be examined more closely in the articles below. As a general rule, dynamic stretches are used as part of a warm up and static stretches or PNF flexibility training is used for increasing range of motion.

Flexibility Training Articles

The Physiology of Flexibility

Here's a quick review of what determines a person's flexibility - an some of the physiological components important in stretching...

Static Stretching Exercises and Flexibility Training Program

Static stretching exercises are best performed when your body is completely warmed up - often at the end of game or training session. Avoid static stretching immediately before competition, especially if your sport is speed and power based...

Dynamic Stretches & Stretching Routine

Use these dynamic stretches as part of your warm up routine. Dynamic stretching has been shown to decrease muscle tightness which may be associated to an increased risk of muscles and tendon tears...

Self Myofascial Release Exercises

While not strictly flexibility training, self myofascial release techniques can have a number of performance and rehabilitation benefits. With just the aid of a foam roll, athletes can reduce muscular pain and those 'trigger points' also associated with muscle tears...

47

Isometric Stretching Explained

One of most effective methods for improving static passive flexibility is through the use of isometric stretching.

An advanced form of flexibility training that must be prescribed with caution, it is useful for developing extreme range of motion associated with martial arts for example.

Placing an outstretched leg on a chair and using your bodyweight to bring about a stretch is an example of static passive stretching. If, during the stretch, the hamstrings are contracted (i.e. trying to bend knee by pressing the heel into the chair) the activity becomes an isometric stretch.

An isometric, or static contraction occurs when tension is created in the muscle group without a change in its length. A chair, wall, the floor or a partner can act as the resistance to bring about a static contraction and isometric stretch.

Aside from increasing range of motion, a second purpose of isometric stretching is to develop strength in stretched positions.

If someone with weak hip adductors attempts to see how far they can do a side split, there will come a point where their legs start to slide further and further apart. They simply don't posses the strength to hold themselves in position.

How Isometric Stretching Works

When a muscle is stretched, some muscle fibres are elongated while others will remain at rest. This is similar to the "all or none" principle of muscle contraction. The greater the stretch, the more individual fibres are stretched fully (rather than all fibres being stretched to a greater extent).

When a muscle, that is already in a stretched position, is subjected to an isometric contraction, additional fibres are stretched that would have otherwise remained at rest. Those resting fibres are pulled on from both ends by the muscle groups that are contracting. Fibres already in a stretched position (before the onset of the isometric contraction) are prevented from contracting by the inverse myotatic reflex and stretch to greater extent.

Isometric Stretching Guidelines

Here are the general guidelines that must be followed if isometric stretching is to be beneficial...

1. Leave 48 hours between isometric stretching routines.
2. Perform only one exercise per muscle group in a session.
3. For each muscle group complete 2-5 sets of the chosen exercise.
4. Each set should consist of one stretch held for 10-15 seconds.
5. Isometric stretching is not recommended for anyone under the age of 18.
6. If isometric stretching is to be performed as a separate exercise session, a thorough warm up consisting of 5-10 minutes of light aerobic exercise and some dynamic stretches must precede it.
7. Do not perform isometric stretching as part of a warm up or on the morning of competition. It is too intense and may adversely affect power performance. Stick to dynamic stretches.

48

PNF Stretching

PNF stretching (or proprioceptive muscular facilitation) is one of the most effective forms of flexibility training for increasing range of motion.

PNF techniques can be both passive (no associated muscular contraction) or active (voluntary muscle contraction). While there are several variations of PNF stretching, they all have one thing in common - they facilitate muscular inhibition. It is believed that this is why PNF is superior to other forms of flexibility training .

Both isometric and concentric muscle actions completed immediately before the passive stretch help to achieve autogenic inhibition - a reflex relaxation that occurs in the same muscle where the golgi tendon organ is stimulated. Often the isometric contraction is referred to as 'hold' and the concentric muscle contraction is referred to as 'contract'.

A similar technique involves concentrically contracting the opposing muscle group to that being stretched in order to achieve reciprocal inhibition - a reflex muscular relaxation that occurs in the muscle that is opposite the muscle where the golgi tendon organ is stimulated.

Using these techniques of 'contracting', 'holding' and passive stretching (often referred to as 'relax') results in three PNF stretching techniques. Each technique, although slightly different, involves starting with a passive stretch held for about 10 seconds.

For clarity and to compare each technique, think of a hamstring stretch in the supine (on back, face up) position for each example. The athlete places one leg extended, flat on the floor and the other extended in the air as close to right angles to the body as possible.

Hold-Relax

- A partner moves the athlete,s extended leg to a point of mild discomfort. This passive stretch is held for 10 seconds.
- On instruction, the athlete isometrically contracts the hamstrings by pushing their extended leg against their partner's hand. The partner should apply just enough force so that the leg remains static. This is the 'hold' phase and lasts for 6 seconds.
- The athlete is then instructed to 'relax' and the partner completes a second passive stretch held for 30 seconds. The athlete's extended leg should move further than before (greater hip flexion) due to autogenic inhibition activated in the hamstrings.

Contract-Relax

- A partner moves the athlete's extended leg to a point of mild discomfort. This passive stretch is held for 10 seconds.
- On instruction, the athlete concentrically contracts the hamstrings by pushing their extended leg against their partner's hand. The partner should apply enough force so that there is resistance while allowing the athlete to push their leg to the floor (i.e. through the full range of motion). This is the 'contract' phase.
- The athlete is then instructed to 'relax' and the partner completes a second passive stretch held for 30 seconds. The athlete's extended leg should move further than before (greater hip flexion) due to autogenic inhibition activated in the hamstrings.

Hold-Relax with Opposing Muscle Contraction

- A partner moves the athlete's extended leg to a point of mild discomfort. This passive stretch is held for 10 seconds.
- On instruction, the athlete isometrically contracts the hamstrings by pushing their extended leg against their partner's hand. The partner should apply just enough force so that the leg remains static. This is the 'hold' phase and lasts for 6 seconds. This initiates autogenic inhibition.
- The partner completes a second passive stretch held for 30 seconds,

however the athlete is instructed to flex the hip (i.e. pull the leg in the same direction as it is being pushed). This initiates reciprocal inhibition allowing the final stretch to be greater.

Here are some other general guidelines when completing PNF stretching:

1. Leave 48 hours between PNF stretching routines.
2. Perform only one exercise per muscle group in a session.
3. For each muscle group complete 2-5 sets of the chosen exercise.
4. Each set should consist of one stretch held for up to 30 seconds after the contracting phase.
5. PNF stretching is not recommended for anyone under the age of 18.
6. If PNF stretching is to be performed as a separate exercise session, a thorough warm up consisting of 5-10 minutes of light aerobic exercise and some dynamic stretches must precede it.
7. Avoid PNF immediately before, or on the morning of competition.

49

Self Myofascial Release

Self myofascial release techniques (SMRT), although not new, have become more and more prominent amongst athletes and fitness enthusiasts alike.

Both allopathic and alternative Therapists have embraced the use of myofascial release massage to reduce chronic pain and rehabilitate a range of injuries. Some therapists claim a long list of benefits, from curing tennis elbow to IBS relief. While some claims may be contentious, it seems likely that many sports men and women can benefit from this regenerative therapy.

It’s important to understanding two key terms in order to appreciate how self myofascial release technique acts favourably on the body. They are ’fascia’ and ’trigger points’. Both are explored below before moving on to some sample self myofascial release exercises.

Fascia & Trigger Points

Fascia is a specialized connective tissue layer surrounding muscles, bones and joints and gives support and protection to the body. It consists of three layers - the superficial fascia, the deep fascia and the subserous fascia. Fascia is one of the 3 types of dense connective tissue (the others being ligaments and tendons) and it extends without interruption from the top of the head to the tip of the toes.

Fascia is usually seen as having a passive role in the body, transmitting mechanical tension, which is generated by muscle activity or external forces. Recently, however some evidence suggests that fascia may be able to actively contract in a smooth muscle-like manner and consequently influence musculoskeletal dynamics.

Obviously, if this is verified by future research, any changes in the tone or structure of the fascia could have significant implications for athletic movements and performance. This research notwithstanding, the occurrence of trigger points within dense connective tissue sheets is thought to be correlated with subsequent injury.

Trigger points have been defined as areas of muscle that are painful to palpation and are characterized by the presence of taut bands. Tissue can become thick, tough and knoted. They can occur in muscle, the muscle-tendon junctions, bursa, or fat pad . Sometimes, trigger points can be accompanied by inflammation and if they remain long enough, what was once healthy fascia is replaced with inelastic scar tissue.

It has been speculated that trigger points may lead to a variety of sports injuries - from camps to more serious muscle and tendon tears. The theory, which seems plausible, is that trigger points compromise the tissue structure in which they are located, placing a greater strain on other tissues that must compensate for its weakness. These in turn can break down and so the spiral continues.

According to many therapists, trigger points in the fascia can restrict or alter the motion about a joint resulting in a change of normal neural feedback to the central nervous system. Eventually, the neuromuscular system becomes less efficient, leading to premature fatigue, chronic pain and injury and less efficient motor skill performance. An athlete's worst nightmare!

What causes a trigger point to form?

The list of proposed causes includes acute physical trauma, poor posture or movement mechanics, over training, inadequate rest between training sessions and possibly even nutritional factors .

Self myofascial release is a relatively simple technique that athletes can use to alleviate trigger points. Studies have shown myofascial release to be an effective treatment modality for myofascial pain syndrome, although most studies have focused on therapist-based rather than self-based treatment.

Self Myofascial Release Exercises

For these exercises you will need a foam roll (which is very inexpensive). You can get them from anywhere that sell sports medicine or physical therapy supplies. Online, try www.power-systems.com who sell a variety of foam rolls.

Adductor Self Myofascial Release

1. Extend the thigh and place foam roll in the groin region with body prone (face down) on the floor.
2. Be cautious when rolling near the adductor complex origins at the pelvis.
3. If a “tender point” is located, stop rolling, and rest on the tender point until pain decreases by 75%.

Hamstring Self Myofascial Release

1. Place hamstrings on the roll with hips unsupported.
2. Feet can be crossed so that only leg at a time is one the foam roll.
3. Roll from knee toward posterior hip.
4. If a “tender point” is located, stop rolling, and rest on the tender point until pain decreases by 75%.

Quadriceps Slef Myofascial Release

1. Body is positioned prone (face down) with quadriceps on foam roll
2. It is very important to maintain proper core control (abdominal drawn-in position & tight gluteus) to prevent low back compensations
3. Roll from pelvic bone to knee, emphasizing the lateral (outside) thigh
4. If a “tender point” is located, stop rolling, and rest on the tender point until pain decreases by 75%.

Iliotibial Band Self Myofascial Release

1. Position yourself on your side lying on foam roll.
2. Bottom leg is raised slightly off floor.
3. Maintain head in “neutral” position with ears aligned with shoulders.
4. This may be PAINFUL for many, and should be done in moderation.

5. Roll just below hip joint down the outside thigh to the knee.
6. If a “tender point” is located, stop rolling, and rest on the tender point until pain decreases by 75%.

Upper Back Self Myofascial Release

1. Place hands behind head or wrap arms around chest to clear the shoulder blades across the thoracic wall.
2. Raise hips until unsupported.
3. Stabilize the head in a “neutral” position.
4. Roll mid-back area on the foam roll.
5. If a “tender point” is located, stop rolling, and rest on the tender point until pain decreases by 75%.

General Guidelines

- Spend 1-2 minutes per self myofascial release technique and on each each side (when applicable).
- When a trigger point is found (painful area) hold for 30-45 seconds.
- Keep the abdominal muscles tight which provides stability to the lumbo-pelvic-hip complex during rolling.
- Remember to breathe slowly as this will help to reduce any tense reflexes caused by discomfort.
- Complete the self myofascial release exercises 1-2 x daily.

50

The Wingate Test for Anaerobic Power

The Wingate test, also known as the Wingate Anaerobic Test (WANT), was developed at the Wingate Institute, in Israel, during the 1970s.

It is perhaps the most popular assessment for peak anaerobic power, anaerobic fatigue and total anaerobic capacity.

Before we look at the Wingate test in a little more detail, what exactly is anaerobic power?

Anaerobic power reflects the ability of the adenosine triphosphate and phosphocreatine (ATP-PCr) energy pathways to produce energy.

In short... adenosine triphosphate (ATP) is created and stored in muscle cells. These muscle cells then generate mechanical work (i.e. running) from the energy produced in a naturally occurring chemical reaction that converts ATP into adenosine diphosphate (ADP) and a phosphate (P)...

ATP is stored in limited supplies that are quickly consumed by muscle cells during exercise.

So... the body uses an organic compound found in muscle tissue called phosphocreatine and the resulting ADP to re-synthesize ATP.

The ATP-PC energy pathway defines the energy created by a breakdown of PCr to a re-synthesized ATP.

- Peak anaerobic power represents the highest mechanical power generated during any 3-5 second interval of the test (see below).
- Anaerobic capacity in the Wingate test is the total amount of work accomplished over a 30-second bout. Finally...
- Anaerobic fatigue is the percentage decline in power compared with the peak power output.

Wingate Test Protocol

The Wingate test requires the subject to pedal a mechanically braked bicycle ergometer (an arm ergometer can also be used), for 30 seconds, at an "all out" pace.

A counter is used to record revolutions of the flywheel in 5-second intervals.

Although the actual Wingate test is performed in a 30-second time span, the individual is advised to complete a warm-up (3-5 minutes), followed by a recovery cool down (1-2 minutes).

On commencing the test (usually by a verbal signal from the tester), the individual pedals "all out" with no resistance. Within 3 seconds, the predetermined fixed resistance is applied to the flywheel and remains there for the duration of the 30-second test.

Resistance

There are two primary bicycle ergometers used for the Wingate test... the Fleisch ergometer and the modified Monark ergometer. Fleisch ergometer resistance = 0.045 kg per kilogram of body weight Monark ergometer resistance = 0.075 kg per kilogram of body weight.

For power athletes and sprint athletes, resistance is often increased to values in the range of 1.0 kg per kilogram of body weight to 1.3 kg per kilogram of body weight.

So on the Monarch ergometer a 70kg athlete the flywheel resistance would equal 5.25kg (70 x 0.075).

Test Scores

Calculated measures from the Wingate test include:

1. Peak Power (PP)

Peak power is ideally measured in first 5-second interval of the Wingate test and is expressed as follows:

Force x Total Distance (Time in minutes)

Force is the amount of resistance (kg) added to the flywheel. Total distance is the number of revolutions x the distance per revolution. Time is 5 seconds or 0.0833 minutes. The result for peak power is expressed in watts (W).

2. Relative Peak Power (RPP)

Relative peak power is determined simply by dividing peak power by body mass and is expressed as W/kg

3. Anaerobic Fatigue (AF)

Anaerobic fatigue is calculated as follows:

Highest 5-second peak power output - Lowest 5-second peak power output (Highest 5-second peak power output. Then multiply by 100 to get the percentage decline.

4. Anaerobic Capacity (AC)

Anaerobic capacity is expressed as kilogram-Joules (1 kg-m = 9.804 J) and is calculated by adding together each 5-second peak power output over the 30 seconds.

Refferences:

1. Ankle Sprains at a Military Male School: Taping Versus Bracing.Farzad Najafipour; Farshad Najafipour; Ahura Ahmadi. Journal of Archives in Military Medicine : 2014, Volum 2, Issue 3, Aug
2. Effect of Imagery Technic on Chronic Low Back Pain.Farzad Najafipour; Farshad Najafipour; Amir Norozi ; and Ahura Ahmadi. Journal of Archives in Military Medicine: 2014, Volum 2, Issue 4, Nov
3. Factors influencing pacing in triathlon.Wu SS, Peiffer JJ, Brisswalter J, Nosaka K, Abbiss CR.Open Access J Sports Med. 2014 Sep 16;5:223-34.
4. Developmental gene networks: a triathlon on the course to T cell identity.Yui MA, Rothenberg EV.Nat Rev Immunol. 2014 Aug;14(8):529-45.
5. Tough mudder injuries, triathlon drownings, and team rhabdomyolysis in the Navy.Eichner ER.Curr Sports Med Rep. 2014 Mar-Apr;13(2):66-7.
6. Heat stroke risk for open-water swimmers during long-distance events.Macaluso F, Barone R, Isaacs AW, Farina F, Morici G, Di Felice V.Wilderness Environ Med. 2013 Dec;24(4):362-5.
7. Trends in Triathlon Performance: Effects of Sex and Age.Lepers R, Knechtle B, Stapley PJ.Sports Med. 2013 Sep;43(9):851-63.
8. Recreational water-related illness: office management and prevention. Sanborn M, Takaro T.Can Fam Physician. 2013 May; 59(5): 491-5.
9. Training transfer: scientific background and insights for practical application.Issurin VB.Sports Med. 2013 Aug;43(8):675-94.
10. Hydration-dehydration, heat, humidity, and "cool, clear, water".Lockett LJ.Sports Med Arthrosc. 2012 Dec;20(4):240-3.
11. The medical perspective of the Kona Ironman Triathlon.Laird RH, Johnson D.Sports Med Arthrosc. 2012 Dec;20(4):239.
12. The triathlon tips from the top: practical tips for racing and training for a triathlon.Bales J, Bales K, Deakon R, Johnson D.Sports Med Arthrosc. 2012 Dec;20(4):237-8.
13. Masterful care of the aging triathlete.Wright VJ.Sports Med Arthrosc. 2012

Dec;20(4):231-6.

14. Triathlon: how to mentally prepare for the big race.Bales J, Bales K.Sports Med Arthrosc. 2012 Dec;20(4):217-9.
15. Training on a knife's edge: how to balance triathlon training to prevent overuse injuries.Bales J, Bales K.Sports Med Arthrosc. 2012 Dec;20(4):214-6.
16. Triathlon: running injuries.Spiker AM, Dixit S, Cosgarea AJ.Sports Med Arthrosc. 2012 Dec;20(4):206-13.
17. Chronic musculoskeletal conditions associated with the cycling segment of the triathlon; prevention and treatment with an emphasis on proper bicycle fitting.Deakon RT.Sports Med Arthrosc. 2012 Dec;20(4):200-5.
18. Swimming overuse injuries associated with triathlon training.Bales J, Bales K.Sports Med Arthrosc. 2012 Dec;20(4):196-9.
19. Hyperthermic-related challenges in aquatics, athletics, football, tennis and triathlon.Mountjoy M, Alonso JM, Bergeron MF, Dvorak J, Miller S, Migliorini S, Singh DG.Br J Sports Med. 2012 Sep;46(11):800-4.
20. Nutrition for endurance sports: marathon, triathlon, and road cycling.Jeukendrup AE.J Sports Sci. 2011;29 Suppl 1:S91-9.
21. Impact of endurance and ultraendurance exercise on DNA damage.Wagner KH, Reichhold S, Neubauer O.Ann N Y Acad Sci. 2011 Jul;1229:115-23.
22. Defending Dynepo detection.Gmeiner G, Reichel C, Kulovics R, Scheiblhofer V.Drug Test Anal. 2010 Nov-Dec;2(11-12):526-32.
23. Effects of oral salt supplementation on physical performance during a half-ironman: A randomized controlled trial.Del Coso J, González-Millán C, Salinero JJ, Abián-Vicén J, Areces F, Lledó M, Lara B, Gallo-Salazar C, Ruiz-Vicente D.Scand J Med Sci Sports. 2015 Feb 14.
24. Stroke after Piercing Barbed Wire Injury: A Time for Introspection.Jain RS, Agrawal R, Kumar S, Gupta PK.J Stroke Cerebrovasc Dis. 2015 Jan 28. pii: S1052-3057(14)00589-8.
25. Effects of branched amino acids in endurance sports: a review.Salinas-García ME, Martínez-Sanz JM, Urdampilleta A, Mielgo-Ayuso J, Norte Navarro A, Ortiz-Moncada R.Nutr Hosp. 2014 Nov 16;31(2):577-89.
26. Implant design influences patient outcome after total knee arthroplasty: a prospective double-blind randomised controlled trial.Hamilton DF, Burnett R, Patton JT, Howie CR, Moran M, Simpson AH, Gaston P.Bone Joint J.

2015 Jan;97-B(1):64-70.

27. Self-report Versus Direct-Measurement for Assessment of Fluid Intake During a 70.3-mile Triathlon.Wilson PB, Rhodes GS, Ingraham SJ.Int J Sports Physiol Perform. 2015 Jan 5.
28. Energy balance of triathletes during an ultra-endurance event.Barrero A, Erola P, Bescós R.Nutrients. 2014 Dec 31;7(1):209-22.
29. Pacing strategies during the swim, cycle and run disciplines of sprint, Olympic and half-Ironman triathlons.Wu SS, Peiffer JJ, Brisswalter J, Nosaka K, Lau WY, Abbiss CR.Eur J Appl Physiol. 2015 Jan 4.
30. A variant within the AQP1 3'-untranslated region is associated with running performance, but not weight changes, during an Ironman Triathlon.Saunders CJ, Posthumus M, O'connell K, September AV, Collins M.J Sports Sci. 2014 Dec 15:1-7.
31. Condylar-Stabilizing Tibial Inserts Do Not Restore Anteroposterior Stability After Total Knee Arthroplasty.Sur YJ, Koh IJ, Park SW, Kim HJ, In Y.J Arthroplasty. 2014 Nov 26. pii: S0883-5403(14)00894-8.
32. Ugly duckling or Nosferatu? Cardiac injury in endurance sport - screening recommendations.Leischik R, Dworrak B.Eur Rev Med Pharmacol Sci. 2014;18(21):3274-90.
33. An Ironman triathlon reduces neuromuscular performance due to impaired force transmission and reduced leg stiffness.Mueller SM, Knechtle P, Knechtle B, Toigo M.Eur J Appl Physiol. 2014 Dec 4.
34. The prevalence of trimetazidine use in athletes in Poland: excretion study after oral drug administration.Jarek A, Wójtowicz M, Kwiatkowska D, Kita M, Turek-Lepa E, Chajewska K, Lewandowska-Pachecka S, Pokrywka A.Drug Test Anal. 2014 Nov-Dec;6(11-12):1191-6.
35. Water and sediment quality, nutrient biochemistry and pollution loads in an urban freshwater lake: balancing human and ecological services.Waltham NJ, Reichelt-Brushett A, McCann D, Eyre BD.Environ Sci Process Impacts. 2014 Dec;16(12):2804-13.
36. Cardiac Damage Biomarkers Following a Triathlon in Elite and Non-elite Triathletes.Park CH, Kim KB, Han J, Ji JG, Kwak YS.Korean J Physiol Pharmacol. 2014 Oct;18(5):419-23.
37. Cardiovascular screening for recreational, leisure, vigorous and competitive sport activities over 35 years.Leischik R, Littwitz H, Dworrak

B, Spelsberg N, Seyfarth M, Tiroch K.Dtsch Med Wochenschr. 2014 Oct;139(43):2188-94.

38. The impact of triathlon training and racing on athletes' general health.Vleck V, Millet GP, Alves FB.Sports Med. 2014 Dec;44(12):1659-92.
39. Analysis of session-RPE and profile of mood states during a triathlon training camp.Comotto S, Bottoni A, Moci E, Piacentini MF.J Sports Med Phys Fitness. 2014 Oct 7.
40. The best triathletes are older in longer race distances - a comparison between Olympic, Half-Ironman and Ironman distance triathlon.Knechtle R, Rüst CA, Rosemann T, Knechtle B.Springerplus. 2014 Sep 18;3:538.
41. Factors influencing pacing in triathlon.Wu SS, Peiffer JJ, Brisswalter J, Nosaka K, Abbiss CR.Open Access J Sports Med. 2014 Sep 16;5:223-34.
42. Profile of injures prevalence in athletes who participated in SESC Triathlon Caiobá-2011.Bertola IP, Sartori RP, Corrêa DG, Zotz TG, Gomes AR.Acta Ortop Bras. 2014;22(4):191-6.
43. Report of a recurrent cerebral venous thrombosis in a young athlete.Richard S, Lacour JC, Frotscher B, Enea A, Mione G, Ducrocq X.BMC Neurol. 2014 Sep 22;14:182.
44. Innovative approach to interpret the variability of biomarkers after ultra-endurance exercise: the multifactorial analysis.Vassalle C, Piaggi P, Weltman N, Prontera C, Garbella E, Menicucci D, Lubrano V, Piarulli A, Castagnini C, Passera M, Pellegrini S, Metelli MR, Bedini R, Gemignani A, Pingitore A.Biomark Med. 2014;8(6):881-91.
45. A comparison of performance of Deca Iron and Triple Deca Iron ultra-triathletes.Knechtle B, Rosemann T, Lepers R, Rüst CA.Springerplus. 2014 Aug 24;3:461.
46. Intensity profile during an ultra-endurance triathlon in relation to testing and performance.Barrero A, Chaverri D, Erola P, Iglesias X, Rodríguez FA.Int J Sports Med. 2014 Dec;35(14):1170-8.
47. Biventricular Response of the Heart to Endurance Exercise Training in Previously Untrained Subjects.Rojek A, Bialy D, Przewlocka-Kosmala M, Negrusz-Kawecka M, Mysiak A, Kosmala W.Echocardiography. 2014 Sep 9.
48. Endurance sport and "cardiac injury": a prospective study of recreational

ironman athletes.Leischik R, Spelsberg N.Int J Environ Res Public Health. 2014 Sep 3;11(9):9082-100.

49. Treatment of lateral knee pain using soft tissue mobilization in four female triathletes.Winslow J.Int J Ther Massage Bodywork. 2014 Sep 3;7(3):25-31.
50. Examining the relationship between sex and motivation in triathletes.López-Fernández I, Merino-Marbán R, Fernández-Rodríguez E.Percept Mot Skills. 2014 Aug;119(1):42-9.
51. Generic anthropometric and performance characteristics among elite adolescent boys in nine different sports.Pion J, Segers V, Fransen J, Debuyck G, Deprez D, Haerens L, Vaeyens R, Philippaerts R, Lenoir M.Eur J Sport Sci. 2014 Aug 21:1-10.
52. Exercise-induced arterial hypertension - an independent factor for hypertrophy and a ticking clock for cardiac fatigue or atrial fibrillation in athletes?Leischik R, Spelsberg N, Niggemann H, Dworrak B, Tiroch K.F1000Res. 2014 May 12;3:105.
53. Sex difference in top performers from Ironman to double deca iron ultra-triathlon.Knechtle B, Zingg MA, Rosemann T, Rüst CA.Open Access J Sports Med. 2014 Jun 26;5:159-72.
54. Developmental gene networks: a triathlon on the course to T cell identity.Yui MA, Rothenberg EV.Nat Rev Immunol. 2014 Aug;14(8):529-45.
55. Increased shape and size offerings of femoral components improve fit during total knee arthroplasty.Dai Y, Scuderi GR, Penninger C, Bischoff JE, Rosenberg A.Knee Surg Sports Traumatol Arthrosc. 2014 Dec; 22(12): 2931-40.
56. Triathletes are over-represented in a population of patients with ALS.Gotkine M, Friedlander Y, Hochner H.Amyotroph Lateral Scler Frontotemporal Degener. 2014 Dec;15(7-8):534-6.
57. Laparoscopic hernia repair with adductor tenotomy for athletic pubalgia: an established procedure for an obscure entity.Rossidis G, Perry A, Abbas H, Motamarry I, Lux T, Farmer K, Moser M, Clugston J, Caban A, Ben-David K.Surg Endosc. 2015 Feb;29(2):381-6.
58. Similar early migration when comparing CR and PS in Triathlon™ TKA: A prospective randomised RSA trial.Molt M, Toksvig-Larsen S.Knee.

2014 Oct;21(5):949-54.

59. Performance and sex difference in ultra-triathlon performance from Ironman to Double Deca Iron ultra-triathlon between 1978 and 2013.Rüst CA, Rosemann T, Knechtle B.Springerplus. 2014 May 1;3:219.
60. Does high flexion after total knee replacement really improve our patients' quality of life at a short-term follow-up? : a comparative case-control study with hyperflex PFC Sigma versus a Triathlon knee series.Mencière ML, Epinette JA, Gabrion A, Arnalsteen D, Mertl P.Int Orthop. 2014 Oct;38(10):2079-86.
61. Effects of deceptive running speed on physiology, perceptual responses, and performance during sprint-distance triathlon.Taylor D, Smith MF.Physiol Behav. 2014 Jun 22;133:45-52.
62. Relationship between physiological parameters and performance during a half-ironman triathlon in the heat.Del Coso J, González C, Abian-Vicen J, Salinero Martín JJ, Soriano L, Areces F, Ruiz D, Gallo C, Lara B, Calleja-González J.J Sports Sci. 2014;32(18):1680-7.
63. IGF-I receptor 275124A>C (rs1464430) polymorphism and athletic performance.Ben-Zaken S, Meckel Y, Nemet D, Eliakim A.J Sci Med Sport. 2014 Mar 18.
64. Heart rate recovery in elite Spanish male athletes.Peinado AB, Benito PJ, Barriopedro M, Lorenzo I, Maffulli N, Calderón FJ.J Sports Med Phys Fitness. 2014 Jun;54(3):264-70.
65. A novel running mechanic's class changes kinematics but not running economy.Craighead DH, Lehecka N, King DL.J Strength Cond Res. 2014 Nov;28(11):3137-45.
66. Nation related participation and performance trends in 'Ironman Hawaii' from 1985 to 2012.Dähler P, Rüst CA, Rosemann T, Lepers R, Knechtle B.BMC Sports Sci Med Rehabil. 2014 Apr 15;6:16.
67. Half-ironman induces changes in the kidney function of triathletes.Puggina EF, Machado DR, Tourinho Filho H, Barbanti VJ.An Acad Bras Cienc. 2014 Mar;86(1):429-36.
68. Triathlon sport -- doping und brain doping--hand in hand?.Sportverletz Sportschaden. 2014 Mar;28(1):4.
69. Five-year survivorship and patient-reported outcome of the Triathlon single-radius total knee arthroplasty.Scott CE, Clement ND, Macdonald

DJ, Hamilton DF, Gaston P, Howie CR, Burnett R.Knee Surg Sports Traumatol Arthrosc. 2014 Mar 13.

70. Tough mudder injuries, triathlon drownings, and team rhabdomyolysis in the Navy.Eichner ER.Curr Sports Med Rep. 2014 Mar-Apr;13(2):66-7.
71. Functional outcomes comparing Triathlon versus Duracon total knee arthroplasty: does the Triathlon outperform its predecessor?Palmer J, Sloan K, Clark G.Int Orthop. 2014 Jul;38(7):1375-8.
72. Tracking career performance of successful triathletes.Malcata RM, Hopkins WG, Pearson SN.Med Sci Sports Exerc. 2014 Jun;46(6):1227-34.
73. The LEAF questionnaire: a screening tool for the identification of female athletes at risk for the female athlete triad.Melin A, Tornberg AB, Skouby S, Faber J, Ritz C, Sjödin A, Sundgot-Borgen J.Br J Sports Med. 2014 Apr;48(7):540-5.
74. A near-fatal case of exercise-associated hyponatremia.Severac M, Orban JC, Leplatois T, Ichai C.Am J Emerg Med. 2014 Jul;32(7):813.e1-2.
75. Comparison of patient reported outcomes after Triathlon(®) and Kinemax Plus prostheses.Dixon S, Blom AW, Whitehouse MR, Wylde V.Ann R Coll Surg Engl. 2014 Jan;96(1):61-6.
76. Bike and run pacing on downhill segments predict Ironman triathlon relative success.JohnsonEC, Pryor JL, Casa DJ, Belval LN, Vance JS, DeMartini JK, Maresh CM, Armstrong LE.J Sci Med Sport. 2015 Jan;18(1):82-7.
77. Age, sex and (the) race: gender and geriatrics in the ultra-endurance age.Whyte G.Extrem Physiol Med. 2014 Jan 1;3(1):1.
78. Compression stockings do not improve muscular performance during a half-ironman triathlon race.Del Coso J, Areces F, Salinero JJ, González-Millán C, Abián-Vicén J, Soriano L, Ruiz D, Gallo C, Lara B, Calleja-Gonzalez J.Eur J Appl Physiol. 2014 Mar;114(3):587-95.
79. The effect of tourniquet use on fixation quality in cemented total knee arthroplasty a prospective randomized clinical controlled RSA trial.Molt M, Harsten A, Toksvig-Larsen S.Knee. 2014 Mar;21(2):396-401.
80. Variability in power output during cycling in international Olympic-distance triathlon.Etxebarria N, D'Auria S, Anson JM, Pyne DB, Ferguson RA.Int J Sports Physiol Perform. 2014 Jul;9(4):732-4.
81. High-intensity cycle interval training improves cycling and running

performance in triathletes.Etxebarria N, Anson JM, Pyne DB, Ferguson RA.Eur J Sport Sci. 2014;14(6):521-9.

82. An epidemiological investigation of training and injury patterns in triathletes.Zwingenberger S, Valladares RD, Walther A, Beck H, Stiehler M, Kirschner S, Engelhardt M, Kasten P.J Sports Sci. 2014;32(6):583-90.
83. Physiological assessment of isolated running does not directly replicate running capacity after triathlon-specific cycling.Etxebarria N, Hunt J, Ingham S, Ferguson R.J Sports Sci. 2014;32(3):229-38.
84. Somatotype, training and performance in Ironman athletes.Kandel M, Baeyens JP, Clarys P.Eur J Sport Sci. 2014;14(4):301-8.
85. Early PROMs following total knee arthroplasty--functional outcome dependent on patella resurfacing.Baker PN, Petheram T, Dowen D, Jameson SS, Avery PJ, Reed MR, Deehan DJ.J Arthroplasty. 2014 Feb;29(2):314-9.
86. Predictive variables for half-Ironman triathlon performance.Gilinsky N, Hawkins KR, Tokar TN, Cooper JA.J Sci Med Sport. 2014 May;17(3):300-5.
87. Elite triathletes in 'Ironman Hawaii' get older but faster.Gallmann D, Knechtle B, Rüst CA, Rosemann T, Lepers R.Age (Dordr). 2014 Feb;36(1):407-16.
88. Master triathletes have not reached limits in their Ironman triathlon performance.Stiefel M, Knechtle B, Lepers R.Scand J Med Sci Sports. 2014 Feb;24(1):89-97.
89. European athletes dominate performances in Double Iron ultra-triathlons--a retrospective data analysis from 1985 to 2010.Rüst CA, Knechtle B, Knechtle P, Lepers R, Rosemann T, Onywera V.Eur J Sport Sci. 2014;14 Suppl 1:S39-50.