



# ENDURANCE SUMMIT **OUTUBRO 2023**

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# ENDURANCE SUMMIT **OUTUBRO 2023**

**07 de Outubro** | Transamerica Expo Center

**FORÇA NOS ESPORTES DE  
ENDURANCE:**

Como treinar seu atleta



# FORÇA

nos esportes de

# ENDURANCE

Como treinar seu atleta

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ADAPTAÇÕES INDUZIDAS PELO TREINAMENTO DE FORÇA E SUAS RELAÇÕES COM A PERFORMANCE

TREINAMENTO DE FORÇA E ENDURANCE:  
O ESTADO DA ARTE

TREINAMENTO DE FORÇA E MODALIDADES DE ENDURANCE: APLICAÇÕES PRÁTICAS

ADAPTAÇÕES INDUZIDAS PELO TREINAMENTO DE FORÇA E SUAS RELAÇÕES COM A PERFORMANCE.

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FORÇA MÁXIMA

RESISTÊNCIA

POTÊNCIA

TAXA DESEN. FORÇA



FORÇA MÁXIMA

POTÊNCIA

RESISTÊNCIA

TAXA DESEN. FORÇA

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Capac. Anaer.

Veloc. Máx.





FORÇA MÁXIMA

POTÊNCIA

RESISTÊNCIA

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Veloc. Máx.





# TREINAMENTO DE FORÇA e ENDURANCE:

O ESTADO DA ARTE



# Stren Endu Theor

Caleb D. Bagley, MA, Head Department of Exercise

## ABSTRACT

THE PURPOSE OF THIS TWO-WORLD-TO-ELUDDA UTILITY OF RESISTANCE FOR ENDURANCE ATHLETE (STRENGTH AND ENDURANCE) TRAINING IN ATHLETIC SETTINGS. BOTH LOW-INTENSITY EXERCISE (LITE) AND HIGH-INTENSITY EXERCISE (HIE) HAVE BEEN TO IMPROVE AS A RESULT. MAXIMAL FORCE, VELOCITY (HVEL) AND LOW-FORCE, HIGH-VELOCITY (LHVEL) STRENGTH TRAINING IS MENDED INITIALLY TO D NEUROMUSCULAR (NM) ENDURANCE ATHLETES. FED STRENGTH TRAINING IS A RESEQUENCED TO STRENGTH TRAINING PHASES OF STRENGTH ENHANCE, BASIC STRENGTH, AND POWER PROVIDE FURTHER ENHANCE IN LITE AND HIE LEVEL ENDURANCE AT

**INTRODUCTION**  
Specific among others regarding the role of training for endurance athletes over 25 years.

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https://doi.org/10.1007/s40279-017-0835-7

## SYSTEMATIC REVIEW

### Effects of Strength Training of Middle- and Long-Distance Runners: A Systematic Review

Richard C. Blagrove<sup>1,2</sup> · Glyn Howatson<sup>1</sup>

Published online: 16 December 2017  
© The Author(s) 2017. This article is an open access publication

**Abstract** Background Middle- and long-distance performance is constrained by several important anaerobic parameters. The efficacy of strength training has received considerable attention in the literature. However, to date, the studies have not been fully synthesized in a topic.

**Objectives** This systematic review aimed to provide a comprehensive critical commentary on the literature that has examined the effects of ST on physiological determinants and performance in middle- and long-distance runners.

**Methods** A search of the literature was conducted using PubMed, Scopus, and Embase. Studies were included if they reported on the effect of ST on physiological determinants and performance in middle- and long-distance runners.

**Results** The review identified 10 studies that met the inclusion criteria. The majority of studies (8/10) reported on the effect of ST on physiological determinants and performance in middle- and long-distance runners.

**Conclusions** The evidence indicates that ST can improve physiological determinants and performance in middle- and long-distance runners.

International Journal of Environmental Research and Public Health

## SYSTEMATIC REVIEW

### Effects of Running-Specific Training and Concurrent Athlete's Performance Parameters

Pablo Prieto-González<sup>1,\*</sup> and Jazmin Sed

Published online: 16 December 2017  
© The Author(s) 2017. This article is an open access publication

**Abstract** Objective: The aim of this study was to examine the effects of running-specific training and concurrent training on performance parameters in runners.

**Methods** A search of the literature was conducted using PubMed, Scopus, and Embase. Studies were included if they reported on the effect of running-specific training and concurrent training on performance parameters in runners.

**Results** The review identified 10 studies that met the inclusion criteria. The majority of studies (8/10) reported on the effect of running-specific training and concurrent training on performance parameters in runners.

**Conclusions** The evidence indicates that running-specific training and concurrent training can improve performance parameters in runners.

## SYSTEMATIC REVIEW

### Acute Neuromuscular Training in Rural and Metropolitan Athletes: A Meta-Analysis

Gustavo Ivo de Carvalho e Silva<sup>1</sup>,  
Micael Deivison de Jesus Alves<sup>1,2</sup>  
Ricardo Aurelio Carvalho Sampaio

Published online: 16 December 2017

© Springer International Publishing 2017

**Abstract** Background: The aim of this study was to examine the effects of acute neuromuscular training on performance parameters in rural and metropolitan athletes.

**Methods** A search of the literature was conducted using PubMed, Scopus, and Embase. Studies were included if they reported on the effect of acute neuromuscular training on performance parameters in rural and metropolitan athletes.

**Results** The review identified 10 studies that met the inclusion criteria. The majority of studies (8/10) reported on the effect of acute neuromuscular training on performance parameters in rural and metropolitan athletes.

**Conclusions** The evidence indicates that acute neuromuscular training can improve performance parameters in rural and metropolitan athletes.

**Keywords:** Competitive training, performance, neuromuscular training, rural athletes, metropolitan athletes.

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Published online: 12 May 2018

Sports Med  
DOI 10.1007/s40279-017-0130-2

## SYSTEMATIC REVIEW

### The Impact of Endurance Training on Performance Parameters: A Systematic Review

Emmet Crowley<sup>1</sup> · Glyn Howatson<sup>1</sup>

Published online: 16 December 2017

© Springer International Publishing 2017

**Abstract** Background: The aim of this study was to examine the effects of endurance training on performance parameters in runners.

**Methods** A search of the literature was conducted using PubMed, Scopus, and Embase. Studies were included if they reported on the effect of endurance training on performance parameters in runners.

**Results** The review identified 10 studies that met the inclusion criteria. The majority of studies (8/10) reported on the effect of endurance training on performance parameters in runners.

**Conclusions** The evidence indicates that endurance training can improve performance parameters in runners.

**Keywords:** Endurance training, performance, neuromuscular training, rural athletes, metropolitan athletes.

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Published online: 12 May 2018

## Review

# Optimizing strength training for running and cycling endurance performance: A review

B. R. Rønnestad<sup>1</sup>, I. Mujika<sup>2,3</sup>

<sup>1</sup>Section for Sport Science, Lillehammer University College, Lillehammer, Norway; <sup>2</sup>Department of Physiology, Faculty of Medicine and Odontology, University of the Basque Country, Leioa, Basque Country, Spain; <sup>3</sup>School of Kinesiology and Health Research Center, Faculty of Medicine, Finis Terrae University, Santiago, Chile  
Corresponding author: Bent R. Rønnestad, PhD, Section for Sport Science, Lillehammer University College, PB. 952, 2604 Lillehammer, Norway. Tel: +47 61288193. Fax: +47 61288200. E-mail: bent.ronnestad@hil.no

Accepted for publication 5 July 2013

Here we report on the effect of combining endurance training with heavy or explosive strength training on endurance performance in endurance-trained runners and cyclists. Running economy is improved by performing combined endurance training with either heavy or explosive strength training. However, heavy strength training is recommended for improving cycling economy. Equivocal findings exist regarding the effects on power output or velocity at the lactate threshold. Concurrent endurance and heavy strength training can increase running speed and power output at  $VO_{2max}$  ( $V_{max}$  and  $W_{max}$ , respectively) or time to exhaustion at  $V_{max}$  and  $W_{max}$ . Combining endurance training with either explosive or heavy strength training can improve running performance, while there is most compelling evidence of an additive effect on cycling performance when heavy strength training is used. It is suggested that the improved endurance performance may relate to delayed activation of less efficient type II fibers, improved neuromuscular efficiency, conversion of fast-twitch type IIX fibers into more fatigue-resistant type IIA fibers, or improved musculo-tendinous stiffness.

**Keywords:** Endurance performance, neuromuscular efficiency, strength training, running economy, cycling economy, lactate threshold, power output, velocity,  $VO_{2max}$ ,  $V_{max}$ ,  $W_{max}$ , time to exhaustion.

The effects of strength training on endurance athletic performance have long been the subject of debate among athletes, coaches, and sport scientists. Strength training includes both explosive strength training and heavy strength training that promote different training adaptations. Heavy strength training can be defined as "all training aiming to increase or maintain a muscle or a muscle group's ability to generate maximum force" (Knuttgén & Kraemer, 1987) and is here equal to training with a load that allows between 1 repetition maximum (RM) and 15 RM. Explosive strength training is here defined as exercises with external loading of 0–60% of 1 RM and maximal mobilization in the concentric phase (0% of 1 RM equals body weight). Performance in most endurance events is mainly determined by the maximal sustained power production for a given competition distance, and the energy cost of maintaining a given competition speed. In shorter endurance events and during accelerations and sprint situations, anaerobic capacity and maximal speed may also contribute to performance. Strength training contributes to enhance endurance performance by improving the economy of movement, delaying fatigue, improving anaerobic capacity, and enhancing maximal speed.

Some of the early studies that investigated the effect of combining endurance and strength training in endurance-trained athletes did not identify any additive

effect on endurance performance (Jensen, 1963; Paavola et al., 1991; Tanaka et al., 1993). However, recent evidence contradicts the findings of those early studies and points toward an additive effect of combining endurance and strength training on running and cycling performance (Tanaka & Swensen, 1998). At the time of this review, there was a lack of good studies on already well-trained endurance athletes, especially in cycling. The purpose of this review is to provide an updated synopsis on the effect of combining endurance training with heavy or explosive strength training on endurance performance in endurance-trained runners and cyclists.

**The effects of strength training on factors determining endurance performance: Maximal oxygen consumption**

Maximal oxygen consumption ( $VO_{2max}$ ) has long been associated with success in endurance sports (Saltin & Astrand, 1967; Costill et al., 1973; Bassett & Howley, 2000) and is one of the major characteristics that determine endurance performance (Di Prampero, 2003; Levine, 2008). Importantly, the highest  $VO_{2max}$  value does not necessarily equate to the best endurance performance, but the best endurance performance typically demands high  $VO_{2max}$  values (Saltin & Astrand, 1967;

effect on endurance performance. However, it is evident that future investigations should include assessments (i.e. squats, jump squats, etc.) in a range of velocities (maximal-speed → speed-strength → reaccelerate appropriate strength programmes (velocity prescription) over a long-term (>6 months) for optimal transfer to performance. However, it is evident that future investigations should include assessments (i.e. squats, jump squats, etc.) in a range of velocities (maximal-speed → speed-strength → reaccelerate appropriate strength programmes (velocity prescription) over a long-term (>6 months) for optimal transfer to performance.

## in Endurance

where swimming, sprint, Olympic, overall volume, risk of injury, is, periodization, due to injury, unclear whether athletes each day sessions is (objective metrics) to complement explore emerging proving training

ormance relies on a complex interplay biomechanical factors. Cardiovascular in thought to be the main limiting factor marine. Classical measures such as ke ( $VO_{2max}$ ) and lactate threshold (LT) ly used in the laboratory to predict the al of runners, cyclists, triathletes and ). Consequently, physical preparation generally focused on developing these alities. However, elite endurance ath- b<sub>max</sub> levels can have differing abilities before maximum oxygen uptake cannot ing ability. Economy, and assessments, rance-specific muscle power compo- (power during maximal oxygen uptake ) and maximal anaerobic running are now thought to be superior perfor- in elite population [2].

mount of metabolic energy expended at power output [3]. Economical move- and is determined by training history, mechanics and physiology [4]. During

quantification;

swimming, cycling, le array of event last about 1 h, vel. In addition r three different training sessions injury sessions, however, ng performance, multidisciplinary aining strategies,

etc demands for on competition, Triathlon Series d Champion title.

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training is a fundamental compo-  
letes competing at the highest level.  
shown that RT training can enhance  
rmance (38) and reduce injuries  
own physiological, biomechanical  
thus improving sporting perfor-  
taining in swimming has been  
research has shown that swimming  
al by the exertion of high impulses  
h the majority of propulsive forces  
city (46) being produced by the  
Strong conditions ( $r = 0.93$ ) have  
er body muscular strength and  
40). Previous research investigating  
revisions has shown significant im-  
g performance (1.16, 1.7, 48), when  
y or high force RT training pro-  
sequently, many of these studies  
r rationale for why coaches choose  
ning exercises. Therefore, there is  
practices and prescription of dry-  
s among elite swimming strength

investigated strength and condition-  
ers a range of sports including  
competitors (44), basketball (39),  
8), and rugby (22). These studies  
o overview of strength and condi-  
ance of new ideas to diversify and  
s. Olympic style weightlifting fea-  
eral of the sports with a high per-  
orting its inclusion within their  
d training consistency, not  
orm of ST into their training  
The squat and clean were reported  
RT training exercise. More specif-  
to SWIM training alone, and this  
sperimental findings [2,7,10,13,14]  
nt training might pose a negative

limiting sessions aiming to improve  
propulsive force [1–3]. During a  
(RT) including various modes of  
in 3–8 sets with 1–6 repeti-  
TT a variety of sporting  
positions, >85% of 1RM, 2–3-min  
ed sessions should be incorporated.  
Therefore, coaches should plan two or  
water swimming training (SWIM).  
training a mesocycle or longer period  
ing LD triathletes from training  
to SWIM training alone, and this  
sperimental findings [2,7,10,13,14]  
nt training might pose a negative

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KATE M. I. ROBERT J. Caled B. Bayley MA, He Department of Exercise

**ABSTRACT**  
Lusk, KM, Bl Bayley, MA, He Department of Exercise  
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**Key Words**  
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L ong-dura current streng after strength train

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INTRODUCTION  
Conflicts among regarding the rol training for endu despite over 25 years

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http://dx.doi.org/10.1007/s40279-017-0835-7

SYSTEMATIC REVIEW

## Effects of Strength Training and Long-Term Endurance Training on Performance in Middle- and Long-Distance Runners: A Systematic Review

Richard C. Blagrove<sup>1,2</sup> · Glyn Ho

Published online: 16 December 2017  
© The Author(s) 2017. This article is an o

**Abstract**  
Background Middle- and long-distance running performance is constrained by several anaerobic parameters. The efficacy of strength training (ST) for distance runners has received little attention in the literature. However, to date studies have not been fully synthesized. **Objectives** This systematic review provides a comprehensive critical commentary that has examined the effects of strength training on performance in middle- and long-distance runners.

**Methods** A search of the literature was conducted to identify studies that examined the effects of strength training on performance in middle- and long-distance runners. **Results** The methodological quality of the included studies was generally high. The majority of studies (n = 10) showed a positive effect of strength training on performance in middle- and long-distance runners. The most common parameters measured were 1000 m time (n = 6), 5 km time (n = 4), and 10 km time (n = 4). The most common training modalities used were resistance training (n = 10), plyometrics (n = 4), and interval training (n = 4). **Conclusions** Strength training appears to be an effective means of improving performance in middle- and long-distance runners. Future research should focus on identifying the optimal training modalities and dosages for this population.

**Keywords** Strength training, Running, Aerobic performance, Endurance, Middle-distance, Long-distance

International Journal of Environmental Research and Public Health

## Effects of Running Training and Long-Term Endurance Training on Performance in Middle- and Long-Distance Runners: A Systematic Review

Fabio Prieto-González<sup>1,2</sup> and J

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**Keywords** Strength training, Running, Aerobic performance, Endurance, Middle-distance, Long-distance

de Carvalho e Silva et al.  
Sports Medicine - Open (2022) 8:105  
https://doi.org/10.1186/s40792-022-00497-w

## SYSTEMATIC REVIEW

# Acute Neuromuscular, Physiological and Performance Responses to Resistance Training in Runners: A Systematic Review and Meta-Analysis

Gustavo Ivo de Carvalho e Silva<sup>1</sup>, Leandro Henrique Almeida Micael Delvison de Jesus Alves<sup>1,2,3</sup>, Felipe J. Aida<sup>1,2,3</sup>, Mateus Ricardo Aurelio Carvalho Sampaio<sup>1,2</sup>, Beat Knechtle<sup>4,5,6,7,8,9,10</sup>

**Abstract**  
**Background:** Strength training (ST) is commonly used to improve performance in runners. However, the acute effects of ST on neuromuscular, physiological, and performance parameters remain unclear. **Objective:** The purpose of this systematic review and meta-analysis was to synthesize the acute effects of ST on neuromuscular, physiological, and performance parameters in runners. **Methods:** A search of the literature was conducted to identify studies that examined the acute effects of ST on neuromuscular, physiological, and performance parameters in runners. **Results:** The methodological quality of the included studies was generally high. The majority of studies (n = 10) showed a positive effect of ST on performance in runners. The most common parameters measured were 1000 m time (n = 6), 5 km time (n = 4), and 10 km time (n = 4). The most common training modalities used were resistance training (n = 10), plyometrics (n = 4), and interval training (n = 4). **Conclusions:** Strength training appears to be an effective means of improving performance in runners. Future research should focus on identifying the optimal training modalities and dosages for this population.

**Keywords:** Competitive training, Running, Aerobic performance, Endurance, Middle-distance, Long-distance

**Introduction**  
Running is a popular sport that has gained significant attention in recent years. One of the key factors influencing running performance is neuromuscular adaptation. Strength training (ST) is commonly used to improve performance in runners. However, the acute effects of ST on neuromuscular, physiological, and performance parameters remain unclear. This systematic review and meta-analysis aims to synthesize the acute effects of ST on these parameters in runners.

**Methods**  
A search of the literature was conducted to identify studies that examined the acute effects of ST on neuromuscular, physiological, and performance parameters in runners. The search was limited to English-language peer-reviewed articles published between 1980 and 2017.

**Results**  
The methodological quality of the included studies was generally high. The majority of studies (n = 10) showed a positive effect of ST on performance in runners. The most common parameters measured were 1000 m time (n = 6), 5 km time (n = 4), and 10 km time (n = 4). The most common training modalities used were resistance training (n = 10), plyometrics (n = 4), and interval training (n = 4). **Conclusions** Strength training appears to be an effective means of improving performance in runners. Future research should focus on identifying the optimal training modalities and dosages for this population.

**Keywords** Competitive training, Running, Aerobic performance, Endurance, Middle-distance, Long-distance

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Sports Med  
DOI 10.1007/s40279-017-0730-2

## SYSTEMATIC REVIEW

# The Impact of Resistance Training on Swimming Performance: A Systematic Review

Emmet Crowley<sup>1</sup> · Andrew J. Harrison<sup>1</sup> · Mark Lyons<sup>1</sup>

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**Abstract**  
**Background** The majority of propulsive forces in swimming are produced from the upper body, with strong correlations between upper body strength and sprint performance. There are significant gaps in the literature relating to the impact of resistance training on swimming performance, specifically the transfer to swimming performance. **Objective** The aims of this systematic literature review are to (1) explore the transfer of resistance-training modalities to swimming performance, and (2) examine the effects of resistance training on technical aspects of swimming. **Methods** Four online databases were searched with the following inclusion criteria: (1) journal articles with outcome measures related to swimming performance, and (2) competitive swimmers participating in a structured resistance-training programme. Exclusion criteria were (1) participants with a mean age <16 years; (2) untrained, novice, masters and paraplegic swimmers; (3) triathletes and waterpolo players; (4) swimmers with injuries or illness; and (5) studies of starts and turns specifically. Data

were extracted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, and the Physiotherapy Evidence Database (PEDro) scale was applied. **Results** For optimal transfer, specific, low-volume, high-velocity/force resistance-training programmes are optimal. Stroke length is best achieved through resistance training with low repetitions at a high velocity/force. Resisted swims are the most appropriate training modality for improving stroke rate. **Conclusion** Future research is needed with respect to the effects of long-term resistance-training interventions on both technical parameters of swimming and overall swimming performance. The results of such work will be highly informative for the scientific community, coaches and athletes.

**Key Points**  
The current literature shows that resistance training can improve swimming performance in response to various types of resistance-training programmes. For optimal transfer, low-volume, high-velocity/force resistance-training programmes are recommended. Trends identified in the literature suggest that for improving stroke length, low repetitions at high intensities are needed and resisted swims could present a viable training modality for increasing stroke rate.

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## Running and cycling endurance

Lillehammer, Norway, <sup>2</sup>Department of Physiology, Faculty of Medicine, Universidad de Murcia, Murcia, Spain, <sup>3</sup>School of Kinesiology and Health Research, Chile, <sup>4</sup>Department of Sport Sciences, University of Jyväskylä, Finland, <sup>5</sup>Department of Sport Sciences, University of Jyväskylä, Finland, <sup>6</sup>Department of Sport Sciences, University of Jyväskylä, Finland, <sup>7</sup>Department of Sport Sciences, University of Jyväskylä, Finland, <sup>8</sup>Department of Sport Sciences, University of Jyväskylä, Finland, <sup>9</sup>Department of Sport Sciences, University of Jyväskylä, Finland, <sup>10</sup>Department of Sport Sciences, University of Jyväskylä, Finland

**W**... respectively) or time to exhaustion at  $V_{max}$  and  $W_{max}$ . Combining endurance training with either explosive or heavy strength training can improve running performance, while there is most compelling evidence of an additive effect on cycling performance when heavy strength training is used. It is suggested that the improved endurance performance may relate to delayed activation of less efficient type II fibers, improved neuromuscular efficiency, conversion of fast-twitch type IIX fibers into more fatigue-resistant type IIA fibers, or improved musculo-tendinous stiffness.

**effect on endurance performance** (Jensen, 1963; Paavolainen et al., 1991; Tanaka et al., 1993). However, recent evidence contradicts the findings of those early studies and points toward an additive effect of combining the endurance and strength training on running and cycling performance (Tanaka & Swensen, 1998). At the time of this review, there was a lack of good studies on already well-trained endurance athletes, especially in cycling. The purpose of this review is to provide an updated synopsis on the effect of combining endurance training with heavy or explosive strength training on endurance performance in endurance-trained runners and cyclists.

### The effects of strength training on factors determining endurance performance

Maximal oxygen consumption ( $VO_{2max}$ ) has long been associated with success in endurance sports (Saltin & Astrand, 1967; Costill et al., 1973; Bassett & Howley, 2000) and is one of the major characteristics that determine endurance performance (Di Prampero, 2003; Levine, 2008). Importantly, the highest  $VO_{2max}$  value does not necessarily equate to the best endurance performance, but the best endurance performance typically demands high  $VO_{2max}$  values (Saltin & Astrand, 1967;

## Endurance

however, it is evident that investigations should focus on the effects of strength training on running and cycling performance. Specifically, the effects of strength training on running and cycling performance should be investigated. This includes the effects of strength training on running and cycling performance, as well as the effects of strength training on running and cycling performance. The effects of strength training on running and cycling performance should be investigated. This includes the effects of strength training on running and cycling performance, as well as the effects of strength training on running and cycling performance.

as a complex interplay of factors. Cardiovascular fitness is the main limiting factor in endurance performance. Other factors such as lactate threshold (LT) and muscle fiber composition are also important. The purpose of this review is to provide an updated synopsis on the effect of combining endurance training with heavy or explosive strength training on endurance performance in endurance-trained runners and cyclists.

strength and conditioning of sports including (4), basketball (3), and (2). These studies of strength and conditioning to diversify and style weightlifting factors with a high percentage within their strength (8%), basketball and clean were reported exercise. More specifically highlighted that various commonly used it was considered the lowest by langes. This scientific and strength carries outlined in

**Key Points**  
The current literature shows that resistance training can improve swimming performance in response to various types of resistance-training programmes. For optimal transfer, low-volume, high-velocity/force resistance-training programmes are recommended. Trends identified in the literature suggest that for improving stroke length, low repetitions at high intensities are needed and resisted swims could present a viable training modality for increasing stroke rate.

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Int. J. Environ. Res. Public Health 2022, 19, 11117



Acute and Long-Term Swimming Training

Gavril Azevedo, Pedro Botelho and Agostinho Trindade

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Abstract: The purpose of this review is to elucidate the utility of resistance training for endurance athletes...

Introduction

Long-term training demands in the sport increase in intensity and volume over time...

Conclusions: Long-term training demands in the sport increase in intensity and volume over time...

Keywords: Endurance, Strength, Training

Journal of Strength and Conditioning Research

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SYSTEMATIC REVIEW

Strength and Endurance Theory

Effects of Strength of Middle- and Long-Distance Runners: A Systematic Review and Meta-Analysis

Richard C. Blagrove

Kate M. Luckie and Robert J. Mead

School of Health Sciences, Aston University

Abstract

The purpose of this review was to elucidate the utility of resistance training for endurance athletes...

Introduction

Conflicts among coaches regarding the role of strength training for endurance athletes...

Keywords: Strength, Endurance, Running

Journal of Strength and Conditioning Research

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Effects of Running-Specific Strength Training, and Concurrent Training, on Middle- and Long-Distance Runners: A Systematic Review and Meta-Analysis

Pablo Prieto-González and Jaromír Sedláček

Health and Physical Education Department of Sport Kinesiology, Pavlov Institute of Sports, Slovakia

Abstract

The present study aimed to examine the effects of running-specific strength training, concurrent training, and aerobic training on endurance performance...

Introduction

Conflicts among coaches regarding the role of strength training for endurance athletes...

Keywords: Running, Strength, Endurance

Journal of Environmental Research and Public Health

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SYSTEMATIC REVIEW

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Acute Neuromuscular, Physiological and Performance Responses After Strength Training in Runners: A Systematic Review and Meta-Analysis

Gustavo Ivo de Carvalho e Silva, Leandro Henrique Albuquerque Brandão, Devisson dos Santos Silva, Micael Delivson de Jesus Alves, Felipe J. Aida, Matheus Santos de Sousa Fernandes, Ricardo Aurélio Carvalho Sampaio, Beat Knechtle and Raphael Fabricio de Souza

Abstract

Background: Strength training (ST) is commonly used to improve muscle strength, power, and neuromuscular adaptations... Objective: The present study aimed to examine the effects of ST on neuromuscular, physiological, and performance variables...

Introduction

Strength training is a common component of training programs for endurance athletes...

Keywords: Strength training, Running, Endurance

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Endurance

Effects of Strength of Middle- and Long-Distance Runners: A Systematic Review and Meta-Analysis

Faculty of Medicine and Health Research

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The purpose of this review was to elucidate the utility of resistance training for endurance athletes...

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**DRY-ELITE** Acute and Long-Distance Triathlon Training Program

Garvill Anonadias, Pedro and Argyris Toubekis

Abstract: E training program research in triathlon training coaches. T land RT tri were to ne exercises coaches at practice a eralities. Te swimming (n = 7), Gt States of A national go format e A. Acce and Long-Term Effects of Informal e Coaching Education and Decreasing Training on Running Class, and Performance. Sports 2022, 19, 29. https://doi.org/10.3390/sports1902029

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Future rese and the tri- mance.

Key Words: triathlon, resistance, endurance

Introduction: Long-distance triathlon (LDT) is a demanding sport, and despite the sport continues to grow, research in participation from coaches, athletes, and sports scientists is limited.

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# Strength Endurance Theory to

## Strength Training of Middle- and Long-Distance Triathletes: A Systematic Review

Caleb D. Bazley, MA, Heather A. Abbott, MEd, Department of Exercise and Sport Science

Richard C. Blagrove<sup>1,2</sup>, Glyn Howatson<sup>1,2,3</sup>

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Abstract: Middle- and long-distance running performance is constrained by several important anaerobic parameters. The efficacy of strength training (ST) for distance runners has received consideration in the literature. However, to date, the studies have not been fully synthesized in a review.

Objectives: This systematic review aimed to provide a comprehensive critical commentary on the literature that has examined the effects of ST modality on physiological determinants and performance

of middle- and long-distance runners. Methods: A systematic search of PubMed, Scopus, and Embase databases was conducted to identify relevant studies published between 1980 and 2017. The search terms used were: "strength training", "endurance", "middle-distance", "long-distance", "triathlon", "running", "performance", "anaerobic", "power", "strength", "endurance", "middle-distance", "long-distance", "triathlon", "running", "performance", "anaerobic", "power", "strength", "endurance".

Results: A total of 10 studies were included in the review. The studies examined the effects of ST on physiological determinants and performance of middle- and long-distance runners. The results showed that ST had a positive effect on physiological determinants and performance of middle- and long-distance runners.

Conclusions: The results of this systematic review suggest that ST is an effective training modality for improving physiological determinants and performance of middle- and long-distance runners. Further research is needed to determine the optimal ST protocol for this population.

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# Effects of Running-Specific Strength Training, Endurance Training, and Concurrent Training on Recreational Endurance Athletes' Performance and Selected Anthropometric Parameters

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Abstract: Objective: The present study aimed to verify the effects of running-specific strength training alone, endurance training alone, and concurrent training on recreational endurance athletes' performance and selected anthropometric parameters. Method: Thirty male recreational endurance runners were randomly assigned using a blocking technique to either a running-specific strength training group (RSSTG), an endurance training group (ETG), or a concurrent training group (CTG). RSSTG performed three strength-training sessions per week orientated to running. ETG underwent three endurance sessions per week, and CTG underwent a 3-day-per-week concurrent training program performed on non-consecutive days, alternating the strength and endurance training sessions applied to RSSTG and ETG. The training protocol lasted 12 weeks and was designed using the ATR (Accumulation, Transmutation, Realization) block periodization system. The following assessments were conducted before and after the training protocol: body mass (BM), body mass index (BMI), body fat percentage (BFP), lean mass (LM), countermovement jump (CMJ), 1RM (one-repetition maximum) squat, running economy at 12 and 14 km/h (RE12 and RE14), maximum oxygen consumption (VO2max), and anaerobic threshold (AnT). Results: RSSTG significantly improved the results in CMJ, 1RM squat, RE12, and RE14. ETG significantly improved in RE12, RE14, VO2max, and AnT. Finally, CTG obtained significant improvements in BFP, LM, CMJ, 1RM squat, RE12, RE14, VO2max, and AnT. RSSTG obtained improvements significantly higher than ETG in CMJ, 1RM squat, and RE14. ETG results were significantly better than those obtained by RSSTG in AnT. Moreover, CTG marks were significantly higher than those obtained by ETG in CMJ and RE14. Conclusion: Performing a 12-week concurrent training program integrated into the ATR periodization system effectively improves body composition and performance variables that can be obtained with exclusive running-specific strength and endurance training in recreational runners aged 30 to 40. Running-specific strength training enhances maximum and explosive strength and RE, whereas exclusive endurance training improves VO2max, AnT, and RE. Performing concurrent training on non-consecutive days effectively prevents the strength and endurance adaptations attained with single-mode exercise from being attenuated. The ATR periodization system is useful in improving recreational endurance athletes' performance parameters, especially when performing concurrent training programs.

Keywords: concurrent training; endurance training; running-specific strength training; periodization; recreational runner

Citation: Prieto-González, P.; Sedlacek, J. Effects of Running-Specific Strength Training, Endurance Training, and Concurrent Training on Recreational Endurance Athletes' Performance and Selected Anthropometric Parameters. Int. J. Environ. Res. Public Health 2022, 19, 10773. https://doi.org/10.3390/ijerph191710773

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Sports Medicine - Open Access

# ular, Physiological Responses After Strength Training: A Systematic Review

Henrique Albuquerque Brandão<sup>1</sup>, Devisson dos Santos Silva<sup>1,2,3</sup>, Aídar<sup>2,3</sup>, Matheus Santos de Sousa Fernandes<sup>3</sup>, Inechtle<sup>6,7</sup> and Raphael Fabrício de Souza<sup>1,2,3</sup>

Abstract: The purpose of this systematic review was to investigate the physiological responses after strength training in different populations. The search was conducted in PubMed, Scopus, and Embase databases. The search terms used were: "strength training", "physiological responses", "endurance", "middle-distance", "long-distance", "triathlon", "running", "performance", "anaerobic", "power", "strength", "endurance", "middle-distance", "long-distance", "triathlon", "running", "performance", "anaerobic", "power", "strength", "endurance".

Results: A total of 10 studies were included in the review. The studies examined the effects of ST on physiological determinants and performance of middle- and long-distance runners. The results showed that ST had a positive effect on physiological determinants and performance of middle- and long-distance runners.

Conclusions: The results of this systematic review suggest that ST is an effective training modality for improving physiological determinants and performance of middle- and long-distance runners. Further research is needed to determine the optimal ST protocol for this population.

Keywords: triathlon, resistance, endurance

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# Strength Training for Endurance Athletes: Theory to Practice

Caleb D. Bazyley, MA, Heather A. Abbott, MEd, Christopher R. Bellon, MA, Christopher B. Taber, MS, and Michael H. Stone, PhD  
Department of Exercise and Sport Science, East Tennessee State University, Johnson City, Tennessee

## ABSTRACT

**THE PURPOSE OF THIS REVIEW IS TWOFOLD: TO ELUCIDATE THE UTILITY OF RESISTANCE TRAINING FOR ENDURANCE ATHLETES, AND PROVIDE THE PRACTITIONER WITH EVIDENCED-BASED PERIODIZATION STRATEGIES FOR CONCURRENT STRENGTH AND ENDURANCE TRAINING IN ATHLETIC POPULATIONS. BOTH LOW-INTENSITY EXERCISE ENDURANCE (LIEE) AND HIGH-INTENSITY EXERCISE ENDURANCE (HIEE) HAVE BEEN SHOWN TO IMPROVE AS A RESULT OF MAXIMAL, HIGH FORCE, LOW VELOCITY (HFLV) AND EXPLOSIVE, LOW-FORCE, HIGH-VELOCITY STRENGTH TRAINING. HFLV STRENGTH TRAINING IS RECOMMENDED INITIALLY TO DEVELOP A NEUROMUSCULAR BASE FOR ENDURANCE ATHLETES WITH LIMITED STRENGTH TRAINING EXPERIENCE. A SEQUENCED APPROACH TO STRENGTH TRAINING INVOLVING PHASES OF STRENGTH-ENDURANCE, BASIC STRENGTH, STRENGTH, AND POWER WILL PROVIDE FURTHER ENHANCEMENTS IN LIEE AND HIEE FOR HIGH-LEVEL ENDURANCE ATHLETES.**

## INTRODUCTION

Conflicts among coaches exist regarding the role of strength training for endurance athletes despite over 25 years of research

supporting its efficacy and application (34-36,46,47,58,64,65,67,71,82). Historically, resistance and endurance training have been viewed as training modalities at opposite ends of a continuum with divergent adaptations (17,41). In a recent meta-analysis, Wilson et al. (92) reported an inverse relationship between frequency and duration of endurance training and subsequent changes in hypertrophy, strength, and power. Alternatively, strength training has been shown to have a positive effect on endurance performance (46,49,51,65,73). Previous research reports that concurrent strength and endurance training can increase endurance performance in high-level athletes to a greater extent than endurance training alone (46,47,58,64,65,82). The interference effects between strength and endurance training are outside the scope of this review and have been discussed extensively in previous studies (23,24,44,54,92). Endurance in sport has been defined as the ability to maintain or repeat a given force or power output (80). Endurance training can be further subdivided into low-intensity exercise endurance (LIEE) and high-intensity exercise endurance (HIEE). LIEE can be defined as long-duration endurance activities or the ability to sustain or to repeat low-intensity exercise. HIEE can be defined as the ability to sustain or to repeat high-intensity exercise and has been associated with sustained activities of  $\leq 2$  minutes (80). Competitive endurance athletes need more than enhanced

aerobic power ( $\dot{V}O_{2max}$ ) and LIEE (34). Requirements for endurance athletes should also include muscular strength, anaerobic power, and HIEE (34-36,46,58,68,82). Furthermore, strength training has been shown to positively influence both LIEE and HIEE across a spectrum of endurance events with greater effects observed in HIEE (34,46,50,58,82,83).

Strength can be defined as the ability to produce force (76). Strength is a skill, which can be expressed in a magnitude of 0-100% (80). In the current endurance literature, 2 primary forms of strength training have been investigated: maximal, high-force, low-velocity, strength training (HFLV) and explosive, low-force, high-velocity strength training (LFHV). Previous studies have examined the effectiveness of concurrent endurance and circuit resistance training, but have demonstrated inferior results (49,73,84). Maximum strength can be defined as the maximal amount of force a muscle or group of muscles can exert against an external resistance and corresponds with the high-force, low-velocity portion of the concentric force-velocity relationship (15,81). The term "explosive strength training" has been used in previous studies in reference to low-force, high-velocity training (0-60% 1 repetition maximum [RM] loads) with maximal movement intent

**KEY WORDS:** periodization; endurance performance; concurrent training

## STRENGTH TRAINING TRIATHLETES: BARRI

KATE M. LUCKIN,<sup>1</sup> CLAIRE E. BADENHO  
ROBERT J. MERRELLS,<sup>1</sup> MAX K. BULSAR  
<sup>1</sup>School of Health Sciences, University of Notre Da  
University, Auckland, New Zealand; <sup>2</sup>School of P  
<sup>3</sup>Institute for Health Research, University of Notr

## ABSTRACT

Luckin, KM, Badenhorst, CE, Cripps, AJ, Landers, GU, Bulsara, MK, and Hoyle, GF. Strength training in triathletes: Barriers and characteristics. *J Strength Cond Res* 2020;34(10):2018-2028. The purpose of this investigation was to determine the barriers to strength training and the characteristics of triathletes who do strength train. A total of 100 triathletes (224 v men; age [y]: 39 ± 10) completed a 68-question self-administered survey that assessed endurance and strength characteristics, experience in triathlon, and perceived barriers to strength training. Mean training time per week was 14.92 ± 5.25, with 54.6% reporting a strength training frequency of 2-3 times per week. Heavy strength training was the most reported (39.4%), with significantly more men completing strength training ( $p < 0.001$ ). Results from participants not completing strength training indicated that perceived barriers (53.1%) in addition to lack of knowledge on exercise prescription and form (52.5%) are prominent perceived barriers to strength training completion. Identification of the barriers to strength training by long-distance triathletes that prevent them from completing strength training and endurance training may help coaches, athletes, and sports scientists who seek to provide strength training for injury prevention and performance improvement.

**KEY WORDS:** triathlon, resistance, endurance

## INTRODUCTION

Long-distance triathlon (LDT) is a demanding sport, and despite its growth, the sport continues to grow rapidly with increases in participation from both profes-

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## Acute and Long-Term Swimming Training

Gavril Arsoniadis<sup>1,2,3,\*</sup>, Petros Botos<sup>1,2,3,\*</sup>, and Argyris Toubekis<sup>1,2,3,\*</sup>

EMMET CROWLEY, ANDREW  
*BioMechanics Research Unit, D.*

**ABSTRACT**  
Crowley, E, Harrison, AJ, and I. Training practices of elite swim coaches. *J Strength Cond Res* 2020;34(10):2018-2028. The purpose of this investigation was to determine the training practices of elite swim coaches. This is the first comprehensive survey of elite swim coaches. The study was conducted in Australia, with 100 elite swim coaches (224 v men; age [y]: 39 ± 10) completing a 68-question self-administered survey that assessed endurance and strength characteristics, experience in triathlon, and perceived barriers to strength training. Mean training time per week was 14.92 ± 5.25, with 54.6% reporting a strength training frequency of 2-3 times per week. Heavy strength training was the most reported (39.4%), with significantly more men completing strength training ( $p < 0.001$ ). Results from participants not completing strength training indicated that perceived barriers (53.1%) in addition to lack of knowledge on exercise prescription and form (52.5%) are prominent perceived barriers to strength training completion. Identification of the barriers to strength training by long-distance triathletes that prevent them from completing strength training and endurance training may help coaches, athletes, and sports scientists who seek to provide strength training for injury prevention and performance improvement.

**KEY WORDS:** h monitoring; n

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## DRY-LAND R ELITE SWIM COACHES

EMMET CROWLEY, ANDREW  
*BioMechanics Research Unit, D.*

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DRY-LAND RT  
ELITE SWIMMERS  
COACHES

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Gavriil Arsoniadis<sup>1,2</sup>, Petros Botonis<sup>1,2</sup>, Gregory C.  
and Argyris Toubekis<sup>1,3,4</sup>

ABSTRACT

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exercises used by elite swimming  
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tralia ( $n = 5$ ), and the United States  
( $n = 5$ )) were recruited. Coaches  
completed a questionnaire consist-  
ing of 7 sections: coach's biograph-  
ical information, dry-land RT prac-  
tices, and additional information  
coaches had varying levels of  
workload with different level swim-  
mer RT training exercises were used  
different dry-land RT training prac-  
tices. Traditional RT training and  
plyometric (87%) was the most com-  
monly used. The most popular dry-  
land RT training exercise used by  
elite swimming strength and health  
Future research needs to focus on  
the transfer of RT training to  
swimmers.

**Keywords:** health  
monitoring; nutrition

1. Introduction

Triathlon is a combination of  
endurance and strength training  
and running are core components  
of the sport. The high training  
demands of triathlon require  
athletes to be well-trained in  
both endurance and strength  
disciplines. The various forms of  
endurance and strength training  
used by triathletes have been  
extensively reviewed (1,2). How-  
ever, several studies

**KEY WORDS** survey, transfer, sp

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Future research needs to focus on  
the transfer of RT training to  
swimmers.

**ABSTRACT**  
Crowley, E, Harrison, AJ, and Ly  
training practices of elite swimmers  
coaches. *J Strength Cond Res*  
research to date has investigated  
training practices of elite swimmers  
coaches. This is the first compre-  
hensive RT training practices in swim-  
mer to examine (a) the dry-land  
exercises used by elite swimming  
coaches and (b) the rationale for  
practices and prescription of spe-  
cific exercises. Twenty-three ( $n = 21$   
swimming strength and condition  
( $n = 7$ ), Great Britain ( $n = 5$ ), Aus-  
tralia ( $n = 5$ ), and the United States  
( $n = 5$ )) were recruited. Coaches  
completed a questionnaire consist-  
ing of 7 sections: coach's biograph-  
ical information, dry-land RT prac-  
tices, and additional information  
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Citation: Arsoniadis, G, Botonis, P,  
Bogdanis, G, Toubekis, A, Argyris,  
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STRENGTH TRAINING IN LONG-DISTANCE  
TRIATHLETES: BARRIERS AND CHARACTERISTICS

KATE M. LUCKIN,<sup>1</sup> CLAIRE E. BADENHORST,<sup>2</sup> ASHLEY J. CRIPPS,<sup>1</sup> GRANT J. LANDERS,<sup>3</sup>  
ROBERT J. MERRELLS,<sup>1</sup> MAX K. BULSARA,<sup>4</sup> AND GERARD F. HOYNE<sup>1</sup>

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ABSTRACT

Luckin, KM, Badenhorst, CE, Cripps, AJ, Landers, GJ, Merrells, RJ,  
Bulsara, MK, and Hoyne, GF. Strength training in long-distance  
triathletes: Barriers and characteristics. *J Strength Cond Res* XX(X):  
000–000, 2018—The purpose of this investigation was to identify  
perceived and physical barriers toward the completion of concurrent  
strength training and endurance training in long-distance triathletes.  
Three hundred ninety long-distance triathletes (224 women, 166  
men; age [y]: 39 ± 10) completed a 68-question self-administered,  
semiquantitative survey that assessed endurance and strength training  
characteristics, experience in triathlon, and perceived barriers  
regarding the completion of strength training. Mean training hours  
per week was 14.92 ± 5.25, with 54.6% reporting participation in  
strength training. Heavy strength training was the most commonly  
reported (39.4%), with significantly more men completing this form  
of strength training ( $p < 0.001$ ). Results from participants who did  
not complete strength training indicated that perceived time constraints  
(53.1%) in addition to lack of knowledge on exercise progression  
and form (52.5%) are prominent perceived barriers to strength training  
completion. Identification of the barriers perceived by long-distance  
triathletes that prevent them from completing concurrent strength  
training and endurance training may be useful for coaches, athletes,  
and sports scientists who seek to incorporate strength training for  
injury prevention and performance improvement.

**KEY WORDS** triathlon, resistance, endurance

INTRODUCTION

Long-distance triathlon (LDT) is a physically  
demanding sport, and despite its grueling nature,  
the sport continues to grow rapidly with large increases  
in participation from both professional and  
amateur athletes. For this investigation, a LDT is classified as  
any distance longer than an olympic distance triathlon (a  
1,500-m swim, 40-km cycle, and a 10-km run completed consecutively).  
The 2 most common forms of LDTs are half iron distance (HID) (1.9-km  
swim, 90-km cycle, and 21.1-km run) and full iron distance (FID) (3.8-km  
swim, 180-km cycle, and 42.2-km run). Long-distance (LD) triathletes  
typically complete large volumes of training, with a reported average of  
13.5–21.5 h·wk<sup>-1</sup> for amateur triathletes (6,18). Only 55.7–63.3% of LD  
triathletes complete some form of strength training (ST) (5,6). Strength  
training for this investigation is classified as any form of resistance  
band, mass or body mass-resisted exercises. Swimming, cycling,  
or running-specific “strength” was not classified as ST (e.g., swimming  
with paddles or cycling and running up a hill).  
Previous research has indicated that the completion of concurrent  
ST and endurance training in runners, cyclists, and triathletes can  
significantly improve running and cycling economy (1,2,7,13,15,16).  
Running and cycling economy are key primary physiological factors  
underpinning endurance performance and are also considered accurate  
predictors of performance in groups of homogenous athletes (1,6).  
Improvements in cycling and running economy as a result of ST occur  
with no interference in the development of maximal oxygen uptake  
(13,17). Strength training programs comprising exercises completed  
with lower repetitions and heavier weights generally result in the  
largest improvements in economy in both endurance runners and  
cyclists (2,3,13,15–17). This form of ST is frequently referred to as  
heavy strength training (HS), with exercise load being greater than  
80% of 1 repetition maximum (RM) and performed in 3–8 sets  
with 1–6 repetitions (4). The incorporation of ST in a variety of  
sporting programs can also reduce injury occurrence (10), likely  
contributing to consistent and regular training and subsequent  
improvements in sports performance. Despite the reported  
improvements to performance and training consistency, not all  
(LD) triathletes incorporate a form of ST into their training  
programs. There is currently no research providing clear indications  
of the barriers preventing LD triathletes from completing ST.  
By successfully identifying the barriers preventing triathletes from  
ST, these can then be addressed by coaches and scientists for  
optimal triathlon performance.

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Training for  
Athletes:  
Practice

Christopher R. Bellon, MA, Christopher B. Taber, MS, and Michael H. Stone, PhD  
East Tennessee State University, Johnson City, Tennessee

Strength training in long-distance triathletes: Barriers and characteristics. *J Strength Cond Res* XX(X): 000–000, 2018—The purpose of this investigation was to identify perceived and physical barriers toward the completion of concurrent strength training and endurance training in long-distance triathletes. Three hundred ninety long-distance triathletes (224 women, 166 men; age [y]: 39 ± 10) completed a 68-question self-administered, semiquantitative survey that assessed endurance and strength training characteristics, experience in triathlon, and perceived barriers regarding the completion of strength training. Mean training hours per week was 14.92 ± 5.25, with 54.6% reporting participation in strength training. Heavy strength training was the most commonly reported (39.4%), with significantly more men completing this form of strength training (p < 0.001). Results from participants who did not complete strength training indicated that perceived time constraints (53.1%) in addition to lack of knowledge on exercise progression and form (52.5%) are prominent perceived barriers to strength training completion. Identification of the barriers perceived by long-distance triathletes that prevent them from completing concurrent strength training and endurance training may be useful for coaches, athletes, and sports scientists who seek to incorporate strength training for injury prevention and performance improvement.

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**KEY WORDS:**  
periodization; endurance performance;  
concurrent training

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Review

Acute and Long-Term Effects of Concurrent Resistance and Swimming Training on Swimming Performance

Gavriil Arsoniadis 1, Petros Botonis 1,2, Gregory C. Bogdanis 3, Gerasimos Terzis 3 and Argyris Toubekis 1,3,\*

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3 Sports Performance Laboratory, School of Physical Education and Sports Science, National and Kapodistrian University of Athens, 17237 Dafne, Greece; gbogdanis@phed.uoa.gr (G.C.B.); gterzis@phed.uoa.gr (G.T.)
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DRY-LAND RESISTANCE ELITE SWIMMING STRENGTH COACHES

EMMET CROWLEY, ANDREW J. HARRISON, AND NAROA ETXEBARRIA

ABSTRACT

Crowley, E. Harrison, AJ, and Lyons, M. Dry-land resistance training practices of elite swimming strength and condition coaches. J Strength Cond Res XX(X): 000–000, 2018

Abstract: Dry-land resistance exercise (RT) is routinely applied concurrent to swimming (SWIM) training sessions in a year-round training plan. To date, the impact of the acute effect of RT on SWIM or SWIM on RT performance and the long-term RT-SWIM or SWIM-RT training outcome has received limited attention. The existing studies indicate that acute RT or SWIM training may temporarily decrease subsequent muscle function. Concurrent application of RT-SWIM or SWIM-RT may induce similar physiological alterations. Such alterations are dependent on the recovery duration between sessions. Considering the long-term effects of RT-SWIM, the limited existing data present improvements in front crawl swimming performance, dry-land upper and lower body maximum strength, and conditioning coaches, from IR (n = 7), Great Britain (n = 5), Australia (n = 6), and the US States of America (n = 5) were recruited through their national governing bodies. Coaches completed an online questionnaire consisting of 7 sections; subject informed consent, coach's biography, coach education, coaching commitments, dry-land RT training practices and cues, and additional information. The results showed coaches had varying levels of experience, education worked with different level swimmers. A total of 95 dry RT training exercises were used by the coaches across different dry-land RT training practices (warm-up, circuit traditional RT training and plyometrics). Traditional RT training (87%) was the most commonly practiced. The pull-up squat were the most popular dry-land RT training exercises used by elite swimming strength and conditioning coaches. Future research needs to focus on exploring the specific and the transfer of RT training exercises to swimming performance.

Keywords: health; period monitoring; nutrition

Review

Training and Coaching

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2 Department of Physiology, Faculty of Health Sciences, University of the Basque Country, Spain; n.etxebarria@exeter.ac.uk
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Received: 12 March 2019; Accepted: 15 February 2020

Abstract: Triathlon is characterized by heavy aerobic endurance performance in cycling, and running are common long-distance, and Ironman triathlons undertaken by triathletes to improve performance, or excessive fatigue, or strategies, and work/rest balance, or maladaptation. Even cellular signals triggered by fatigue interfere with each other. This is an important aspect of training that should be considered when designing the large body of endurance training trends and strategies from the readiness and performance data.

Keywords: health; period monitoring; nutrition

1. Introduction

Triathlon is characterized by heavy aerobic endurance performance in cycling, and running are common long-distance, and Ironman triathlons undertaken by triathletes to improve performance, or excessive fatigue, or strategies, and work/rest balance, or maladaptation. Even cellular signals triggered by fatigue interfere with each other. This is an important aspect of training that should be considered when designing the large body of endurance training trends and strategies from the readiness and performance data.

KEY WORDS survey, transfer, specificity, coaching

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https://www.mdpi.com/journal/sports

IN LONG-DISTANCE TRIATHLONS AND CHARACTERISTICS

HORST, ASHLEY J. CRIPPS, GRANT J. LANDERS, SARA, AND GERARD F. HOYNE

Abstract: The purpose of this study was to investigate the characteristics of elite triathletes in long-distance triathlon.

Background: Long-distance triathlon (LDT) is a demanding sport that requires a high level of endurance and strength. The purpose of this study was to investigate the characteristics of elite triathletes in long-distance triathlon.

Methods: A total of 15 elite triathletes participated in the study. They completed a series of tests to measure their endurance, strength, and other characteristics.

Results: The results of the study showed that elite triathletes have a high level of endurance and strength. They also have a high level of aerobic capacity and a low level of body fat.

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Training and Coaching

The Effect of Strength Training on Endurance Performance in Elite Swimmers

- Kris Beattie · Ian C. Kenny · Brian P. Carson
B. R. Ronnestad, I. Mujika
Emmet Crowley, Andrew J. Harrison, Naroa Etxebarria

Received: 12 March 2019; Accepted: 15 February 2020

Abstract: The purpose of this study was to investigate the effect of strength training on endurance performance in elite swimmers.

Keywords: health; period monitoring; nutrition

1. Introduction

Endurance performance is a key component of success in long-distance triathlon. Strength training is a common method used to improve endurance performance.

KEY WORDS survey, transfer, specificity, coaching

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Sports 2019, 7, 101; doi:10.3390/sports7



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Training and Coaching

Endurance Athletes and Characteristics

- H. Horst, A. J. Cripps, G. J. Landers, S. Sara, and G. F. Hoyne
H. Stone, PhD

Received: 12 March 2019; Accepted: 15 February 2020

Abstract: The purpose of this study was to investigate the characteristics of endurance athletes.

Keywords: health; period monitoring; nutrition

1. Introduction

Endurance athletes are characterized by a high level of aerobic capacity and a low level of body fat.

KEY WORDS survey, transfer, specificity, coaching

Address correspondence to Emmet Crowley, emmet.crowley@ul.ie

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### Training and Competition

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Received: 12 March 2019; Accepted: 25 April 2019;

**Abstract:** Triathlon is characterized by the mix of running and cycling, which are completed sequentially in long-distance, and Ironman formats. The aim of this study was to examine (a) the dry-land RT training practices and (b) the rationale provided by coaches about their training practices and prescription of specific dry-land RT training exercises. Twenty-three (n = 21 males, n = 2 females) elite triathletes completed an online questionnaire consisting of 7 sections; subject information, coaching, coach education, current training commitments, dry-land RT training practices and exercises, and additional information. The results showed that coaches had varying levels of experience, education and worked with different level swimmers. A total of 95 dry-land RT training exercises were used by the coaches across 4 different dry-land RT training practices (warm-up, circuit training, traditional RT training and plyometrics). Traditional RT training (87%) was the most commonly practiced. The pull-up and squat were the most popular dry-land RT training exercises used by elite swimming strength and conditioning coaches. Future research needs to focus on exploring the specificity and the transfer of RT training exercises to swimming performance.

**Keywords:** health; periodization; intensity; nutrition

### 1. Introduction

Triathlon is characterized by the multilateral nature of running and cycling, which are completed sequentially in long-distance, and Ironman formats, ranging from the mixed relay race (also known as triathlon triathlon) to the long-distance triathlon (Ironman), which requires high volumes of training and a high level of aerobic and anaerobic capacity. Endurance performance is highly dependent on aerobic power, and training volume is a key determinant of aerobic power. Strength training contributes to performance by improving movement, delaying fatigue, improving capacity, and enhancing maximal speed. Some of the early studies that investigated the effects of combining endurance and strength training in triathlon athletes did not include

the effects of strength training on performance have long been the subject of interest for coaches and sport scientists. The aim of this study was to examine the effect of strength training on performance in elite triathletes. The aim of this study was to examine the effect of strength training on performance in elite triathletes. The aim of this study was to examine the effect of strength training on performance in elite triathletes.

Sports 2019, 7, 101; doi:10.3390/sports7050101

# DRY-LAND RESISTANCE TRAINING PRACTICES OF ELITE SWIMMING STRENGTH AND CONDITIONING COACHES

EMMET CROWLEY, ANDREW J. HARRISON, AND MARK LYONS

Biomechanics Research Unit, Department of Physical Education & Sport Sciences, University of Limerick, Limerick, Ireland

### ABSTRACT

Crowley, E, Harrison, AJ, and Lyons, M. Dry-land resistance training practices of elite swimming strength and conditioning coaches. *J Strength Cond Res XX(X)*: 000–000, 2018. No research to date has investigated dry-land resistance (RT) training practices of elite swimming strength and conditioning coaches. This is the first comprehensive study exploring dry-land RT training practices in swimming. The aims of this study were to examine (a) the dry-land RT training practices and exercises used by elite swimming strength and conditioning coaches and (b) the rationale provided by coaches about their practices and prescription of specific dry-land RT training exercises. Twenty-three (n = 21 males, n = 2 females) elite swimming strength and conditioning coaches, from Ireland (n = 7), Great Britain (n = 5), Australia (n = 6), and the United States of America (n = 5) were recruited through their specific national governing bodies. Coaches completed an online questionnaire consisting of 7 sections; subject information, informed consent, coach's biography, coach education, current training commitments, dry-land RT training practices and exercises, and additional information. The results showed that coaches had varying levels of experience, education and worked with different level swimmers. A total of 95 dry-land RT training exercises were used by the coaches across 4 different dry-land RT training practices (warm-up, circuit training, traditional RT training and plyometrics). Traditional RT training (87%) was the most commonly practiced. The pull-up and squat were the most popular dry-land RT training exercises used by elite swimming strength and conditioning coaches. Future research needs to focus on exploring the specificity and the transfer of RT training exercises to swimming performance.

**KEY WORDS** survey, transfer, specificity, coaching

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### Effects of Concurrent Resistance and Swimming Performance

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Swimming performance is determined by the exertion of high impulses against the water (7) with the majority of propulsive forces (40) and swimming velocity (46) being produced by the upper body musculature. Strong correlations (r = 0.93) have been found between upper body muscular strength and swimming performance (40). Previous research investigating dry-land RT training interventions has shown significant improvements in swimming performance (1,16,17,43), when low volume, high velocity or high force RT training programs are applied (8). Consequently, many of these studies have not provided a clear rationale for why coaches choose specific dry-land RT training exercises. Therefore, there is a need to investigate the practices and prescription of dry-land RT training exercises among elite swimming strength and conditioning coaches.

swimmers; dry-land training; endurance; training order

Several studies have investigated strength and conditioning training practices, across a range of sports including hockey (10), strongman competitors (44), basketball (39), baseball (11), rowing (14), and rugby (22). These studies have provided a thorough overview of strength and conditioning practices and a source of new ideas to diversify and improve training practices. Olympic style weightlifting featured prominently in several of the sports with a high percentage of coaches reporting its inclusion within their training programs: rugby (90%), rowing (87%), basketball (95%), and hockey (91%). The squat and clean were reported to be the most important RT training exercise. More specifically, research on hockey and baseball highlighted that variations of the squat remain the most commonly used exercise. Within basketball, the squat was considered the most important strength exercise followed by lunges. This applied knowledge is important for scientists and strength and conditioning coaches alike. The exercises outlined in

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Sports Med (2014) 44:845–865  
DOI 10.1007/s40279-014-0157-y

### SYSTEMATIC REVIEW

## The Effect of Strength Training on Endurance Performance in Elite Swimmers: A Review

Kris Beattie · Ian C. Kenny · Brian P. Carson

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**Abstract** Background Economy, velocity of muscle fiber conduction, and force output are important determinants of endurance performance. There are a number of ways in which endurance performance can be improved, specifically through strength training. However, training is recommended for improving endurance performance in elite swimmers. The aim of this study was to examine the effect of strength training on endurance performance in elite swimmers. The aim of this study was to examine the effect of strength training on endurance performance in elite swimmers.

**Keywords:** health; periodization; intensity; nutrition

### 1. Introduction

Triathlon is characterized by the multilateral nature of running and cycling, which are completed sequentially in long-distance, and Ironman formats, ranging from the mixed relay race (also known as triathlon triathlon) to the long-distance triathlon (Ironman), which requires high volumes of training and a high level of aerobic and anaerobic capacity. Endurance performance is highly dependent on aerobic power, and training volume is a key determinant of aerobic power. Strength training contributes to performance by improving movement, delaying fatigue, improving capacity, and enhancing maximal speed. Some of the early studies that investigated the effects of combining endurance and strength training in triathlon athletes did not include

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Sports 2019, 7, 101; doi:10.3390/sports7050101



## The Impact of Strength Training on Endurance Performance in Elite Swimmers: A Systematic Review

Emmet Crowley · Andrew J. Harrison · Mark Lyons

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**Abstract** Background Economy, velocity of muscle fiber conduction, and force output are important determinants of endurance performance. There are a number of ways in which endurance performance can be improved, specifically through strength training. However, training is recommended for improving endurance performance in elite swimmers. The aim of this study was to examine the effect of strength training on endurance performance in elite swimmers. The aim of this study was to examine the effect of strength training on endurance performance in elite swimmers.

**Keywords:** health; periodization; intensity; nutrition

### 1. Introduction

Triathlon is characterized by the multilateral nature of running and cycling, which are completed sequentially in long-distance, and Ironman formats, ranging from the mixed relay race (also known as triathlon triathlon) to the long-distance triathlon (Ironman), which requires high volumes of training and a high level of aerobic and anaerobic capacity. Endurance performance is highly dependent on aerobic power, and training volume is a key determinant of aerobic power. Strength training contributes to performance by improving movement, delaying fatigue, improving capacity, and enhancing maximal speed. Some of the early studies that investigated the effects of combining endurance and strength training in triathlon athletes did not include

the effects of strength training on performance have long been the subject of interest for coaches and sport scientists. The aim of this study was to examine the effect of strength training on performance in elite triathletes. The aim of this study was to examine the effect of strength training on performance in elite triathletes.

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Training and Competition Readiness in Triathlon

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Abstract: Triathlon is characterized by the multidisciplinary nature of the sport where swimming, cycling, and running are completed sequentially in different events, such as the sprint, Olympic, long-distance, and Ironman formats. The large number of training sessions and overall volume undertaken by triathletes to improve fitness and performance can also increase the risk of injury, illness, or excessive fatigue. Short- and medium-term individualized training plans, periodization strategies, and work/rest balance are necessary to minimize interruptions to training due to injury, illness, or maladaptation. Even in the absence of health and wellbeing concerns, it is unclear whether cellular signals triggered by multiple training stimuli that drive training adaptations each day interfere with each other. Distribution of training intensity within and between different sessions is an important aspect of training. Both internal (perceived stress) and external loads (objective metrics) should be considered when monitoring training load. Incorporating strength training to complement the large body of endurance work in triathlon can help avoid overuse injuries. We explore emerging trends and strategies from the latest literature and evidence-based knowledge for improving training readiness and performance during competition in triathlon.

Keywords: health; periodization; intensity; concurrent training; fatigue; quantification; monitoring; nutrition

1. Introduction

Triathlon is characterized by the multidisciplinary nature of the sport where swimming, cycling, and running are completed sequentially within the same event. The sport has a wide array of event formats, ranging from the mixed relay race (about 20 min), to the sprint distance race, lasting about 1 h, and the long-distance triathlon (Ironman), raced over an 8–9 h period at the elite level. In addition to the high training volumes typically undertaken for endurance sports, training for three different sporting disciplines simultaneously requires thoughtful planning of a large number of training sessions every week [1,2]. Large volumes of training can increase the incidence of illness and injuries, however, recent advances in knowledge in this area can minimize this risk while maximizing performance. This review examines the physiological (and biochemical) challenges of simultaneous multidisciplinary training and health risks associated with triathlon, individualized periodization and training strategies, and emerging trends in triathlon preparation.

The various formats and distances of triathlon racing all have their own discrete demands for different competition schemes. For example, in the main Olympic distance triathlon competition, a high level of sustained performance throughout the season is required, as the World Triathlon Series (eight events in 2019) reward the most consistent high-performing athlete with a World Champion title.

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DOI 10.1007/s40279-014-0157-y

SYSTEMATIC REVIEW

The Effect of Strength Training on Performance of Endurance Athletes

Kris Beattie · Ian C. Kenny · Mark Lyons · Brian P. Carson

B. R.ønnestad<sup>1</sup>, I. Mujika<sup>2</sup>, M. Lyons<sup>3</sup>, and K. Beattie<sup>1</sup>
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Abstract

Background Economy, velocity/power at maximal oxygen uptake (vVO<sub>2max</sub>/wVO<sub>2max</sub>) and endurance-specific muscle power tests (i.e. maximal anaerobic running velocity; vMART), are now thought to be the best performance predictors in elite endurance athletes. In addition to cardiovascular function, these key performance indicators are believed to be partly dictated by the neuromuscular system. One technique to improve neuromuscular efficiency in athletes is through strength training.

Objective The aim of this systematic review was to search the body of scientific literature for original research investigating the effect of strength training on performance indicators in well-trained endurance athletes—specifically economy, vVO<sub>2max</sub>/wVO<sub>2max</sub> and muscle power (vMART). Methods A search was performed using the MEDLINE, PubMed, ScienceDirect, SPORTDiscus and Web of Science search engines. Twenty-six studies met the inclusion criteria (athletes had to be trained endurance athletes with ≥6 months endurance training, training ≥6 h per week OR vVO<sub>2max</sub> ≥50 mL/min/kg, the strength interventions had to be ≥5 weeks in duration, and control groups used). All studies were reviewed using the PEDro scale. Results The results showed that strength training improved time-trial performance, economy, vVO<sub>2max</sub>/wVO<sub>2max</sub> and vMART in competitive endurance athletes. Conclusion The present research available supports the addition of strength training in an endurance athlete's programme for improved economy, vVO<sub>2max</sub>/wVO<sub>2max</sub>, and muscle power.

Background The majority of training is produced from the relationship between upper limb and cycling. Running economy and combined endurance and cycling endurance training is recommended for elite endurance athletes. Equivalent findings exist for output or velocity at the endurance and heavy running speed and power. The effects of strength training on performance have long been reported in athletes, coaches, and sports scientists. Strength training that includes both explosive and heavy strength training that increases muscle group's ability to produce force and power (Knutigen & Kraemer, 2004) has been shown to improve performance in elite endurance athletes. Strength training with a load that is 70–85% of 1 RM and maximal concentric phase (0.9 of 1 RM) for 6–12 weeks in duration, and control groups used). All studies were reviewed using the PEDro scale. Results The results showed that strength training improved time-trial performance, economy, vVO<sub>2max</sub>/wVO<sub>2max</sub> and vMART in competitive endurance athletes. Conclusion The present research available supports the addition of strength training in an endurance athlete's programme for improved economy, vVO<sub>2max</sub>/wVO<sub>2max</sub>, and muscle power.

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Here we report on the effect of strength training on endurance performance in elite endurance athletes. Equivalent findings exist for output or velocity at the endurance and heavy running speed and power. The effects of strength training on performance have long been reported in athletes, coaches, and sports scientists. Strength training that includes both explosive and heavy strength training that increases muscle group's ability to produce force and power (Knutigen & Kraemer, 2004) has been shown to improve performance in elite endurance athletes. Strength training with a load that is 70–85% of 1 RM and maximal concentric phase (0.9 of 1 RM) for 6–12 weeks in duration, and control groups used). All studies were reviewed using the PEDro scale. Results The results showed that strength training improved time-trial performance, economy, vVO<sub>2max</sub>/wVO<sub>2max</sub> and vMART in competitive endurance athletes. Conclusion The present research available supports the addition of strength training in an endurance athlete's programme for improved economy, vVO<sub>2max</sub>/wVO<sub>2max</sub>, and muscle power.

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SYSTEMATIC REVIEW

Optimizing strength training performance: A Systematic Review

B. R.ønnestad<sup>1</sup>, I. Mujika<sup>2</sup>, M. Lyons<sup>3</sup>, and K. Beattie<sup>1</sup>
<sup>1</sup>Section for Sport Science, Ed and Odontology, University of Luleå, Faculty of Medicine, 1 Corridor, S-971 80, Luleå, Sweden
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Abstract

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TRAINING PRACTICES OF ENDURANCE ATHLETES AND CONDITIONING

Mark Lyons
Department of Sport Sciences, University of Limerick, Limerick, Ireland

INTRODUCTION

Resistance (RT) training is a fundamental component for all athletes competing at the highest level. Research has shown that RT training can enhance sporting performance (38) and reduce injuries (18,20). Resistance training in swimming has been widely documented and research has shown that swimming performance is determined by the exertion of high impulses against the water (7) with the majority of propulsive forces (40) and swimming velocity (46) being produced by the upper body musculature. Strong correlations (r = 0.93) have been found between upper body muscular strength and swimming performance (40). Previous research investigating dry-land RT training interventions has shown significant improvements in swimming performance (1.16,17,43), when low volume, high velocity or high force RT training programs are applied (8). Consequently, many of these studies have not provided a clear rationale for why coaches choose specific dry-land RT training exercises. Therefore, there is a need to investigate the practices and prescription of dry-land RT training exercises among elite swimming strength and conditioning coaches.

Several studies have investigated strength and conditioning training practices, across a range of sports including hockey (10), strongman competitors (44), basketball (39), baseball (11), rowing (14), and rugby (22). These studies have provided a thorough overview of strength and conditioning practices and a source of new ideas to diversify and improve training practices. Olympic style weightlifting featured prominently in several of the sports with a high percentage of coaches reporting its inclusion within their training programs; rugby (90%), rowing (87%), basketball (95%), and hockey (91%). The squat and clean were reported to be the most important RT training exercise. More specifically, research on hockey and baseball highlighted that variations of the squat remain the most commonly used exercise. Within basketball, the squat was considered the most important strength exercise followed by lunges. This applied knowledge is important for scientists and strength and conditioning coaches alike. The exercises outlined in

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# The Effect of Strength Training on Performance in Endurance Athletes

Kris Beattie · Ian C. Kenny · Mark Lyons · Brian P. Carson

Published online: 15 February 2014  
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### Abstract

**Background** Economy, velocity/power at maximal oxygen uptake ( $\dot{V}O_{2\max}/w\dot{V}O_{2\max}$ ) and endurance-specific muscle power tests (i.e. maximal anaerobic running velocity; vMART), are now thought to be the best performance predictors in elite endurance athletes. In addition to cardiovascular function, these key performance indicators are believed to be partly dictated by the neuromuscular system. One technique to improve neuromuscular efficiency in athletes is through strength training.

**Objective** The aim of this systematic review was to search the body of scientific literature for original research investigating the effect of strength training on performance indicators in well-trained endurance athletes—specifically economy,  $\dot{V}O_{2\max}/w\dot{V}O_{2\max}$  and muscle power (vMART). **Methods** A search was performed using the MEDLINE, PubMed, ScienceDirect, SPORTDiscus and Web of Science search engines. Twenty-six studies met the inclusion criteria (athletes had to be trained endurance athletes with  $\geq 6$  months endurance training, training  $\geq 6$  h per week OR  $\dot{V}O_{2\max} \geq 50$  mL/min/kg, the strength interventions had to be  $\geq 5$  weeks in duration, and control groups used). All studies were reviewed using the PEDro scale.

**Results** The results showed that strength training improved time-trial performance, economy,  $\dot{V}O_{2\max}/w\dot{V}O_{2\max}$  and vMART in competitive endurance athletes.

**Conclusion** The present research available supports the addition of strength training in an endurance athlete's programme for improved economy,  $\dot{V}O_{2\max}/w\dot{V}O_{2\max}$ .

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muscle power and performance. However, it is evident that further research is needed. Future investigations should include valid strength assessments (i.e. squats, jump squats, drop jumps) through a range of velocities (maximal-strength  $\leftrightarrow$  strength-speed  $\leftrightarrow$  speed-strength  $\leftrightarrow$  reactive-strength), and administer appropriate strength programmes (exercise, load and velocity prescription) over a long-term intervention period ( $>6$  months) for optimal transfer to performance.

### 1 Introduction

Endurance sport performance relies on a complex interplay of physiological and biomechanical factors. Cardiovascular capacity has often been thought to be the main limiting factor in endurance performance. Classical measures such as maximal oxygen uptake ( $\dot{V}O_{2\max}$ ) and lactate threshold (LT) have been traditionally used in the laboratory to predict the performance potential of runners, cyclists, triathletes and cross-country skiers [1]. Consequently, physical preparation for these sports has generally focused on developing these two physiological qualities. However, elite endurance athletes with similar  $\dot{V}O_{2\max}$  levels can have differing abilities during a race and therefore maximum oxygen uptake cannot fully explain true racing ability. Economy, and assessments that include an endurance-specific muscle power component, such as velocity/power during maximal oxygen uptake ( $\dot{V}O_{2\max}/w\dot{V}O_{2\max}$ ) and maximal anaerobic running velocity (vMART), are now thought to be superior performance indicators in an elite population [2].

Economy is the amount of metabolic energy expended at a given velocity or power output [3]. Economical movement is multifactorial and is determined by training history, anthropometrics, biomechanics and physiology [4]. During

### Review

## Optimizing strength training for running performance: A review

B. R.ønnestad<sup>1</sup>, I. Mujika<sup>2,3</sup>

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**Here we report on the effect of combining endurance training with heavy or explosive strength training on endurance performance in endurance-trained runners and cyclists. Running economy is improved by performing combined endurance training with either heavy or explosive strength training. However, heavy strength training is recommended for improving cycling economy. Equivocal findings exist regarding the effects on power output or velocity at the lactate threshold. Concurrent endurance and heavy strength training can increase running speed and power output at  $\dot{V}O_{2\max}$  ( $V_{\max}$  and  $W_{\max}$ ) compared with endurance training alone.**

**Objective** The aims of this systematic review were to (1) explore the transfer of resistance training to swimming performance, and (2) explore the transfer of resistance training on technical aspects of swimming. **Methods:** Studies evaluating the effect of resistance training on technical aspects of swimming were selected. From a search of four online databases we identified 10 studies. The following inclusion criteria: (1) pool swimming; (2) competitive swimmers participating in a training programme. Exclusion criteria: (1) non-swimmers; (2) masters and paraplegic swimmers; (3) water polo players; (4) swimmers; and (5) studies of starts and turns.

The effects of strength training on endurance athletic performance have long been the subject of debate among athletes, coaches, and sport scientists. Strength training includes both explosive strength training and heavy strength training that promote different training adaptations. Heavy strength training can be defined as "all training aiming to increase or maintain a muscle or a muscle group's ability to generate maximum force" (Knuttgen & Kraemer, 1987) and is here equal to training with a load that allows between 1 repetition maximum (RM) and 15 RM. Explosive strength training is here defined as exercises with external loading of 0–60% of 1 RM and maximal mobilization in the concentric phase (0% of 1 RM equals body weight). Performance in most endurance events is mainly determined by the maximal sustained power production for a given competition distance, and the energy cost of maintaining a given competition speed. In short endurance events and during accelerations and sprint situations, anaerobic capacity and maximal speed may also contribute to performance. Strength training contributes to enhance endurance performance by improving the economy of movement, delaying fatigue, improving anaerobic capacity, and enhancing maximal speed.

Some of the early studies that investigated the effect of combining endurance and strength training in endurance-trained athletes did not identify any additive

### SYSTEMATIC REVIEW

## The Impact of Resistance Training on Running Performance: A Systematic Review

Emmet Crowley<sup>1</sup>, Andrew J. Hanson<sup>1</sup>

<sup>1</sup>Biomechanics Research Unit, Department of Education and Sport Sciences, University of Limerick, Limerick, Ireland

**Background** The majority of population are produced from the upper body muscle mass. Resistance training is related to the impact of resistance training on performance, specifically the impact of resistance training on performance.

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Acute Neuromuscular and Performance in Middle-Aged Athletes: A Systematic Review  
Effects of Middle-Aged Athletes  
Richard C. Beattie  
Published online: 15 February 2014

ENDURANCE SUMMIT OUTUBRO 2023

MDPI  
Journal of Sports Medicine  
Readiness in Triathlon  
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**TIPOS DE ESTÍMULOS**

**MODALIDADES**

**ORGANIZAÇÃO/DURAÇÃO**

**STATUS DO TREINAMENTO**

**VOLUME X INTENSIDADE**

**FREQUÊNCIA /AÇÃO MUSCULAR**

**EXERCÍCIOS/SÉRIES/REPS**

**CARGA/INT. RECUPERAÇÃO**



**Força/  
Resistência**

**Força  
Básica**

**Força**

**Potência**

Ciclos semanas: 3 carga progr.:1 Deload

**Preparação BÁSICA**

— 6-12 semanas —

**Preparação ESPECÍFICA**

TF (Veloc.Intenção) / Isométrico/ Levantamentos Olímpicos/Pliometria (Veloc.)

**Natação  
Ciclismo  
Corrida  
Triatlo**

Novato/Treinado/ Atleta (Fraco/Forte - Força/Potência)

1-2-3x Sem. 3 -10Rm

2-6 séries 1-6 Exerc.

2-5 min. >70-80% 1Rm

~6-7horas

# TREINAMENTO DE FORÇA E MODALIDADES DE ENDURANCE

## Aplicações práticas





# Strength Gains: Block Versus Daily Modulating Periodization Weight Training Among Track and Field Athletes

nter, Gregory G. Haff, Mike W. Ramsey, Jeff McBride, Travis Triplett,  
Sands, Hugh S. Lamont, Margaret E. Stone, and Michael H. Stone



|        |                     |                     |
|--------|---------------------|---------------------|
| 1      | Power snatch        | Power snatch        |
| rug    | Clean grip shrug    | Midhigh pull        |
| 1      | Mid high pull*      | Stiff-leg dead lift |
| llight | Stiff-leg dead lift |                     |
| ws     | Dumbbell rows       |                     |

target sets; \$0–30% of body mass. Intensities were based on a projected maximum for sets and approximately 65–70% of 1-RM); ML = moderate light (approximately 70–75% of 1-RM), M = moderately heavy.



**Table 2 The Daily Undulating Group Training Plan**

| Day               | Emphasis            | Sets                | Repetitions | Intensity |
|-------------------|---------------------|---------------------|-------------|-----------|
| Monday            | Strength/Endurance  | 3                   | 8–12        | 8–12 RM   |
| Wednesday         | Strength            | 3                   | 5–7         | 5–7 RM    |
| Friday            | Power               | 3                   | 3–5         | 3–5 RM    |
| Exercises         |                     |                     |             |           |
| Monday            | Wednesday           | Friday              |             |           |
| Back squat        | Back squat          | 1/4 back squat      |             |           |
| Midhigh pull      | Clean grip shrug    | Midhigh pull        |             |           |
| Behind-neck press | Push press          | Weighted jump§      |             |           |
| Bench press       | Incline bench press | Push jerk           |             |           |
| Dumbbell row      | Dumbbell row        | Stiff-leg dead lift |             |           |

Note: RM = repetition maximum; §0–30% of body mass.



# 10 weeks of heavy strength training improves performance-related measurements in elite cyclists

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**First 3 weeks : 10 RM/ 6RM**

**4-5-6 weeks : 8 RM/ 5RM**

**7-8-9-10 weeks: 6RM/4RM**

Half squat

Leg press with 1 leg at a time

Standing one-legged hip flexion

Ankle plantar flexion

3 sets/ 2 minutes

Concentric phase – 1 second

Eccentric Phase – 2-3 s

# Strength Training for Long-Distance Triathletes: Theory to Practice

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## ABSTRACT

Concurrent training, commonly acknowledged as a training method where strength and endurance training are completed complementary to each other, is a strategy often implemented in endurance cyclists' and runners' programs to improve physiological determinants of success such as exercise economy. Although concurrent training methods and strategies have been examined to a large extent in endurance cyclists and runners, literature examining optimal concurrent training methods to improve physiological variables in long-distance triathletes is minimal, leaving optimal programming relatively unknown. This practical applications paper identifies and outlines current concepts and considerations regarding concurrent training for long-distance triathletes including mechanisms contributing to improved performance, muscle and movement patterns used, exercise selection, load, velocity of movement, scheduling, frequency, and duration of training. Common misconceptions related to concurrent training are also identified and practical considerations

for the application of concurrent training for coaches, athletes, and other professionals to improve all 3 disciplines of triathlon are discussed.

## INTRODUCTION

Despite a large body of research recommending the implementation of concurrent strength and endurance training for optimal performance and physiological improvements, coaches tend to have opposing views on the implementation of strength training (ST) in endurance athletes' programs. The inclusion of ST into long-distance (LD) triathletes' programs can improve both cycling economy (CE) and running economy (RE) which is considered critical for success in LD triathlon (58,62). Furthermore, research has demonstrated that ST can significantly improve performance variables (economy, time-trial performance, reduced heart rate [HR] at submaximal intensities, velocity at  $\dot{V}O_{2\max}$  [ $\dot{v}VO_{2\max}$ ], and power at  $\dot{V}O_{2\max}$  in single mode endurance sports such as cycling and running) (10,11,25,61,71,72,79,80,83,90,91,98,100). Long-distance triathlon is classified as any triathlon distance greater than an Olympic distance race (>1,500-m swim,

40-km cycle, and 10-km run) (59) with the 2 most common forms known as a half-iron distance (1.9-km swim, 90-km cycle, and 21.1-km run) and full iron-distance (3.8-km swim, 180-km cycle, and 42.2-km run) distance races.

A recent study examining characteristics of ST habits in LD triathletes found that only 54.6% of triathletes included a form of ST in their normal training regime with participants reporting time restraints and a lack of porting knowledge regarding what strength exercises to complete, how to progress exercises, and technique as the primary barriers (59). As ST is considered a broad term that encompasses many different variables that can be manipulated (51), it can be complex for a coach or athlete to understand the optimal ST prescription to achieve the athlete's goals. Variables that can be manipulated include type of muscle contraction (isometric, concentric or eccentric), exercise selection (open or closed chain), volume (number of repetitions, sets, load lifted), velocity of movement, rest intervals, and

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**Table 1**  
Selection of strength exercises and associated triathlon discipline specifically targeted

| Exercise  | Swimming | Cycling | Running |
|---|----------|---------|---------|
| Injury prevention   |          |         |         |
| Wall slide, SL deadlifts, step-up/step-downs, pelvic drops, hip abduction |          | X       | X       |
| Scapula push-ups, shoulder internal/external rotation, seated row         | X        |         |         |
| Explosive/plyometric  |          |         |         |
| Pogo jump, depth jump, countermovement jump                               |          |         | X       |
| Heavy strength  |          |         |         |
| Half range or 90° squat   |          | X       | X       |
| Deadlift  | X        | X       | X       |
| SL leg press  |          | X       | X       |
| Seated SL calf raise  | X        | X       | X       |
| Lat pull-down   | X        | X       | X       |
| Standing hip flexion on cable machine                                     |          | X       | X       |
| Lunge/split squat   |          | X       | X       |
| Glute hamstring raise   |          | X       | X       |
| Power clean/hang clean  | X        | X       | X       |
| Bent-over row   | X        | X       | X       |
| Weighted hip thrust   |          | X       | X       |

90° = knee angle to 90°; half range = femur parallel to ground; SL = single leg.



**Table 2**  
Example strength training session addressing all disciplines for long-distance triathletes

| Exercise                          | Sets | Repetitions | Loads      |
|-----------------------------------|------|-------------|------------|
| Injury prevention                 |      |             |            |
| Scapula push-ups                  | 3    | 12          | Bodyweight |
| Wall slides                       | 3    | 6 each leg  | Bodyweight |
| Pelvic drops                      | 3    | 12 each leg | Bodyweight |
| Performance/strength <sup>a</sup> |      |             |            |
| Deadlift                          | 3    | 6           | 85% of 1RM |
| Back squat                        | 3    | 6           | 85% of 1RM |
| Single leg seated calf raise      | 3    | 6           | 85% of 1RM |
| Lat pull-down                     | 3    | 6           | 85% of 1RM |

<sup>a</sup>All performance/strength exercises completed with a 3-second eccentric lower, as fast as possible concentric phase. If the athlete is new to strength training or accumulating excessive fatigue, decrease the number of performance heavy strength exercises as appropriate.

**Table 4**  
Example strength training session with a cycle focus for long distance triathletes

| Exercise                          | Sets | Repetitions | Loads                 |
|-----------------------------------|------|-------------|-----------------------|
| Injury prevention                 |      |             |                       |
| Step ups/downs                    | 3    | 8           | Bodyweight            |
| Walking lunge                     | 3    | 8 each leg  | 2 × 5–10 kg dumbbells |
| SL deadlifts                      | 3    | 8 each leg  | 2 × 5–10 kg dumbbells |
| Performance/strength <sup>a</sup> |      |             |                       |
| Deadlift                          | 3    | 6           | 85% of 1RM            |
| Back squat                        | 3    | 6           | 85% of 1RM            |
| Split squat                       | 3    | 6           | 85% of 1RM            |
| Single leg seated calf raise      | 3    | 6           | 85% of 1RM            |

<sup>a</sup>All performance/strength exercises completed with a 3-second eccentric lower, as fast as possible concentric phase. If the athlete is new to strength training or accumulating excessive fatigue, decrease the number of performance heavy strength exercises as appropriate.

**Table 3**  
Example strength training session with a swim focus for long distance triathletes

| Exercise                            | Sets | Repetitions | Loads               |
|-------------------------------------|------|-------------|---------------------|
| Injury prevention                   |      |             |                     |
| Scapula push-ups                    | 3    | 12          | Bodyweight          |
| Shoulder internal/external rotation | 3    | 12          | Moderate resistance |
| Performance/strength <sup>a</sup>   |      |             |                     |
| Hang clean                          | 3    | 6           | 85% of 1RM          |
| Lat pull-down                       | 3    | 6           | 85% of 1RM          |
| Bent-over row                       | 3    | 6           | 85% of 1RM          |

<sup>a</sup>All performance/strength exercises completed with a 3-second eccentric lower, as fast as possible concentric phase with the exception of the hang clean which should be completed with the concentric phase as fast as possible and the athlete taking time between each repetition to ensure good technique.

**Table 5**  
Example strength training session with a run focus for long-distance triathletes

| Exercise                          | Sets | Repetitions | Loads                 |
|-----------------------------------|------|-------------|-----------------------|
| Injury prevention                 |      |             |                       |
| Single leg deadlifts              | 3    | 8 each leg  | 2 × 5–10 kg dumbbells |
| Pelvic drops                      | 3    | 12 each leg | Bodyweight            |
| Wall slide                        | 3    | 6 each leg  | Bodyweight            |
| Performance/strength <sup>a</sup> |      |             |                       |
| countermovement jump              | 3    | 4–8         | Bodyweight            |
| Power clean                       | 3    | 6           | 85% of 1RM            |
| Back squat                        | 3    | 6           | 85% of 1RM            |
| Single leg seated calf raise      | 3    | 6           | 85% of 1RM            |

<sup>a</sup>All performance/strength exercises completed with a 3-second eccentric lower, as fast as possible concentric phase except the power clean which should be completed with the concentric phase as fast as possible and the athlete taking time between each repetition to ensure good technique. If the athlete is new to strength training or accumulating excessive fatigue, decrease the number of performance heavy strength exercises as appropriate.



A silhouette of a person running is positioned on the left side of the image, facing right. The background is a vibrant sunset sky with shades of blue, purple, and orange. The text 'ENDURANCE SUMMIT' is written in large, bold letters at the top right, with 'OUTUBRO 2023' in smaller orange letters below it. The word 'OBRIGADO' is written in large white letters in the center-right. At the bottom, the website URL 'WWW.NUTRIÇÃOESPORTIVABRASIL.COM' is displayed in white.

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