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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

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Scand. J. Med. Sci. Sports 2014:24:603-612

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Review

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

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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 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.

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 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; 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

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;

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SYSTEMATIC REVIEW

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

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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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Sports Medicine - Open

SYSTEMATIC REVIEW **Open Access**

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

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Abstract

Background: Strength training (ST) is commonly used to improve muscle strength, power, and neuromuscular adaptations and is recommended combined with runner training. It is possible that the acute effects of the strength training session lead to deleterious effects in the subsequent running. The aim of this systematic review and meta-analysis was to verify the acute effects of ST session on the neuromuscular, physiological and performance variables of runners.

Methods: Studies evaluating running performance after resistance exercise in runners in the PubMed and Scopus databases were selected. From 6532 initial references, 19 were selected for qualitative analysis and 13 for meta-analysis. The variables of peak torque (P_T), creatine kinase (CK), delayed-onset muscle soreness (DOMS), rating of perceived exertion (RPE), countermovement jump (CMJ), ventilation (VE), oxygen consumption (VO_2), lactate (La) and heart rate (HR) were evaluated.

Results: The methodological quality of the included studies was considered reasonable; the meta-analysis indicated that the variables P_T ($p = 0.003$), DOMS ($p < 0.0001$), CK ($p < 0.0001$), RPE ($p < 0.0001$) had a deleterious effect for the experimental group; for CMJ, VE, VO_2, La, FC there was no difference. By qualitative synthesis, running performance showed a reduction in speed for the experimental group in two studies and in all that assessed time to exhaustion.

Conclusion: The evidence indicated that acute strength training was associated with a decrease in P_T, increases in DOMS, CK, RPE and had a low impact on the acute responses of CMJ, VE, VO_2, La, HR and submaximal running sessions.

Keywords: Competitive training, Running, Aerobic performance, Strength training

Key Points

- Acute strength training (ST) was associated with a decrease in peak torque and an increase in delayed-onset muscle soreness, creatine kinase and rating of perceived exertion in a subsequent running session.
- ST did not affect submaximal running sessions and had little impact on countermovement jump, minute

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Article

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 attained 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

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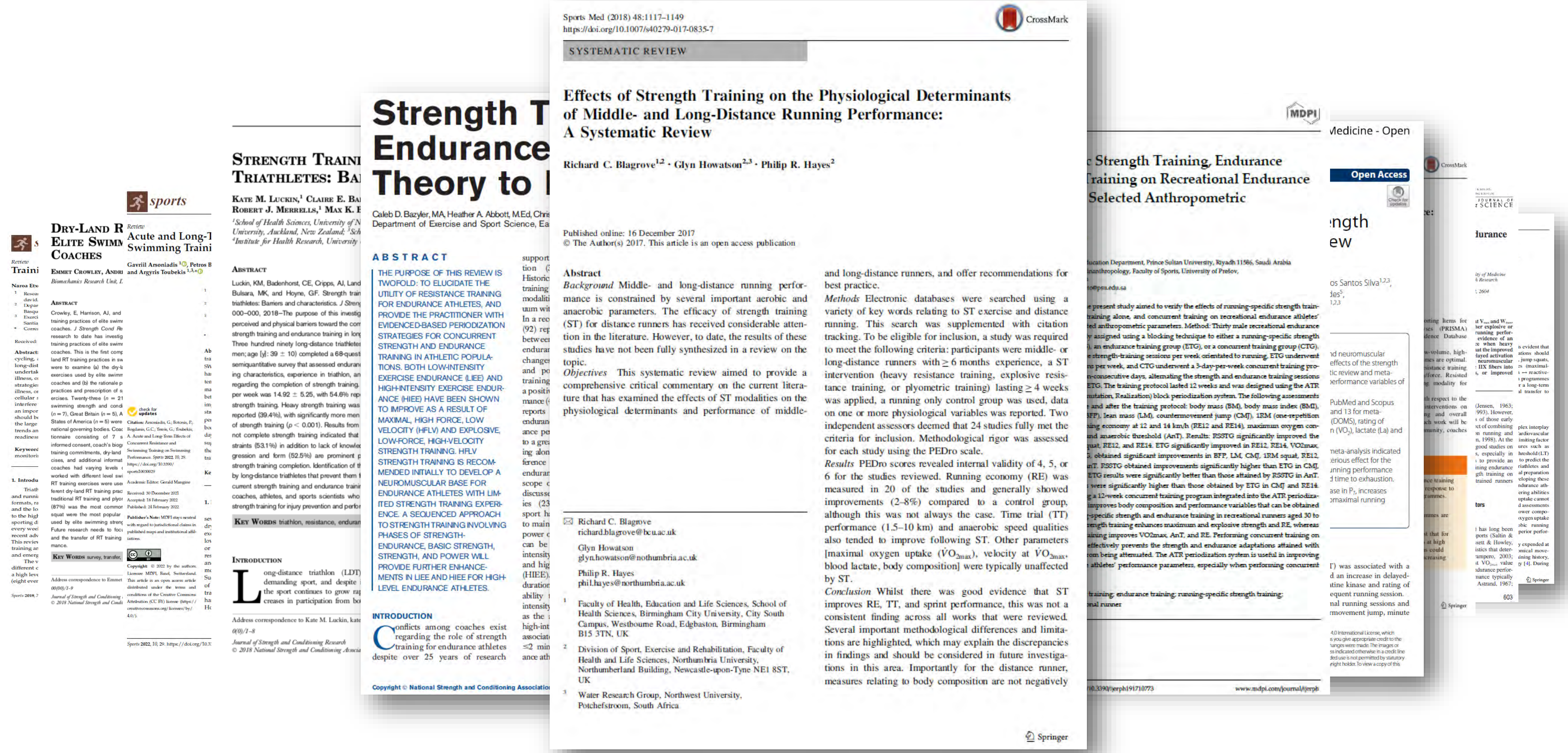

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SYSTEMATIC REVIEW

Effects of Strength Training on the Physiological Determinants of Middle- and Long-Distance Running Performance: A Systematic Review

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Published online: 16 December 2017

Abstract

Background Middle- and long-distance running performance is constrained by several important aerobic and anaerobic parameters. The efficacy of strength training (ST) for distance runners has received considerable attention in the literature. However, to date, the results of these studies have not been fully synthesized in a review on the topic.

Objectives This systematic review aimed to provide a comprehensive critical commentary on the current literature that has examined the effects of ST modalities on the physiological determinants and performance of middle- and long-distance runners, and offer recommendations for best practice.

Methods Electronic databases were searched using a variety of key words relating to ST exercise and distance running. This search was supplemented with citation tracking. To be eligible for inclusion, a study was required to meet the following criteria: participants were middle- or long-distance runners with ≥ 6 months experience, a ST intervention (heavy resistance training, explosive resistance training, or plyometric training) lasting ≥ 4 weeks was applied, a running only control group was used, data on one or more physiological variables was reported. Two independent assessors deemed that 24 studies fully met the criteria for inclusion. Methodological rigor was assessed for each study using the PEDro scale.

Results PEDro scores revealed internal validity of 4, 5, or 6 for the studies reviewed. Running economy (RE) was measured in 20 of the studies and generally showed improvements (2–8%) compared to a control group, although this was not always the case. Time trial (TT) performance (1.5–10 km) and anaerobic speed qualities also tended to improve following ST. Other parameters [maximal oxygen uptake ($\dot{V}O_{2max}$), velocity at $\dot{V}O_{2max}$, blood lactate, body composition] were typically unaffected by ST.

Conclusion Whilst there was good evidence that ST improves RE, TT, and sprint performance, this was not a consistent finding across all works that were reviewed. Several important methodological differences and limitations are highlighted, which may explain the discrepancies in findings and should be considered in future investigations in this area. Importantly for the distance runner, measures relating to body composition are not negatively

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Strength Training for Endurance Athletes: Theory to Practice

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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 ≤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

ENDURANCE SUMMIT OUTUBRO 2023

Strength Training in Long-Distance Triathletes: Barriers and Characteristics

Kate M. Luckin,[1] Claire E. Badenhorst,[2] Ashley J. Cripps,[1] Grant J. Landers,[3] Robert J. Merrells,[1] Max K. Bulsara,[4] and Gerard F. Hoyne[1]

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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^{-1} 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 (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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Review

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

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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 peak power in swim turn. Accordingly, SWIM-RT training order induces swimming performance improvements in front crawl and increments in maximum dry-land upper and lower body strength. Concurrent application of RT-SWIM or SWIM-RT training applied within a training day leads in similar performance gains after six to twelve weeks of training. The current review suggests that recovery duration between RT and SWIM is a predisposing factor that may determine the training outcome. Competitive swimmers may benefit after concurrent application with both training order scenarios during a training cycle.

Keywords: well-trained swimmers; dry-land training; endurance; training order

check for updates

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1. Introduction

Competitive swimmers participate in dry-land training sessions aiming to improve several aspects of conditioning and increase in-water propulsive force [1–3]. During a dry-land session, swimmers may apply resistance training (RT) including various modes of exercise and specific apparatus [4–6]. Typically, RT may focus on muscular endurance with low external loads (3–4 sets, >12 repetitions, 40–60% of 1 repetition maximum (1-RM) [6–9] or maximum strength using high loads (3–5 sets, 3–5 repetitions, >85% of 1-RM, 2–3 min rest) [3,4,10–12]. Within a training microcycle, all dry-land sessions should be incorporated and adjusted according to swimming training sessions. Then, coaches should plan two or more RT sessions each week, prior to or following in-water swimming training (SWIM). Such a microcycle training plan is regularly repeated during a mesocycle or longer periods of training. There is evidence that long-term concurrent application of RT and SWIM training sessions may improve performance compared to SWIM training alone, and this has been extensively reviewed and supported with experimental findings [2,7,8,10,13,14]. However, several studies have indicated that concurrent training might pose a negative

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Dry-Land Resistance Training Practices of Elite Swimming Strength and Conditioning Coaches

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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

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 (25). RT training improves physiological, biomechanical and neuromuscular qualities thus improving sporting performance (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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Review

Training and Competition Readiness in Triathlon

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check for updates

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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SYSTEMATIC REVIEW

The Effect of Strength Training on Performance in Endurance Athletes

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

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Abstract

Background Economy, velocity/power at maximal oxygen uptake ($v\dot{V}O_{2\,max}/w\dot{V}O_{2\,max}$) 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, $v\dot{V}O_{2\,max}/w\dot{V}O_{2\,max}$ 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 ≥6 months endurance training, training ≥6 h per week OR $\dot{V}O_{2\,max}$ ≥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, $v\dot{V}O_{2\,max}/w\dot{V}O_{2\,max}$ 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, $v\dot{V}O_{2\,max}/w\dot{V}O_{2\,max}$, 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 ↔ strength-speed ↔ speed-strength ↔ 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 ($v\dot{V}O_{2\,max}/w\dot{V}O_{2\,max}$) 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

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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

Ciclos semanas: 3 carga progr.:1 Deload

Força/ Resistência — **Força Básica** — **Força** — **Potência**

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
dulating 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

ı	Power snatch	Power snatch
ırug	Clean grip shrug	Midthigh pull
l	Mid high pull*	Stiff-leg dead lift
llight	Stiff-leg dead lift	
ws	Dumbbell rows	

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

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

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
Midthigh pull	Clean grip shrug	Midthigh 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.

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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 [$v\dot{V}O_2$max], and power at $\dot{V}O_2$max [$p\dot{V}O_2$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 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

KEY WORDS:
concurrent training; resistance; endurance; performance; triathlon; economy

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[a]			
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

[a]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[a]			
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

[a]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[a]			
Hang clean	3	6	85% of 1RM
Lat pull-down	3	6	85% of 1RM
Bent-over row	3	6	85% of 1RM

[a]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[a]			
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

[a]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.


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