STRENGTH TRAINING OF ENDURANCE ATHLETES: INTERFERENCE OR ADDITIVE EFFECTS. A REVIEW

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Review paper

Abstract

Strength training is an indispensable part of the preparation of high-performance athletes. Available information relates both to interference and additive effects of supplementary strength training on endurance performance. The purpose of this review is to describe and consider the impact of strength training (ST) on physiological variables and sport-specific performance of athletes from various endurance sports. In total, 57 professional publications were selected and analysed using various electronic databases such as Google, SIRC, PubMED. The study outcomes evidenced that supplementary strength training may produce both stimulatory and interference effects depending on various environmental and physiological factors. A substantial part of relevant publications confirms additive effects of supplementary strength training. An additional option to avoid interference is associated with the implementation of Block Periodization planning approach, which presupposes separation of highly concentrated strength and endurance workloads within appropriate block mesocycles.

Key words*: Supplementary strength training, endurance training, work economy, block periodization*

Introduction

For a long time, strength training has been an indispensable part of endurance athletes' preparation. Metabolic and neuromuscular prerequisites associated with supplementary strength training were actively considered with regards to event-specific preparedness of endurance athletes; a number of extensive reviews have been published in recent decades (Hickson et al., 1990; Abernethy et al., 1990; Beattie et al., 2014; Bazyler et al., 2015). The current situation related to the interpretation of available evidence and facts is paradoxical: on the one hand, there are messages and remarks concerning the interference impact and risks of muscle injuries and overtraining produced by strength interventions (Dudley and Djamil, 1985; Docherty and Sporer, 2000). On the other hand, strength training is considered as an efficient and valuable tool for performance enhancement of endurance athletes (Harre, 1982; García-Pallares and Izquierdo, 2011; Blagrove et al., 2018). Besides, in recent decades, the newest approaches to training programming have been published, which provide more favourable combinations of strength and endurance workloads within a framework of Block Periodization (BP) training approach (Issurin, 2010 and 2015). These circumstances predisposed the writing of the present review that is aimed to summarise current study outcomes, evidence and concepts related to the application of strength training in a systematic preparation of endurance athletes. A collection of relevant information has been obtained from professional publications within the period from 1980 to 2019 using appropriate electronic databases such as Google, SIRC, PubMED, etc.

Interaction of strength and endurance workloads

The analysis of a large number of publications including extensive reviews revealed that the majority of studies found the positive impact of supplementary strength training on physical conditions and event-specific performances of endurance athletes (Sale et al., 1990; Yamamoto et al., 2008; Harrison et al., 2017). Table 1 summarizes the outcomes of several studies, where effects of additional strength training on endurance performance have been evaluated. In all cases, effects of combined strength and endurance training were compared with the influence of endurance training per se. Training duration varied between 8 and 25 weeks. In 9 cases, supplemental strength training elicited significant superiority of endurance manifestation as compared with traditional endurance training programs.

The plausible mechanisms of endurance enhancement can be associated with favourable muscles hypertrophy (Aagard et al., 2010 and 2011), enhancement of peripheral blood circulation (Bazyler et al., 2015) and increased work economy (Hoff et al., 1999 and 2002; Sunde et al., 2019).

Following the findings of Nelson et al. (1990) and Hakkinen et al. (2003), concurrent strength and training produces significant increases in slow twitch and fast oxidative IIA fibres areas. Similarly, the data of Sale et al. (1990) revealed a shift in muscle fibres to a more oxidative pattern with increased activity of aerobic enzymes. Moreover, the findings of Putman et al. (2004) evidenced that concurrent strength and endurance training causes fast-to-slow fibres transition and attenuated hypertrophy of fast twitch fibres. Importantly, such neuromuscular adaptations were not accompanied by an increase in muscle cross sectional areas and body mass (Aagard P, Andersen, 2010).

Table 1. Summary of studies revealed a positive impact of strength exercises on endurance performance

Study	Subjects	Research design	Outcomes
Hennessy and Watson, 1994	56 trained male rugby players, 4 groups	Concurrent strength and endurance training vs. endurance, strength training and control; 8 wks	Gains of VO2max by 7.3% in E vs. 10.8% in END group; gains of bench press and squat by 14.5% and 5.4% in E group vs. 20.9% and 16.8% in S group (P < 0.05)
Hoff et al., 1999	15 cross country skiers, 2 groups	Concurrent strength and endurance training vs. endurance training; 9 wks	Improvement in work economy and 1RM in E group. Gains of time to exhaustion by 136% and 57% in E and C groups (P < 0.001)
Paavolainen et al., 1999	22 male cross country skiers, 2 groups	Concurrent explosive strength and endurance training vs. endurance training; 9 wks	Improvement in time to 5 km by 3.8% in E group; significant superiority of E group in running economy, anaerobic test, sprint and 5 forward jumps (P < 0.01)
Hoff et al., 2002	19 male cross country skiers, 2 groups	Concurrent strength and endurance training vs. endurance training; 8 wks	Gains of time to exhaustion by 57% and 24.9 % in E and C groups; work economy enhanced by 27% in E group. Gains of 1RM leg press 9.9% vs. 1.5% in E and C groups (P < 0.01)
Spurrs et al., 2003	17 well-trained male runners, 2 groups	Concurrent plyometric strength and endurance training vs. endurance training; 6 wks	Significant improvement in running economy by 5.2%, time to 3 km by 3.8% and countermovement jump in E group. No changes in C group
Mikkola et al., 2007	19 well-trained male cross country skiers, 2 groups	Concurrent explosive strength and endurance training vs. endurance training; 8 wks	Enhancement of 2 km performance by 5.5% vs. 2.9% in E and C groups. Increase in work economy by 7% and isometric force application in E group only (P < 0.01)
Storen et al., 2008	17 well-trained male and female runners, 2 groups	Concurrent strength and endurance training vs. endurance training; 8 wks	Significant improvement in time to exhaustion by 21.3%, running economy by 5.0% and 1RM by 33.2% in E group. No changes in C group
Sunde et al., 2010	13 well-trained male and female cyclists, 2 groups	Concurrent strength and endurance training vs. endurance training; 8 wks	Significant improvement in time to exhaustion by 17.2%, cycling economy by 4.8%, 1RM by 14.2% in E group. No changes in C group
Rønnestad et al., 2015	16 young elite cyclists, 2 groups	Concurrent strength and endurance training vs. endurance training; 25 wks	Significant improvement in power output in 40 min trial by 7%, 30 s trial by 2.5%, leg strength by 20% in E but not in C group
Vikmoen et al., 2017	19 well-trained female duathletes 2 groups	Concurrent strength and endurance training vs. endurance training; 11 wks	Significant improvement in power output in 5 min cycling by 7%, running by 4.7% and 1RM leg strength by 45% in E group. No changes in C group.

Abbreviations: E – experimental group; C – control group; END – endurance group; S – strength group; 1RM – 1 repetition maximum

One more source of performance improvement is associated with enhancement of peripheral blood circulation. Intensive muscular efforts elicit vasoconstriction, which suppresses peripheral blood circulation and evokes occlusion of capillary net (Shephard, 1992). Increasing maximal strength abilities shifts the threshold of blood flow constriction and enhances local and regional blood flow. These more favourable conditions for peripheral blood circulation prevent the suppressive effect of vasoconstriction (Hoff et al., 1999) and facilitate endurance performance.

The third explanation of the additive effect of strength training concerns enhancement of work economy. This effect has been reported by 7 research groups (Table 1) and was attributed to physiological and biomechanical factors. Physiological prerequisites evidence that concurrent strength and endurance training produces conversion of fast-twitch type IIX fibres into more fatigue-resistant type IIA fibres (Aagard et al. 2010 and 2011). A biomechanical factor relates to the administration of explosive type and plyometric contractions, which enhance regulation of muscle-tendon stiffness. This leads to more favourable utilization of elastic energy of forcibly stretched muscles during stretch-shortening cycle realized in endurance sports (Spurrs et al., 2003; Millet et al., 2002).

One more explanation relates to the outcomes of molecular sports science studies. Although several researchers reported on the interference impact of strength workouts in the preparation of endurance athletes (Aagard et al., 2010: Fyfe et al., 2014), other studies revealed the additive effect of high resistance exercises. Namely, the administration of strength workout immediately after the endurance sessions increases signalling related to mitochondrial biogenesis (Wang et al., 2011). A similar workout performed 6 hours after endurance training stimulates more favorable anabolic signals as compared with strength training alone (Lundberg et al., 2012).

Several studies revealed significant effects of supplementary strength training on maximal anaerobic abilities, which can be realized in starting and finishing spurts during endurance performance (Paavolainen et al., 1999; Mikkola et al., 2011). Only one study revealed increased maximal oxygen uptake following combined strength and endurance training (Hennessy and Watson,1994). Apparently that enhanced work economy but not increased energy supply became the dominant metabolic source of endurance performance enhancement produced by supplementary strength training.

It is worth noting that a number of studies did not find benefits of supplementary strength exercises.

Table 2. Summary of studies revealed no effect of strength exercises on endurance performance

Study	Subjects	Research design	Outcomes
Bell et al., 1989	18 male amateur rowers	Rowing training combined with isokinetic strength program: 1) high velocity, 2) low velocity, 3) no strength training (C); 4 d/wk, 5 wks	Increased leg strength. No difference between E and C groups in 90 s rowing ergometer test
Bulgakova et al., 1990	37 young swimmers, age 11-12 yrs	Swimming training combined with dry-land drills (E) vs. in-water strength drills (C); 2 d/wk: 25 wks	Increased dry-land strength in E group; superiority of C group in swimming trials
Tanaka et al., 1993	22 sub-elite swimmers, 19.3±0.2 yrs	Swim training 4-6 miles/day; resistance program 8-12RM; 3 d/wk (E) vs. swim only; 12 wks	No benefits of E group in sprint trials and stroke efficiency
Murray et al., 1994	30 elite male and female rowers	Rowing machine training combined with weight drills 4 d/wk (E) vs. rowing machine only (C); 14 wks	Superiority of no-lift (C) group in the 2000 m trial on rowing machine
Aspenes et al., 2009	26 trained swimmers; age 14-18yrs	Swimming program combined with dry-land power training, 2 d/wk (E) vs. pure swimming (C); 11 wks	No benefits of E group in swim trials, VO_{2max} and swim economy
Gallagher et al., 2010	18 male varsity rowers	Rowing combined with resistance training, 2 d/wk (two E groups) vs. only rowing (C); 8 wks	No benefits of E groups in 2000 m rowing performance
Sadowski et al., 2012	26 trained swimmers; age 14.1±0.4 yrs	Endurance swimming combined with 2 d/wk dry-land power training vs. pure endurance swimming; 6 wks	No benefits of E group in swimming sprint trials

Abbreviations: E – experimental group; C – control group; END – endurance group; S – strength group; 1RM – 1 repetition maximum

A number of studies conducted on junior swimmers during prolonged athletic preparation (6-25 weeks) did not reveal superiority of programs including dry land strength workouts as compared with programs which did not include strength training (Bulgakova et al., 1990; Tanaka et al.,1993; Aspenes et al., 2009; Sadowski et al., 2012). Similarly, several studies on qualified rowers that lasted 5 to 8 weeks failed to find significant benefits of supplementary strength training (Bell et al., 1989; Murray et al., 1994; Gallagher et al., 2010). These data contradict a common practice of including strength exercises in preparation programs of elite swimmers (Maglischo, 2003; Morouço et al., 2012) and rowers (Kleshnev, 2016; Thompson and Wolf, 2016). This inconsistency of the data mentioned can be considered with regards to environmental and biomechanical particularities of aquatic locomotion. The following arguments can be mentioned:

1) Restrictions to enhance work economy associated with benefits of stretch-shortening cycle. Both swimming and rowing have very small contribution of eccentric phases of muscular contraction. Unlike the terrestrial activities increasing of muscular-tendinous stiffness do not provide effect of storage and recoiling of elastic energy produced during forcible stretching of contracted muscles.

2) Favourable conditions for peripheral blood circulation. Compensation of gravitation by hydrostatic force in swimming and relatively long-term phases of the oar air transfer in rowing produce favourable conditions for muscular relaxation which prevent vasoconstriction and provide efficient peripheral blood circulation. Correspondingly, the positive effect of strength exercises associated with enhanced peripheral blood flow is much less relevant for aquatic locomotion as compared with terrestrial sports.

3) Neuromuscular specificity associated with propulsive mechanisms realized in aquatic sports. Muscular activities in swimming and rowing are strongly determined by water stroke mechanics (Kleshnev, 2016; Persyn et al., 2003). This neuromuscular specificity may largely restrict transfer of increased strength abilities obtained in dry land conditions to event-specific preparedness of swimmers and rowers.

Apparently, all the above-mentioned circumstances are not fatal. Following theory of dynamic correspondence of the appropriate exercises, which provide similarity of biomechanical variables with targeted athletic disciplines, can be compiled and successfully implemented in practice (Harrison et al., 2017; Goodwin and Cleather, 2016).

Application of Block Periodization training programs

One more approach to combined development of strength and endurance abilities is based on the application of Block Periodization (BP) training programs. This approach presupposes the administration of training cycles with a high concentration of workloads directed at the development of a minimal number of compatible targeted abilities and separation of various athletic abilities within appropriate training cycles (Issurin et al., 1988; Issurin, 2008). Following this concept, block mesocycles directed at the development of basic athletic abilities (i.e. accumulation) are focused on maximal strength and basic aerobic endurance. Block mesocycles directed at the development of event-specific athletic abilities (i.e. transmutation) contain exercises for strength endurance and anaerobic capacity, whereas block mesocycles of precompetitive preparation (i.e. realization) provide full restoration, increased speed-strength ability and include high-resistance exercises to support favourable anabolic status of athletes (Issurin, 2008).

The available study outcomes evidence that such a training strategy makes it possible to avoid interference between several strength and endurance abilities and provide their efficient interaction towards a forthcoming competition.

Table 3. Summary of studies related to Block Periodized (BP) development of strength and endurance athletic abilities

Study	Subjects	Research design	Outcomes
Issurin et al., 1988	23 world class kayakers	BP seasonal preparation, 5 stages which include 3 block mesocycles, 42 weeks	Seasonal gains of VO2max by 13.9% , strength endurance in 4 min ergometer test by 16.3% and 1000 m kayak performance by 5.9% ($P < 0.05$)
Garcia-Pallares et al., 2009	11world class kayakers	BP structured preparation which includes 3 block mesocycles; 12 wks	Improvement in VO2 max by 9.5%, speed corresponded to VO2 max by 6.2%, 1RM bench pull by 5.3% ($P < 0.05$)
Garcia-Pallares et al., 2010	14world class kayakers	BP structured preparation which includes 3 block mesocycles, 13 wks	Improvement in VO2 max by 9.8%, 1RM bench pull by 6-12% ($P < 0.01$). Remarkable enhancement of competitive performance
Mallo, 2012	22 trained soccer players	BP structured preparation, 5 stages which include 3 block mesocycles, 44 wks	Improvement in endurance by 34.2% in Yo-Yo intermittent test, CMJ by 16.7% and 10 m sprint by 3.3%
Rønnestad et al., 2019	16 trained ice hockey players	Strength/power or endurance program on weekly undulating basis vs. traditional mixed plan, 6 wks	Superior gains of BP group in VO2max: 5.1 vs. 1.1%; peak torque in knee extension: 6.6 vs -4.2% ($P < 0.05$) and 30 s cycling sprint: 4.1 vs -0.3% ($P < 0.1$)

Eventually, the separation of various strength abilities in different block mesocycles provides their beneficial compatibility with various endurance components exploiting appropriate physiological background. Namely, the muscle hypertrophy process combined with the administration of aerobic endurance workloads within accumulation block mesocycle presupposes homeostatic regulation of training adaptation, whereas intense anaerobic workloads directed at the development of sport-specific preparedness and strength endurance demand mobilization of stress reactions with appropriate hormonal responses (Issurin, 2019).

Importantly, the sequencing of three types of block mesocycles realized in previous studies (Table 3) provided rational interaction of strength and endurance workloads. Moreover, in two cases, the realization of BP approach led to obtaining the highest Olympic rewards: 3 gold medals of USSR canoe team (Issurin et al., 1988) and a gold medal of Spanish kayak-double crew (Garcia-Pallares et al., 2010). Apparently, BP approach gives a superior opportunity for combined enhancement of strength and endurance athletic abilities.

Conclusions

The inclusion of strength workouts in the preparation of endurance athletes is an important and valuable component of the training system of both high performance and amateur competitors. Although several authors reported interference effects produced by strength interventions, the majority of researchers and analysts emphasized the additive impact of supplementary strength training on various physiological variables, short-term and long-term athletic performances. The plausible mechanisms of such stimulatory action are associated with favourable muscles hypertrophy, an increase in slow twitch and fast oxidative IIA fibres areas, enhancement of peripheral blood circulation, improved work economy due to increased oxidative capacity of the muscles and more efficient utilization of elastic energy of forcible stretched muscles. Besides, purposeful strength training increases anaerobic capacity, which is realized in start and finish spurts during competitive endurance events.

It is worth noting that in several cases, supplementary strength training did not provide additive effects on sport-specific preparedness of trained athletes. This relates to preparing athletes in aquatic locomotion (Table 2), where favourable conditions for work economy, peripheral blood circulation and neuromuscular specificity of propulsive action restrict utilization of the mentioned benefits of strength training. Eventually, the compilation of exercises following the principle of dynamic correspondence and particularly the application of Block Periodization planning approach make it possible to overcome the above-mentioned shortcomings. Indeed, available experiences in the realization of BP programs evidence that the separation of highly concentrated strength and endurance workloads helps to obtain superior training effects and the most efficient athletic performance (Table 3). Importantly, in two studies, the superiority of BP planning was shown during the preparation of world class kayakers despite the above-mentioned restrictions typical of aquatic locomotion. Apparently, the administration of high resistance strength exercises is compatible with extensive aerobic endurance program, whereas enhancement of strength endurance can be successfully combined with intense sport-specific endurance program.

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