DEVELOPING RUNNING ECONOMY IN TRIATHLONISTS USING EXPLOSIVE-STRENGTH TRAINING

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M.Sc. Thesis
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Spring 2021

ABSTRACT

Kivimäki, A. 2021. Developing running economy in triathlonists using explosive-strength training, Faculty of Sport and Health Sciences, University of Jyväskylä, Science of Sport Coaching and Fitness Testing, Master's thesis, 61 pp, 4 appendices.

Triathlon is a demanding three event multisport (swim, bike, run). In competitions, avoiding total fatigue is most challenging during the run. Improving running economy is one way to ensure better endurance and results. Running economy can be improved by endurance, strength, and sprint training, which result in improvements in aerobic, anaerobic, and neuromuscular power and capacity. The purpose of this study was to investigate with novel triathlon exercise test how explosive-strength training affects running economy after biking.

An 8-week training intervention included explosive-strength training 2 times a week combined. Exercises included traditional barbell exercises, e.g squat, deadlift, and bench press. Focus was to train with barbell and multi-joint moves to gain full load to the neuromuscular system. Drop jumps and core exercises were also included. Novel race situation simulating maximal test, which combines WHO submaximal bicycle ergometer test, 2 minutes change time to maximal treadmill test was also developed. This test was performed before and after the exercise intervention with same bike load steps and treadmill speeds. Development was assessed by measurement of lactate levels and HR as well as analysis of changes in RPE.

In treadmill lactate levels were significantly lower in end test. Average run lactate change was -17,8% ±7,5% ($p < 0,05$ in measuring points 4, 12 and 16 minutes). Running time was extended 03:22 ±01:59, 16,6% ($p < 0,05$). Peak treadmill speed development was 1,0 km/h to 14,2 km/h ±1,5 km/h, 7,6% ($p < 0,05$).

Explosive-strength barbell weight training combined with drop jumping can significantly improve triathlon running economy. The novel triathlon maximal test gave important information to test persons how lactate levels behaved after bike.

Key words: running economy, cost of running, explosive-strength, motor units, drop jump, triathlon, maximal test, neuromuscular

TIIVISTELMÄ

Kivimäki, A. 2021. Triathlonistien pyörän jälkeisen juoksun taloudellisuuden kehittäminen nopeusvoimaharjoittelulla. Liikuntatieteellinen tiedekunta, Jyväskylän yliopisto, Valmennus- ja testausopin opintosuunnan pro gradu tutkielma, 61 s., 4 liitettä.

Triathlon on vaativa kolmen lajin multisport suoritus (uinti, pyöräily, juoksu), jonka kilpailussa vaativin osuus on juoksu ja sen aikainen väsymys. Juoksun taloudellisuuden parantaminen on avain parantuneeseen kestävyyssuorituskykyyn. Juoksun taloudellisuutta voidaan harjoituttaa kestävyys-, voima- ja nopeusharjoittelulla. Tuloksena aerobinen, anaerobinen ja neuromuskulaarinen voima ja kapasiteetti kehittyvät. Tutkimuksen tarkoitus oli selvittää uudella triathlonkuntotestillä paraneeko pyörän jälkeisen juoksun taloudellisuus nopeusvoimaharjoittelulla.

Menetelmänä oli toteuttaa 8 viikon ajan nopeusvoimaharjoitteluohjelmaa 2 kertaa viikossa. Liikkeet olivat perinteisiä levytankoharjoitteita, esim. jalkakyykky, maastaveto ja penkkipunnerrus, lisättynä keskivartalo- ja pudotushyppyharjoitteilla. Tavoitteena oli harjoitella moninivelliikkeitä täyden neuromuskulaarisen harjoitusvasteen aikaansaamiseksi. Lisäksi kehitettiin uusi kilpailutilannetta simuloiva triathlonmaksimitesti, jossa yhdistettiin WHO:n submaximaalinen pp-ergotesti, 2 minuutin vaihto ja maksimaalinen juoksumattotesti. Harjoittelun vaikutus analysoitiin laktaattimittauksilla.

Juoksumatolla laktaattitasot olivat tilastollisesti merkittävästi matalampia lopputestissä. Keskimäärin muutos oli -17,8% ±7,5% ($p < 0,05$ mittauspisteissä 4, 12 ja 16 minuuttia).
Juoksuaika piteni 03:22 ±01:59, 16,6% ($p < 0,05$).
Maksimijuoksunopeus kehittyi 1,0 km/h, nopeuteen 14,2 km/h ±1,5 km/h, 7,6% ($p < 0,05$).

Levytangolla toteutettu nopeusvoimaharjoittelu yhdistettynä pudotushyppyharjoitteluun voi parantaa merkittävästi triathlonin juoksun taloudellisuutta. Uusi triathlonin kuntotesti antoi tärkeää informaatiota koehenkilöille siitä miten laktaattitasot käyttäytyivät pyöräilyn jälkeen.

Avainsanat: juoksun taloudellisuus, nopeusvoimaharjoittelu, motorinen yksikkö, pudotushyppy, triathlon, maksimitesti, neuromuskulaarinen

ABBREVIATION LIST

BPM	Beats per minute
CMJ	Counter-movement jump
ECG	Electrocardiogram
EMG	Electromyography
ESL	Explosive strength loading
iEMG	Integrated electromyography
IMMU	Inertial magnetic measurement unit
HR	Heart rate
HRR	Heart rate recovery
HRV	Heart rate variability
LT	Lactate threshold
MART	Maximal anaerobic running test
MSL	Maximal strength loading
MVC	Maximum voluntary contraction
NIRS	Near-infrared-spectroscopy
PPG	Photoplethysmography
RE	Running economy
RM	Repetition maximum
RPE	Rating of perceived exertion
SSC	Stretch-shortening-cycle
T1	Transition 1, from swim to bike
T2	Transition 2, from bike to run
WHO	World Health Organization

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1 INTRODUCTION

Triathlon is a combined endurance multi-sport, which includes swimming, biking, and running in the very same event without resting pause between events. Only fast gear changes are completed between events in transition areas T1 and T2. It is very demanding to perform three sports in the same event. In swim upper body muscles are mostly used, although swimming is also demanding for the cardiovascular system. Biking needs to be completed at a reasonable pace so that there is enough energy left to run and muscles are not too much fatigued or damaged. Athletes competing in the triathlon need versatile training in order to have the ability to run and compete for medals. (Wu et al., 2014)

Run economy (RE) includes biomechanical and physiological variables. They can be assessed using a number of variables, e.g. stride frequency, stride length, ankle and knee angle changes when running, oxygen consumption, finger blood lactate, and heart rate (Tartaruga et al., 2012).

Lactate metabolism includes intra- and extra-cellular shuttles. In fast-twitch muscle cells lactate is glycolytically produced and in slow muscle cells then oxidated. Lactate can also be used in heart, liver and skin. Some lactate is present in blood circulation and in fast-twitch muscle cells lactate is even possible to transfer to glycogen storages. (G. A. Brooks, 2000)

It is known that pre-contact EMG activity prepares stretch reflexes, tendons and elastic tissues to needed stiffness for ground contact and to guide ground reaction force production to the right direction, mostly by two-joint muscles (Kyröläinen et al., 2005). Jumping power can be one factor behind improvement of running economy (Taipale et al., 2010).

Training program included explosive-strength barbell weight training for the whole body two times a week. Part of training program was drop jump. Explosive-strength training develops muscle motor control, balance, nerve control, motor unit activation, and force production speed while also improving elastic properties with **stretch-shortening-cycles SSC** (Byrne et al., 2010; Komi & Bosco, 1978).

The aim of this thesis was developing **triathlon running economy** with 8 weeks explosive-strength barbell weight training program and measure development with novel triathlon exercise test.

2 TRIATHLON

Triathlon has been present for about 40 years. The disciplines of swimming, bicycling, and running were first combined on the island of Hawaii by men with a military background who wanted to determine who is the most fit athlete in the world. There are still World Championships organised in Hawaii for the full Ironman distance, which includes 3,8km ocean swim, 180km bike and 42,2km running marathon. Nowadays there are also much shorter distances from supersprint and team relays, and also races for juniors even kids. For instance, the Olympic distance triathlon includes 1,5km swim, 40km bike and 10km run. (ITU, 2020b)

Triathlon is also Olympic Games sport event nowadays, will also be raced in Tokyo 2020. There are also growing amount of para-athletes who can race despite of injuries or amputees, even blind people can race with help of sport guides. (ITU, 2020b)

FIGURE 1. Paratriathlon athlete and guide in ITU Alanya Paratriathlon World Cup 2019. Blue rope is visible for blind guidance of blind athlete. (ITU, 2020b).

In swimming it is important not to swim at maximum intensity to save energy to bike and run to achieve best result in complete triathlon event (Peeling et al., 2005). Upper body anaerobic power is important factor in freestyle swimming performance (Hawley & Williams, 1991). Blood lactate can rise over anaerobic threshold in sprint distances and recovery needs 10-20 minutes swimming in lower speed (Neric et al., 2009). In full distance triathlon it is possible that swim does not have significant performance effect to bike (P. Laursen et al., 2000).

Also during the bike leg, it is important to perform at reasonable pace strategy to save muscle energy storages to last event, run. To gain optimal and fastest overall triathlon performance, the most important phase of bike is last kilometres, to recover from neuromuscular and metabolic fatigue before T2 (Wu et al., 2014). Nutritional strategy is very important factor to minimize fatigue, it is advisable to drink NaCl and carbohydrates (not fructose) mix in every 10 minutes. Carbohydrates should be maximum 10g / 100ml in every 10 minutes, bigger amount only delays fat mobilization (Dennis et al., 1997). High amount of fast-twitch muscle cells may present large amount of mitochondria and high potential for aerobic energy production (Green, 1997). Chosen maintained power in cycling cannot be at level of anaerobic threshold in full distance triathlon, muscle acidification leads to premature fatigue (P. B. Laursen & Rhodes, 2001). Higher cycling cadence can give muscle better blood flow and cycling power reducing fatigue (Abbiss & Laursen, 2005). Long cycling exercise can lead to reduced iEMG-activity because of central nervous system command. It is also possible that there is muscle fibre rotation present (St Clair Gibson et al., 2001).

Long cycling leg can generate exercise-induced muscle trauma, which includes problems in ionic pumps, sarcomeres, mitochondria and disruption in chemical (calcium) homeostasis. Also increases in insulin and decrease in creatine kinase concentrations effect to the rate of adenosine triphosphate (ATP) production. This state can be called as temporary systemic insulin resistance. As a result situation can activate pain receptors and even lowered performance in actin/myosin coupling. Athlete is not able to maintain optimal exercise performance in cycling and especially in following run when leg muscles are stiff and coordination is not working normally any more. The eccentric running motion can create even more muscle trauma than the concentric biking motion. (Abbiss & Laursen, 2005)

In T2 work method changes from non-weight bearing concentric to weight bearing stretch-shortening eccentric (Bernard et al., 2009). During run, there is more muscle damage in sarcomeres and neuromuscular fatigue than in bike and it leads to reduced power production (Allen, 2001; Gauche et al., 2006; Hebisz et al., 2019). From blood can be measured many muscular damage indicators like creatine kinase, lactate dehydrogenase, or myoglobin. These indicators may peak several days after full distance triathlon (Christophe Hausswirth & Lehénaff, 2001).

When running is performed directly after bike, cost of oxygen and lower limb muscle recruitment variability will increase compared to individually performed run especially in the first minutes of the run (Guezennec et al., 1996; Hue et al., 1998; Walsh et al., 2015). When compared triathlon to run, plasma free fatty acids were higher (Hue et al., 1998). This could mean that during triathlon, aerobic energy production processes are active already in swim and bike, lipolysis processes have been started because of increased energy demand. Very interesting finding is that 2h 15 minutes lasting marathon is more demanding than same time lasting triathlon, when evaluated by cost of run (oxygen or energy consumption). Possible causes are core temperature rise, lack of fluid balance, decreased glycogen muscle stores, eccentric muscle work, changes in stride length and stride frequency (C. Hausswirth et al., 1996).

There is also psychological side of pacing, how brain uses information collected from peripheral physiological systems. Most important part of this mental pacing is knowledge of remaining length of event, how long time exercise effort needs to be maintained. Internal and external receptors give information to the brain, central drive activates voluntary afferent actions or efferent inhibition commands neural system to continuously fine-tune power output (Abbiss & Laursen, 2005; Kayser, 2003; St Gibson et al., 2006).

In figure 2 is transition area presented, World Triathlon Series women elite race in Abu Dhabi, United Arab Emirates. In elite races there is at least 1,5-meter space between bikes so there is enough space to avoid contacts or slowing traffic. Swimming gear needs to be put in boxes or else athlete will be penalized (ITU, 2020a).

FIGURE 2. Elite women athlete transition area, WTS Abu Dhabi 2018. Transition situation in start of race. *(Picture copyright Arto Kivimäki)*

3 RUNNING ECONOMY

Running economy is important factor when evaluating distance running capabilities. It includes biomechanical and physiological variables. Biomechanical variables include stride frequency, stride length, balance time, elbow motion, ankle and knee angle changes when running. Physiological variables are e.g. oxygen consumption, energy consumption, finger blood lactate and heart rate (Tartaruga et al., 2012). Developing balance control could be one important and factor of running economy. In his research Ph.D. Jarmo Piirainen (2014) has showed that jump exercises can develop balance control as well as weight training can (Piirainen, 2014).

There are many methods for accessing running economy (RE). Running economy can be correlated with e.g. jump test heights, running time at treadmill test and also maximum speed in maximal anaerobic running test (MART) (Barnes & Kilding, 2015; Rusko et al., 1993). Inertial magnetic measurement units (IMMU) could be used to continuously measure three dimensional changes, accelerations to different directions, angle changes and how fatigue changes running mechanics (Reenalda et al., 2016). In addition to that it is also possible to measure electromyographic changes e.g. from the most important muscles in run cycle, two-joint biceps femoris, rectus femoris and gastrocnemius (Kyröläinen et al., 2005; Mero & Komi, 1987).

Ventilatory gases oxygen and carbon dioxide can be used when evaluating lactate or anaerobic threshold without finger blood test. Ventilatory threshold can also be estimated from breathing gases with several different ways including ventilatory equivalents or V-slope method. Energy consumption can also be estimated from breathing gases (American College of Sports Medicine, 2018; Keskinen, 2018).

Heart rate (HR) measurements can be completed with chest band, biceps band or e.g. wrist watch. Technology used is normally photoplethysmography (PPG) as an alternative to electrocardiogram (ECG). PPG readings can be about 5 BPM less than ECG. Measurement error is about 3%. HR monitors can also be used in arm movement sports with lower accuracy

(Essner et al., 2013; Hermand et al., 2019; Lee & Gorelick, 2011; Schrader et al., 1999; Weiler et al., 2017).

After exercise intervention there were no significant relationships found between the change of maximal running performance and recovery values heart rate recovery HRR, heart rate variability HRV, and counter-movement jump CMJ. Most important variable to follow effects of endurance training was running at 90% speed from maximal heart rate. This can be useful way to measure athletes progress on weekly basis, without performing maximal tests (Vesterinen et al., 2017).

Paavolainen et al., (1999) pointed out that explosive-strength training improves 5000m running time by improving both RE and muscle power. Correlations were found between 5000m running velocity with changes in RE (oxygen uptake r = -0,54) and velocity in MART test (r =0,55). The research group reported that this was because of improved neuromuscular properties that developed velocity in MART and improved RE. The research group also found that endurance performance may be limited by insufficient amount of muscle power. Maximal velocity in MART can be used as muscle power measuring test because it is combination of neuromuscular and anaerobic characteristics (Paavolainen et al., 1999). It has been studied that there is only light correlation between VO_{2max} and running economy (Shaw et al., 2015). Shaw et al., (2014) found out that underlying energy consumption is more precise measuring than oxygen consumption and suitable scaling with body mass is recommended.

In figure 3 are presented how different training methods develop different running characteristics related to running performance. There is aerobic and anaerobic power and capacity, glycolysis and lactic acid. PCr store, utilization and buffer capacity. In the end also neuromuscular capacity needs to be trained. This can be done with sprint runs, also with jumps and explosive training. All this together is distance running performance: running time, oxygen consumption VO_{2max}, lactate threshold level (LT), RE and maximal velocity in MART test V_{MART}.

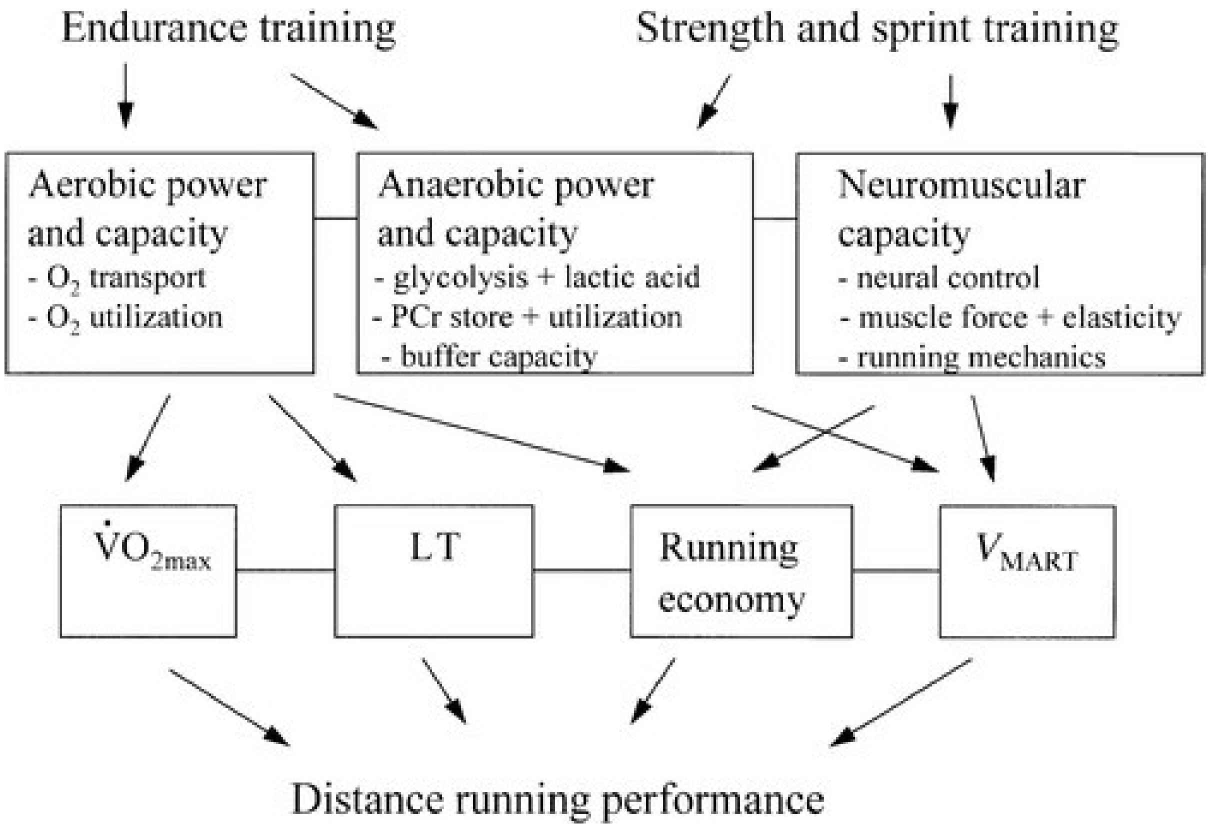

FIGURE 3. Distance running performance characteristics (Paavolainen et al., 1999).

Prampero et al., (1993) suggested that 5% decrease in cost of run (Cr) gives 3,8% faster run time in 5000m run. Similar size of RE developing effect was also found in Giovanelli et al (2017) with ultra-marathons home-based explosive and jumping training programme with only body weights (Giovanelli et al., 2017).

Maximal weight training (> 90% 1RM) with endurance training improved maximal velocity at VO_{2max} level and jumping power improved compared to endurance training. RE measured by oxygen consumption improved significantly 7% (Millet et al., 2002). In similar research Taipale et al., (2010) found out that also explosive strength training had similar effect on run economy and also maximal run speed development. They also found out that jumping power increased both in maximal and explosive training.

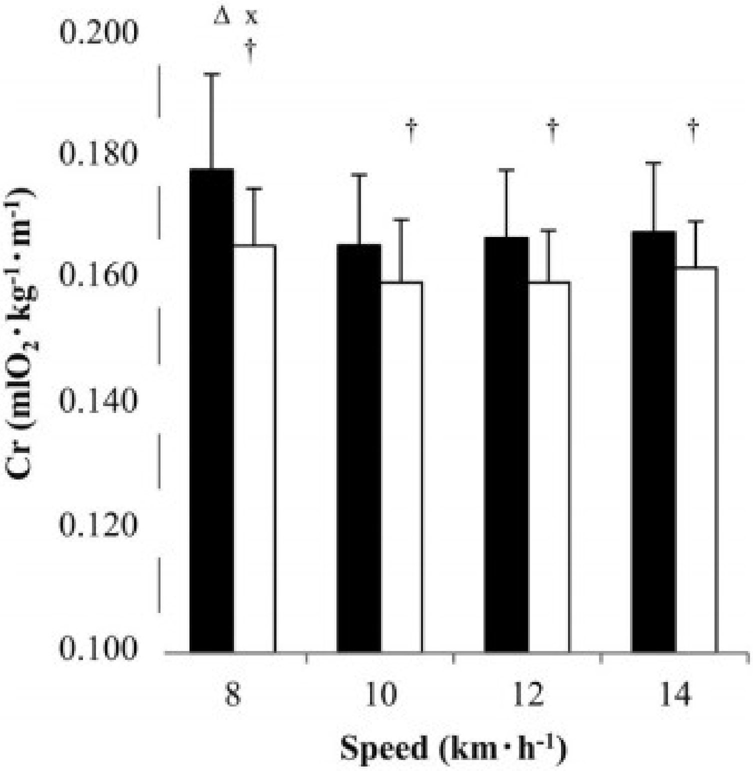

FIGURE 4. “*Cr (Cost of run) as a function of speed in exercise group (n = 13), before (PRE, black bars) and after (POST, white bars) the training period.*” (Giovanelli et al., 2017).

In figure 4 are presented (Giovanelli et al., 2017) measurements in cost of run development from pre to post. Remarkable in this research was that these ultra-marathon test group did not use weights at all, they only trained with body weight at home.

Thomas et al (1999) found out that in 5000m run oxygen consumption correlates with lactate in women group. In men’s group correlation was not statistically significant, although connection was present (Thomas et al., 1999). So it could be estimated that lactate changes correlate to RE development.

4 LACTATE METABOLISM

In sport testing and coaching, lactate is one of the most important metabolic products in energy production processes. It can be measured from finger blood sample also in field tests by portable lactate analysers (Keskinen, 2018).

Lactic acid transfers into lactate (La^-) anions and protons (H^+). Lactate can move by intracellular and extracellular shuttles. In intracellular lactate shuttle (figure 5) lactate goes from cytoplasm where it is created to mitochondria where it is consumed. In mitochondria presents aerobic energy production process with oxygen, lactate is changes to pyruvate. This means that muscle cells are able to create and use lactate (Plowman & Smith, 2007).

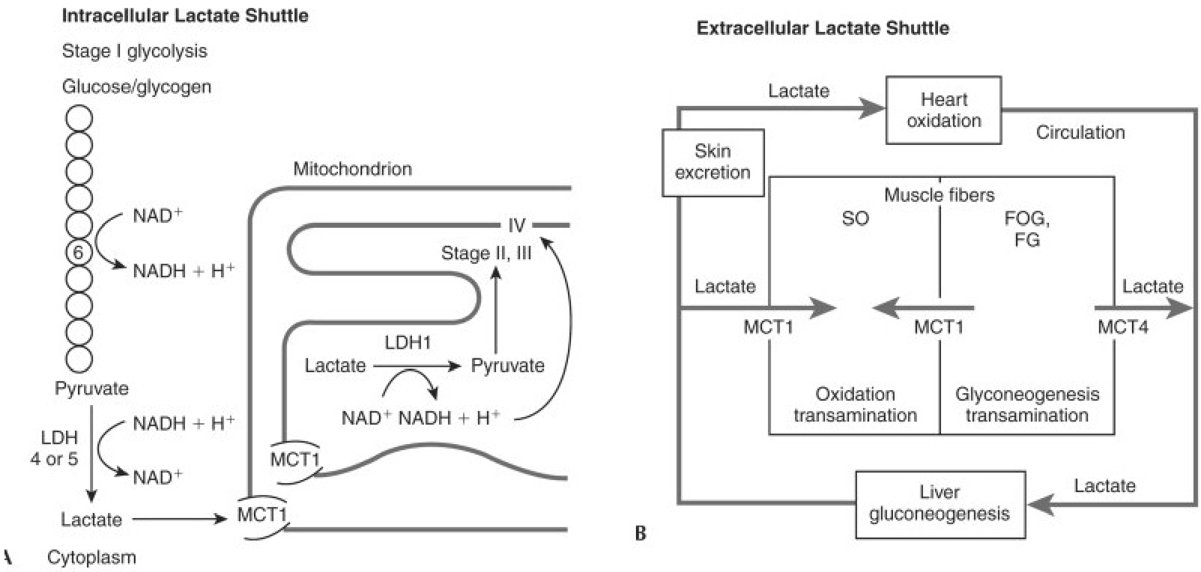

FIGURE 5. Intracellular and extracellular lactate shuttles. (Plowman & Smith, 2007).

In extracellular lactate shuttle lactate can move from lactate producing anaerobic fast-twitch muscle fibres to lactate consuming slow-twitch aerobic fibres. Lactate goes also to the liver, skin and heart by blood system. Remaining lactate in fast-twitch glycolytic muscle fibres is transferred to glycogen storage for later usage. Muscle fibres can also move lactate by transamination, that creates keto and amino acids (mainly alanine). Some of lactate is present in blood circulation and can be measured as rest lactate level. Aerobic process (oxidation) is most important way of cleaning lactate during or after loading. (G. A. Brooks, 2000; George A. Brooks, 2009; Plowman & Smith, 2007).

5 EXPLOSIVE-STRENGTH TRAINING

Maximal effort explosive-strength training gives extra demand for neuromuscular system to recruit maximal amount of motor units with lower weights to create fast force production. This method activates type II fast muscle cells which normally activate only at maximal demands over 80% maximum weights when slower type I muscle cells cannot produce enough power any more. Weight training with lower weights is not so demanding to human body so athlete can recover from it faster (Linnamo et al., 1997, 2000; Millet et al., 2002).

In figure 6 is presented that with explosive weight training research has shown that it develops earlier motor unit activation and gives extra doublets and more maximal firing rates that increase MVC (maximal voluntary contraction) (Van Cutsem et al., 1998).

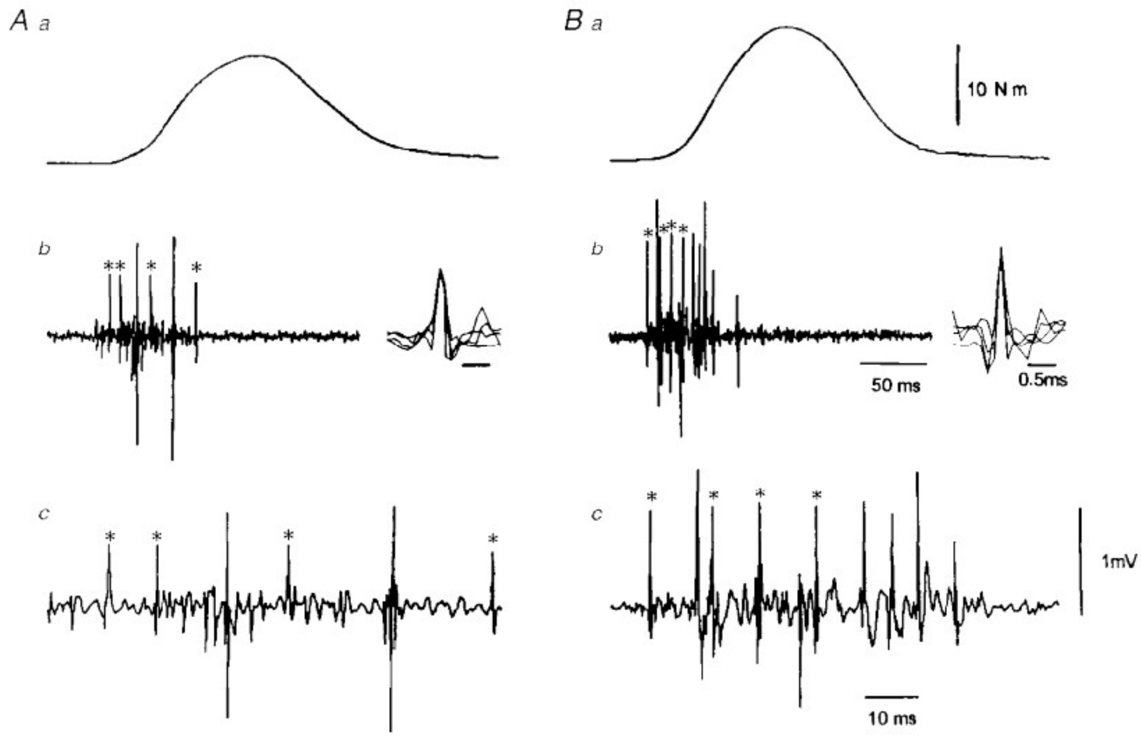

FIGURE 6. Measurements of motor units activation (Van Cutsem et al., 1998).

In figure 7 is presented torque and EMG activity from (Van Cutsem et al., 1998) research, earlier muscle EMG activity is clearly visible from graph. Also bigger torque has been developed because of faster and more motor units recruiting count.

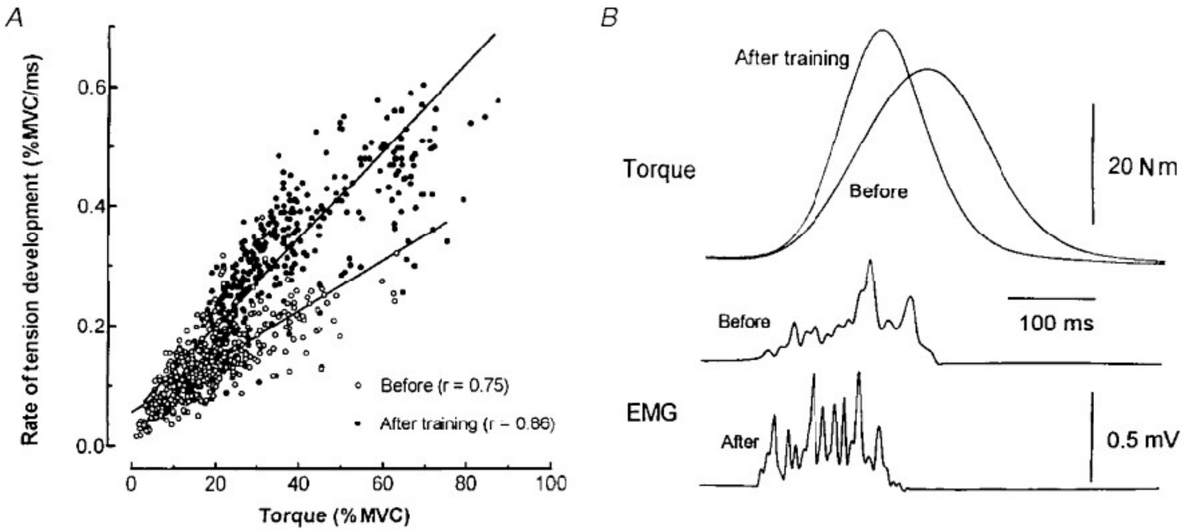

FIGURE 7. Rate of tension development, torque and EMG (Van Cutsem et al., 1998).

Linnamo et al. (1997) pointed out that explosive type loading creates mostly central fatigue as maximal weights loading leads to peripheral fatigue. This can be measured by iEMG (integrated electromyography) from early contraction phase and from peak value as well. In figure 8 is presented early contraction phase fatigue by explosive strength loading (ESL) in before, 5 sets and after. Phenomenon leads to neural side training with explosive-strength.

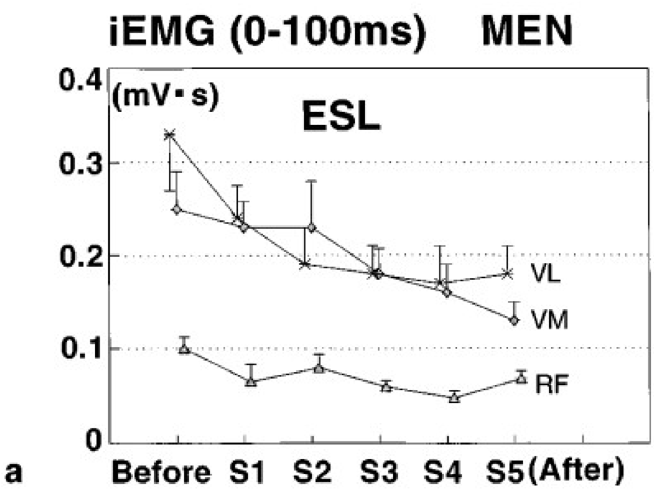

FIGURE 8. iEMG development in explosive strength loading fatigue (Linnamo et al., 1997).

In same research Linnamo et al., (1997) measured also blood lactate development. In figure 9 is presented blood lactate concentrations from different loadings. It is shown that at explosive loading lactate levels remain near anaerobic threshold, so peripheral fatigue is not cumulating over and exercise can be performed for quite a long time.
Maximal strength loading leads to over 10 mmol/l lactate concentrations, which very much are heavily fatiguing maximal effort performances that cannot continue for long time. Women have smaller concentrations, because they could not fatigue themselves to the end in explosive strength loading.

In this research ESL loading was 40% from MSL loading which was performed as 5 x 10 RM sets. It could be estimated that ESL loading was about 30% from fully separately performed 1RM.

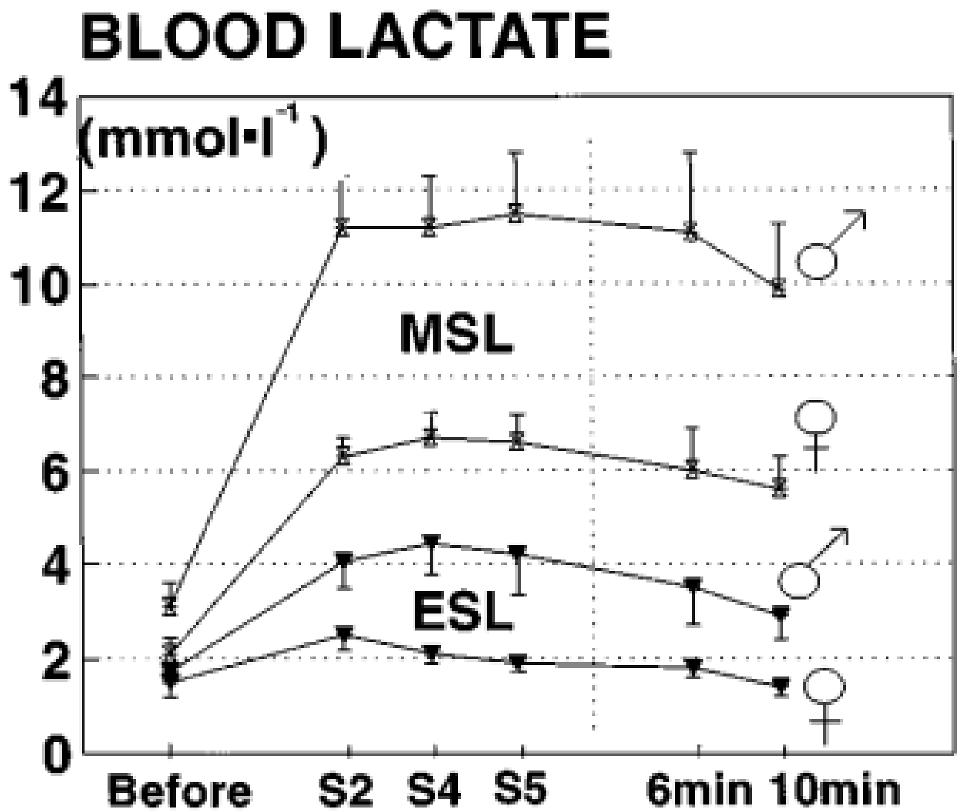

FIGURE 9. Blood lactate concentrations for men and women before, during and after maximal strength (MSL) and explosive strength (ESL) loading. S=Set (Linnamo et al., 1997).

In figure 10 is presented explosive, submaximal and heavy weightlifting acute hormonal responses (Linnamo et al., 2005). Heavy was set of 10 RM (about 70% 1RM), explosive 40% from heavy (about 30% 1RM) and submaximal 70% from heavy (about 50% from 1RM). It is shown that heavy weights give response for growth hormone. In men also explosive training gives effect. This means submaximal training was not effective and women would need also heavy training in addition to explosive. Man can train mostly explosive, of course heavy training gives significant response in growth hormone. Maybe submaximal load 50% 1RM was too light to be performed in normal speed, 50% 1RM is nearly still in explosive area.

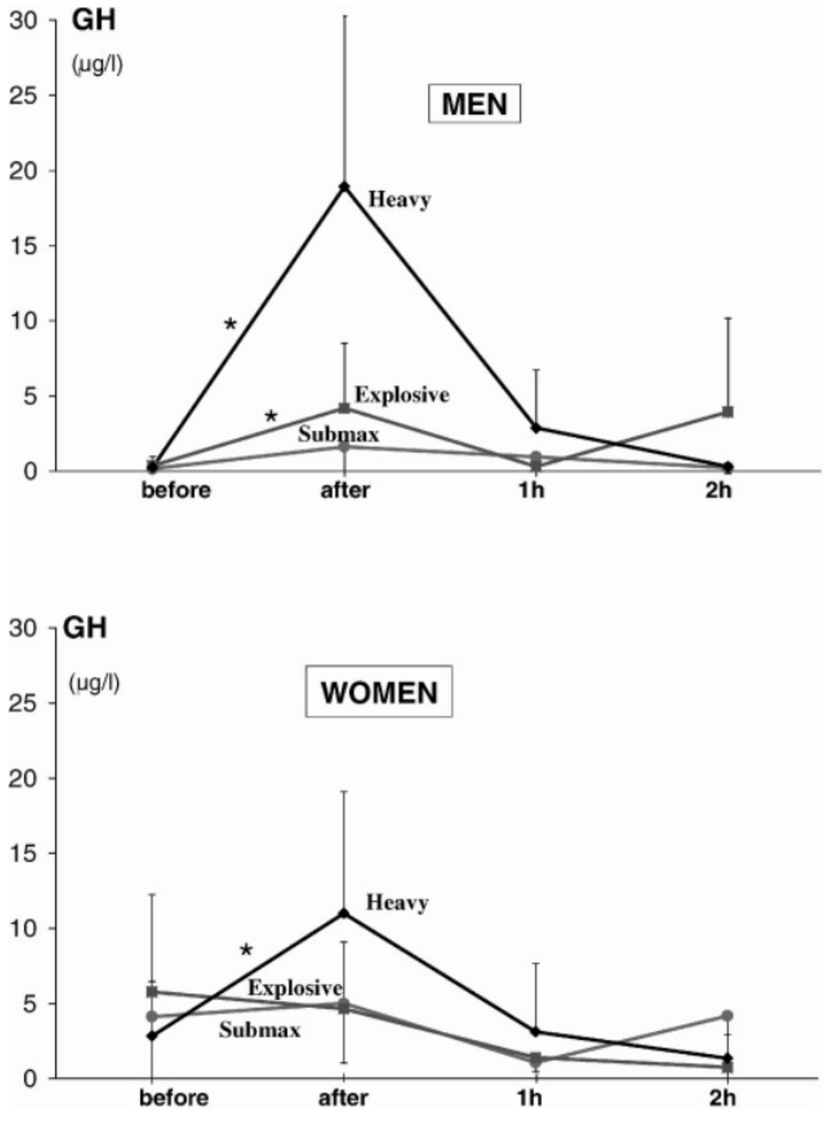

FIGURE 10. *"Mean (6 SD) values for serum growth hormone (GH) concentrations before and after the exercises in (a) men and (b) women (* 5 p < 0.05)"* (Linnamo et al., 2005).

In figure 11 is presented testosterone graphs from same research than in figure 9. We can see similar kind of acute responses. In men group heavy training increases temporarily testosterone. Changes are much smaller than in growth hormone, especially in women group there are no significant changes.

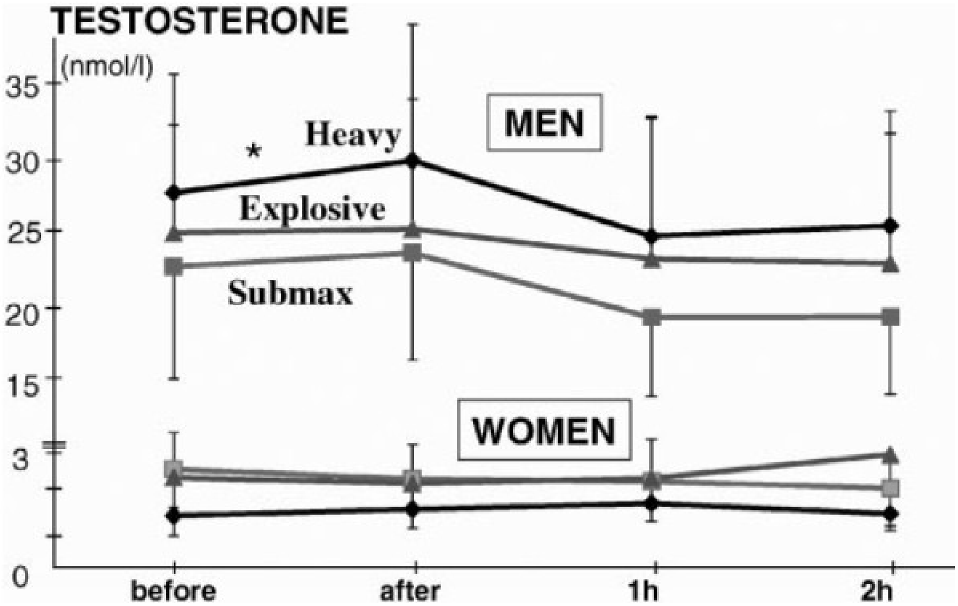

FIGURE 11. *"Mean (6 SD) values for serum testosterone concentrations before and after the exercises (* 5 p < 0.05)"* (Linnamo et al., 2005).

Altogether all this means that maximal and explosive strength training gives developing effect on RE when submaximal or circuit training does not. It is advisable to add maximal or explosive strength training to running training plan. When explosive strength training is performed only 30-40% 1 RM load it is much faster to recover than 90% 1 RM maximal training, so most weight training exercises is good to perform explosive way to maintain good and flexible situation in body for running technique training. Maximal training takes many days to recover and it stiffens muscles and tendons.

6 PLYOMETRIC TRAINING

Jumps / plyometrics are one kind of explosive strength weight training. Drop jumps are a good example of weight training where only an athletes own body mass is used as weight. Drop jump creates stretch-shortening-cycles in muscles when athlete must stop energy from dropping and immediately develop new power for jump. Drop jumps place great demand on the whole body from balance sensors to type II fast muscle cells must activate and work together. Force production speed must develop quicker. Depth jump is one kind of drop jump exercise but it is executed from much higher starting position, e.g. 75-110cm and it gives more maximal effect to muscles and maximal jump height development than drop jump or countermovement jump does. Actually depth jump can create bigger forces than maximum squatting can. Drop jump is meant to develop elastic properties, SSC (Barr & Nolte, 2011; Byrne et al., 2010; Marina et al., 2012; Verkhoshansky, 2007; Young et al., 1999).

History and theory of plyometrics from (Verkhoshansky, 2007). Written by Natalia Verkhoshansky:

"The invention, or development, of the Shock Method started in the fifties thanks to the problems met by a young jumpers coach of the Moscow Aeronautical Institute, Yuri Verkhoshansky. At that time Y. Verkhoshansky was also doing a research on the biodynamical structure of triple jump technique. He discovered that in the triple jump the pressure on the support, during the push up, reaches 300 kg. None of his athletes was able to perform the Squat with such overload on the shoulders. So, he start to search how create the conditions to make possible to perform the legs push up movement with overloaded of 300 kg.

"may be it's possible to create the conditions for such strength effort using the energy of human body fall"

So Verkhoshansky started to find a practical way to realize this idea in the only place that he had at his disposal, the narrow and tall space among the stairways of the Institute's building. In this way has been invented the jumps in low with rebound in aloft, Drop Jumps and the Shock Method."

In figure 12 is presented whole progression of jumping exercises. Starting from warm-up and basic runs we see 4 levels of progression. First level is basic jumps without weights. At second level are normal barbell exercises which can be done explosive (*Verkhoshansky Site*, 2020). 3. level achieves jumps with extra weight like kettlebell squat jumps or counter-movement barbell jumps. At highest level alone stands depth jumps which are mainly meant to professional athletes. All jumping exercises need very good warm-up phases, risk of injury is always present.

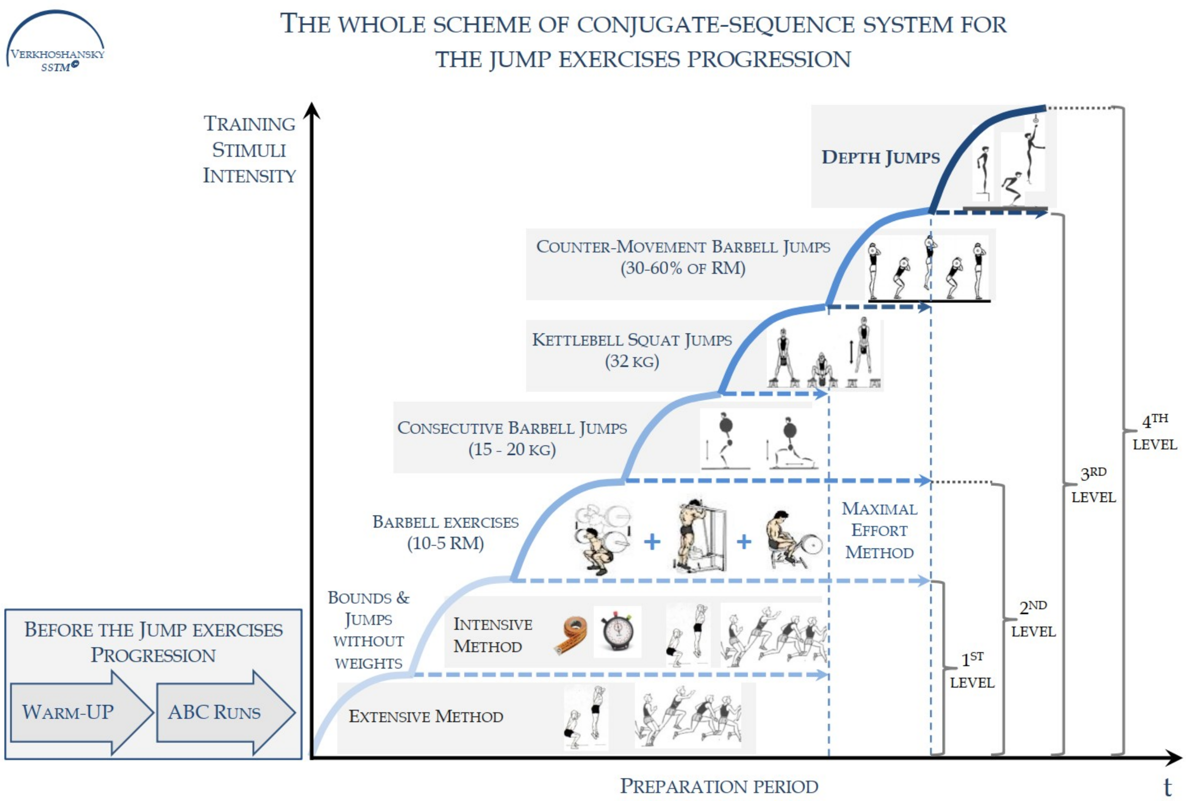

FIGURE 12. Jump exercise progression by Prof. Verkhoshansky (*Verkhoshansky Site*, 2020).

Westside barbell powerlifting coach Simmons recommends maximal weights training combined to explosive strength training, resistance bands and plyometrics, depth jumps (Simmons, 2017). In table 1 are depth jump testimonials (*Verkhoshansky Site*, 2020).

TABLE 1. Depth jump testimonials (Verkhoshansky Site, 2020).

"For jumpers the Depth Jumps are like a sip of fresh water on a hot day. Moreover, they are an optimal method to evaluate the functional state of the athlete and to increase explosive muscle strength."	**Vitali Petrov**, trainer of the former world record holder in pole vault **Sergei Bubka**.
"I had not thought that Depth Jumps could be so useful for the weightlifter."	**Yuri Kozin**, former world weightlifting record holder.
"The Depth Jumps are daily bread for triple jumpers; they are what is most necessary for them, first of all."	**Viktor Saneev**, former world record holder in the triple jump.
"The Depth Jumps replace the muscles with very elastic steel springs. Without them it is not possible to perform the jumps on ice, characterized by a high flight height."	**Stanislav Guk**, trainer of many world champions in figure skating on ice.

7 PURPOSE OF THE STUDY

In triathlon competition it is vital to control pacing level, how to save energy storages to last part, run. Run economy is important to develop so athlete can achieve good total results and eventually have also sprint finish towards winning race.

Purpose of the study was to confirm that with 8 weeks explosive-strength barbell weight training and drop jumping program athlete can develop significantly triathlon run economy. The mechanism that is hypothesized to improve RE is earlier and stronger neuromuscular function that leads to increased jumping power, also tendons and elastic tissue develop by structural changes that could effect running mechanics towards better running technique and delayed fatigue (Komi & Bosco, 1978; Linnamo et al., 1997; Mero & Komi, 1987). Muscle lactate oxidation to energy source during exercise could also be developed (G. A. Brooks, 2000).

Change in lactate levels were measured with novel triathlon exercise test in laboratory with start and end tests. Test included about 10 lactate measurements, so it was possible to estimate run economy development after training intervention. As a result we could find out athletes individually suitable run start speed after T2.

8 METHODS

8.1 Subjects

Test group was hobby triathletes and they train about 5-10 hours per week various sports. The amount of other training hours and loads were not supervised in this research.

Test group was collected from voluntary triathlon team members. In test group was 13 participants, 6 of them could finish training program and perform end test. 2 female and 4 male average age 45,5 years ±8,6 years. Some had private life problems and finally coronavirus disease closed university laboratories so training intervention and final measurements could not be concluded with all the subjects. The study was approved by the Ethical Committee of the University of Jyväskylä.

8.2 Study protocol

In this research was done novel triathlon test including bicycle ergometer and treadmill as start test, 8 weeks explosive strength exercise intervention and triathlon end test to see triathlon run economy development analysed from lactate levels. In tests were collected anthropometric data, heart rate, lactate levels and Borg scale levels.

The 8 week training intervention included 2 times a week barbell weight training and drop jumping.

8.3 Triathlon maximal test

After test familiarization test persons performed maximal oxygen uptake test combined bicycle ergometer Ergometer Monark 839 E (Sweden) and Coachtech system (Jyväskylän yliopisto, Suomi) run test. Treadmill model was Rodby RL3500E (Rodby, Sweden). Test protocol included anthropometric and bodycomposition measurements (height, weight, body fat %) with Inbody 720 device (Inbody, USA). During the bicycling and running tests heart rate was measured with H10 band (Polar, Finland), and lactate concentrations from right hand finger blood samples 4 minutes intervals. Blood samples were analysed in Biosen C-line lactate and glucose analyser (Biosen, England). Also test person's rate of perceived exertion was monitored by Borg's scale interview. From there measurements were estimated aerobic and anaerobic levels by Finnish exercise testers regulations (Keskinen, 2018).

Protocol of novel triathlon maximal test included as guided warm-up 16 minutes bicycle ergometer (4×4minutes steps) + 2 minutes T2 change to treadmill where was performed 4 minutes steps until exhaustion. In run phase run step was 3 minutes and there was one minute pause to take blood samples and collect near-infrared spectroscopy (NIRS) data from 2 devices. Bicycle watts were calculated by WHO sub-maximal bicycle ergometer test equations. Test person could choose start running speed so that they can reach 5 steps at treadmill. Same bicycle watts and running starting speeds were used in both tests. Running start speeds varied from 8-10 km/h. After test there was 10 minutes recovery phase at walking speed 6 km/h.

Deacidification speed was calculated from post 4 → post 10 minutes values, because probably lactate levels were rising at least 4 minutes after test (Gass et al., 1981).

8.4 Training program

In table 2 is presented 8 weeks training program. Program includes 2 different training days, upper and lower body, drop jumping in both days. 16 sessions altogether, 2 times a week. Test group performed 8 to 23 exercises in time of 8 to 12 weeks.

Exercise load was set to 35% from repetition maximum (1RM) for movements to be performed explosive way. Maximum repetitions were not tested because of safety, they were estimated from longer sets (7-10 repetitions). Because of average estimation, 35% was not precise, perhaps varied from 30% to 50%.

In 8 weeks of time small additions to weights was allowed, 5-10kg, if explosive speed could be maintained.

TABLE 2. Explosive-strength barbell weight training program.

Day 1.	**Middle and lower body, drop jump**	
warm-up	rowing	10 min
middle body	sit-up	3 x 20
middle body	lifting legs	3 x 20
middle body	back extension	3 x 20
jump exercise	drop jump	3 x 10
legs	squat	5 x 7 x 35% 1RM
legs/back	deadlift	5 x 7 x 35% 1RM
legs	deadlift with straigth legs	5 x 7 x 35% 1RM
legs	calf raise	5 x 7 x 35% 1RM
cool-down	rowing	10 min

Day 2.	**Middle and upper body, drop jump**	
warm-up	rowing	10 min
middle body	sit-up	3 x 20
middle body	lifting legs	3 x 20
middle body	back extension	3 x 20
jump exercise	drop jump	3 x 10
upper body	barbell high pull and push	5 x 7 x 35% 1RM
chest	bench press	5 x 7 x 35% 1RM
back	barbell bent ov er rows	5 x 7 x 35% 1RM
biceps	barbell bicep curl	5 x 7 x 35% 1RM
cool-down	rowing	10 min

8.5 Training exercises

As a powerlifting national champion I do have long history of developing power. Exercises in training program are presented with pictures and videos. Main muscles and joints are described. Why they were chosen and which effect they give for running economy development.

As warm up exercise it was done rowing for 10 minutes with individual chosen loading. Rowing warms muscles well and prepares also heart, blood system, spine, joints, elastic tissues and neuromuscular system to multi-joint barbell exercises.

Body’s middle section (core) is important in any biomechanical movement, especially running. So three moves: sit-ups, lifting legs and back extension. 3 sets with 20 reps each.

Also plyometrics are important when developing nerve-muscle system reaction capabilities and recruiting fast type II muscle cells and all motor units. Drop jump is excellent exercise because of landing “shock” and immediate need for power creation to opposite direction against gravity. The higher the better – towards depth jump, soviet invention from 1950’s.

Lower body explosive barbell exercises are from powerlifting section. Squat, deadlift and deadlift with straight legs added with standing calf raise make legs and core fully loaded and ready for development. These moves effect triathlon run by giving basic power to foot, core and back muscles so they don’t get so fatigued in bicycle and still can carry body better in run. Enough strength to improve running biomechanics.

Upper body explosive barbell exercises follow traditional style. Barbell high pull and push is excellent multi-joint whole body exercise. Final push sets amount of usable weight. Bench press, barbell bent over rows and barbell bicep curl follow with proper load of upper body. Enough push and pull exercises for full body workout.

8.5.1 Rowing

In rowing exercise target muscles are muscles of your legs and shoulders. As you row forward your biceps, back, gluteus and hamstrings make more work. When drive-phase is at the end almost all muscles from upper body are activated (David, 2012). Catch phase is done from deep and relaxed position to gain maximal amount of movement.

In drive phase it is important to remember that arms remain straight to transmit power from legs and back (Rowing Biomechanics, 2020). Legs begin to produce power when back begins to extend. Optimal release angle 110 is degrees. In recovery body will again go to catch phase.

FIGURE 13. Rowing exercise. https://vimeo.com/393977636

8.5.2 Sit-up

Target muscles are rectus abdominis. Synergists are obliques, iliopsoas, tensor fasciae latae, rectus femoris, pectineus, sartorius and adductors.

Performing directions:
You need to relax waist to every repetition, lower back should touch bench and then have controlled movement by core muscles. You can use extra weight if needed. (‘Decline Sit-up Exercise Instructions and Video’, 2017).

FIGURE 14. Sit-up exercise. https://vimeo.com/393977681
Link to educational video https://weighttraining.guide/exercises/decline-sit-up/

8.5.3 Lifting legs

Target muscles are iliopsoas. Synergists are tensor fasciae latae, sartorius, pectineus, rectus femoris and adductors. Stabilizer muscles are rectus abdominis, internal and external obliques and quadriceps.

It is important to keep your lower back attached to bench to protect your lumbar spine.

FIGURE 15. Lifting legs exercise. https://vimeo.com/393977718

Link to educational video https://weighttraining.guide/exercises/lying-straight-leg-raise/

8.5.4 Back extension

Target muscles are erector spinae and hamstrings. Synergists are gluteus maximus and adductor magnus.

Performing technique tips are not to go too deep, only when you feel small stretch in hamstrings. Also it is not advisable to extend torso too much up.

FIGURE 16. Back extension exercise. https://vimeo.com/393977757

Link to educational video https://weighttraining.guide/exercises/hyperextension/

8.5.5 Drop jump

In drop jump exercise target muscles are quadriceps femoris, gluteus maximus and gastrocnemius. Synergists are hamstrings, soleus, flexors and tibialis posterior. Stabilizers are erector spinae, abdominals and pelvic diagram.

When performing drop jump it is important to jump up with short ground contact time, about 0,2 seconds maximum. This jump exercise develops explosive and reactive properties of muscles when changing muscle work method from concentric to eccentric.

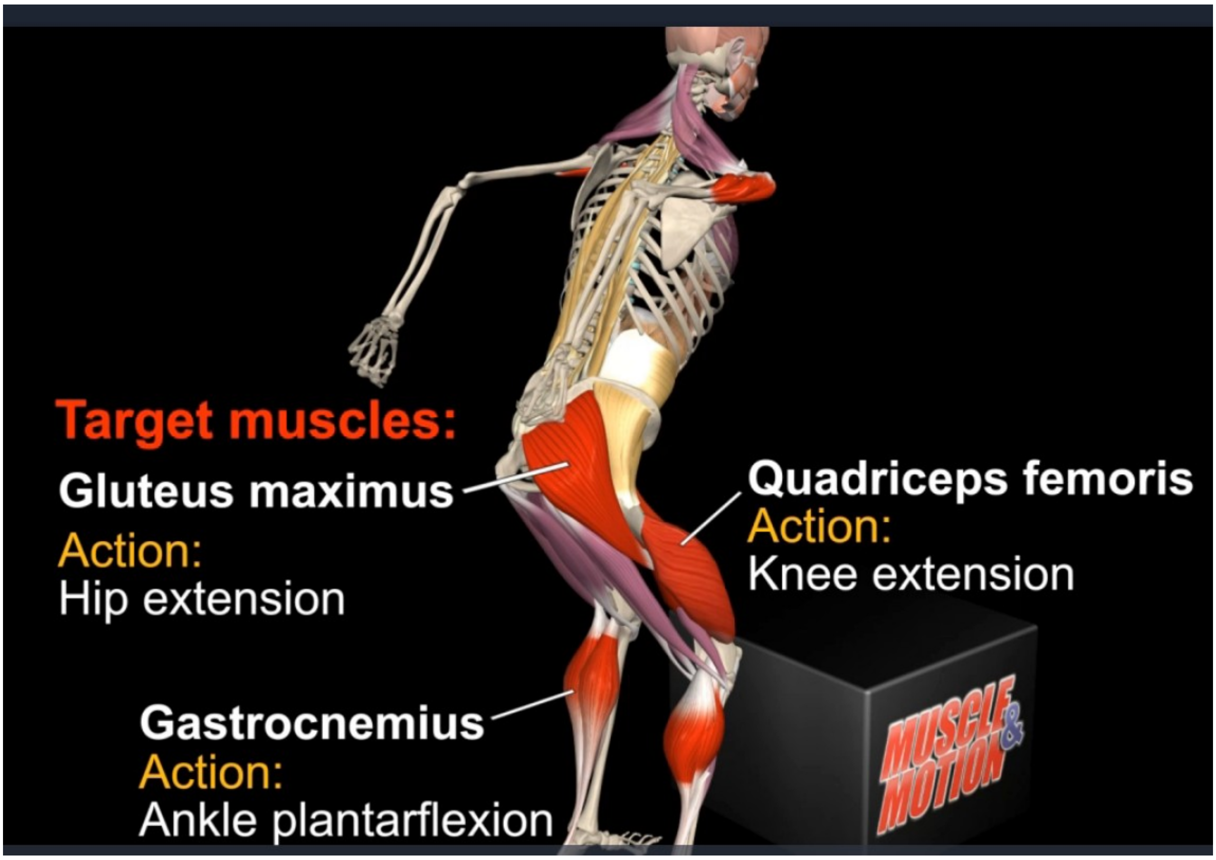

FIGURE 17. Drop jump exercise. https://vimeo.com/393978225

Link to educational video https://app.strength.muscleandmotion.com/exercise/721

Link to depth jump https://www.youtube.com/watch?v=4P1A2R2nT-A&feature=youtu.be

8.5.6 Squat

In full squat exercise target muscles are quadriceps femoris and gluteus maximus. Synergists are hip adductors, soleus, hamstrings and gastrocnemius.

When performing move it is important to move toes out so pelvic can rotate forward and pressure in lumbar spine is lower.

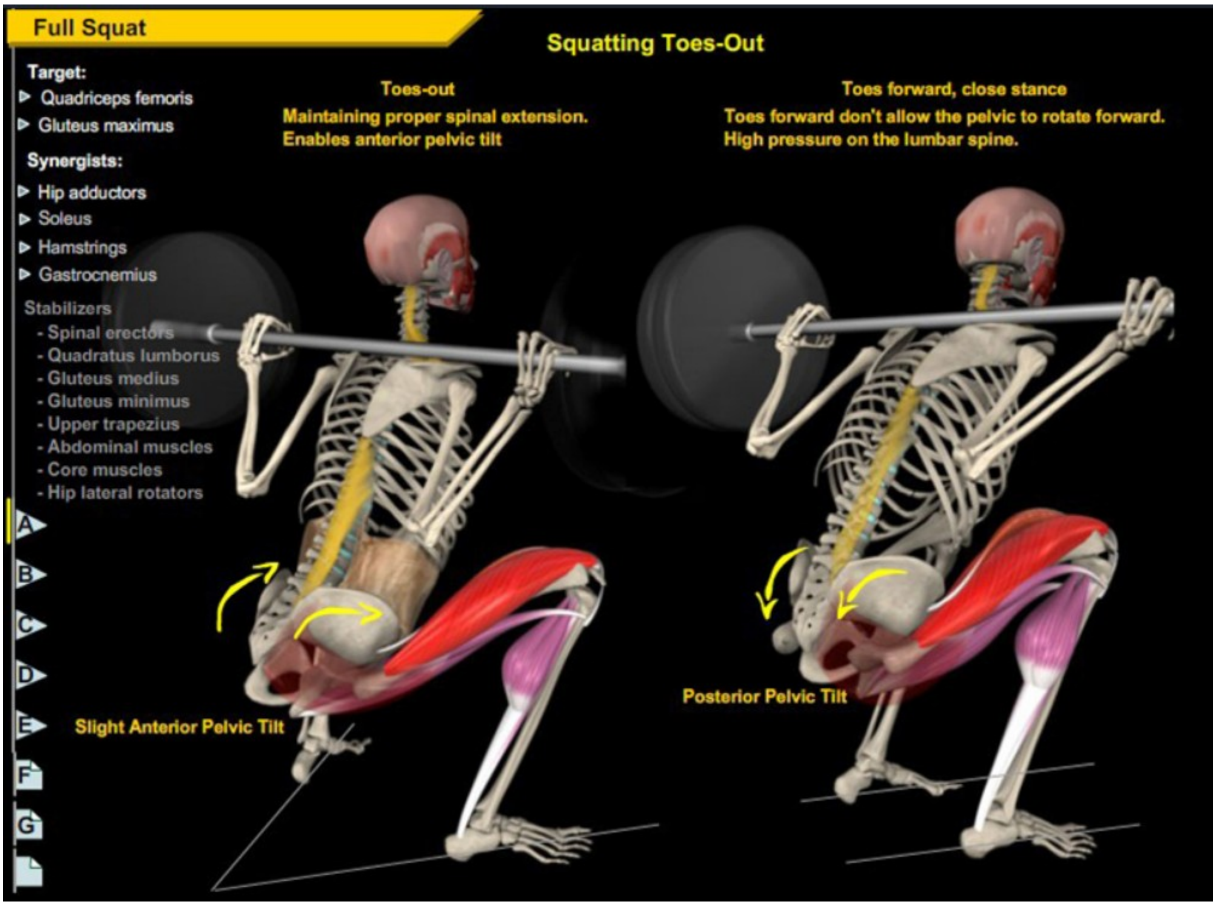

FIGURE 18. Full squat exercise. https://vimeo.com/393977879

Link to educational video https://app.strength.muscleandmotion.com/exercise/322

8.5.7 Deadlift

Target muscles are gluteus maximus. Synergists are quadriceps, hamstrings, adductor magnus and soleus. Stabilizers are gastrocnemius, wrist flexors, trapezius, levator scapulae, rhomboids, erector spinae, rectus abdominis and obliques.

Keep bar near your legs to maintain balance. In the end pull your shoulders back position. You need to relax your hands and shoulders, leg and back muscles are doing the work!

FIGURE 19. Deadlift exercise. https://vimeo.com/393977912

Link to educational video https://weighttraining.guide/exercises/barbell-deadlift/

8.5.8 Deadlift with straight legs

In this Romanian deadlift exercise target muscles are gluteus maximus and hamstrings. Stabilizers are erector spinae, trapezius, latissimus dorsi, transversus abdominis and quadriceps femoris.

When performing this deadlift with straight legs it is important to maintain straight back to prevent injuries especially in lower back spinal disk area.

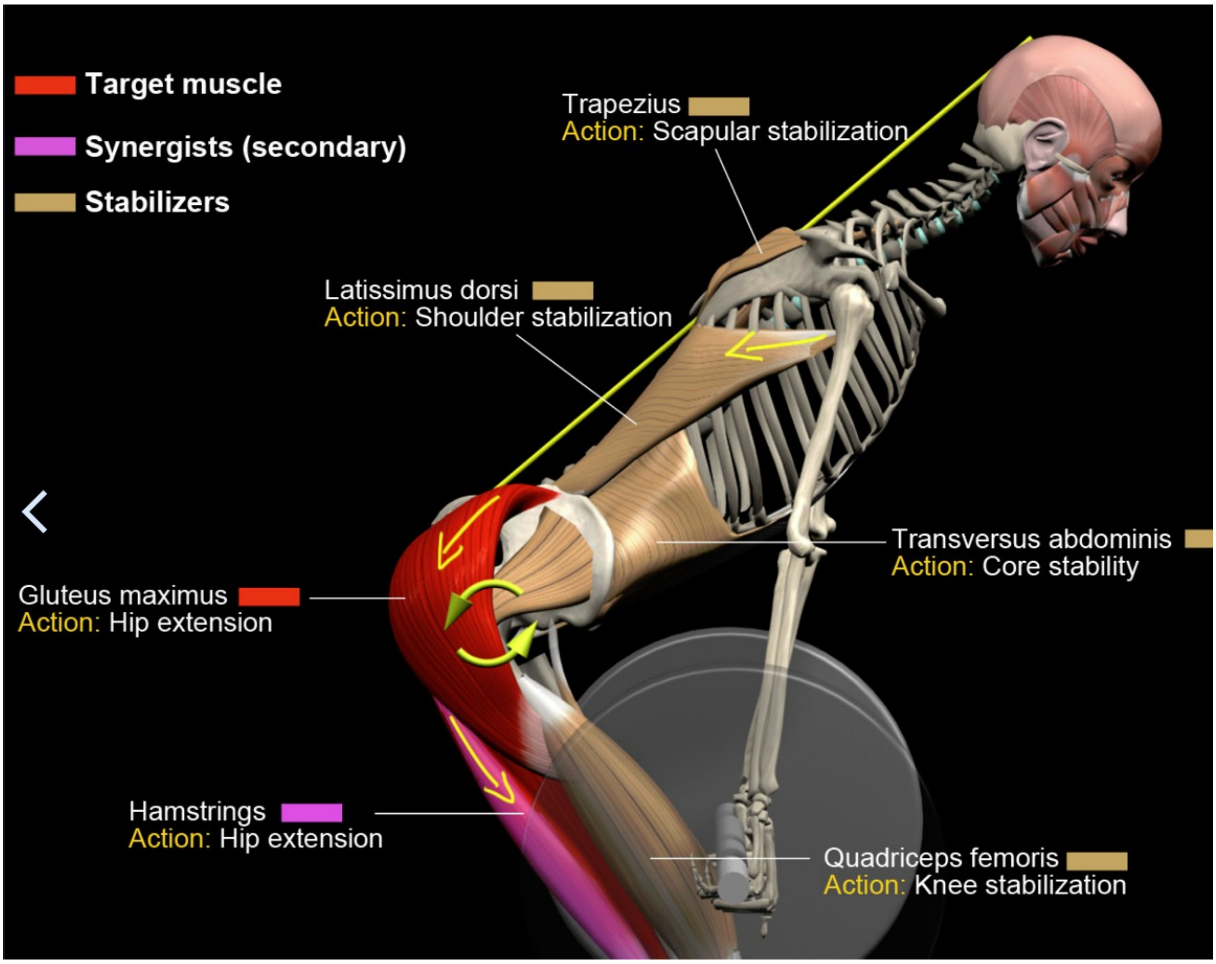

FIGURE 20. Deadlift with straight legs exercise. https://vimeo.com/393977958

Link to educational video https://app.strength.muscleandmotion.com/exercise/437

8.5.9 Calf raise

Target muscles are gastrocnemius. Synergist muscles are soleus and flexors.

Stabilizer muscles are quadriceps femoris, gluteus maximus, biceps femoris long head, semimembranosus and semitendinosus.

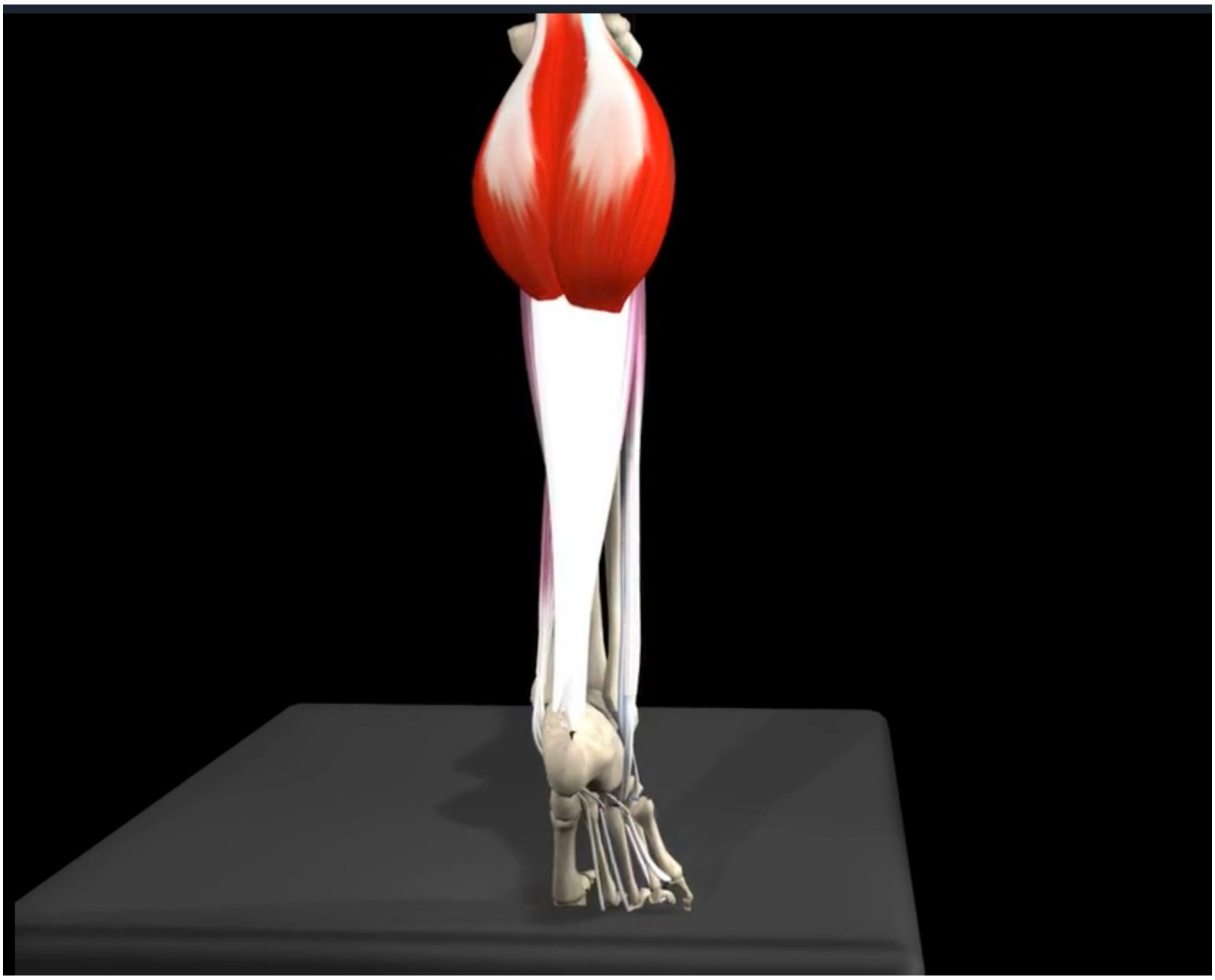

FIGURE 21. Standing calf raise exercise. https://vimeo.com/393977995
Link to educational video https://app.strength.muscleandmotion.com/exercise/196

8.5.10 Barbell high pull and push

Barbell high pull and push are close to Olympic lifts clean and jerk also snatch.
Target muscles in the first phase are quadriceps, gluteus maximus and gastrocnemius. Synergists are hamstrings and trapezius. Almost all the rest muscles are stabilizers. At the second phase move is then push mostly done by deltoid and triceps.

FIGURE 22. Barbell high pull and push exercise. https://vimeo.com/393978070

8.5.11 Bench press

In bench press target muscle is pectoralis major. Synergist are anterior deltoid, triceps brachii, serratus anterior and biceps brachii.

When performing please hold your back in bench. Movement should be constant speed, do not jump-start barbell from chest.

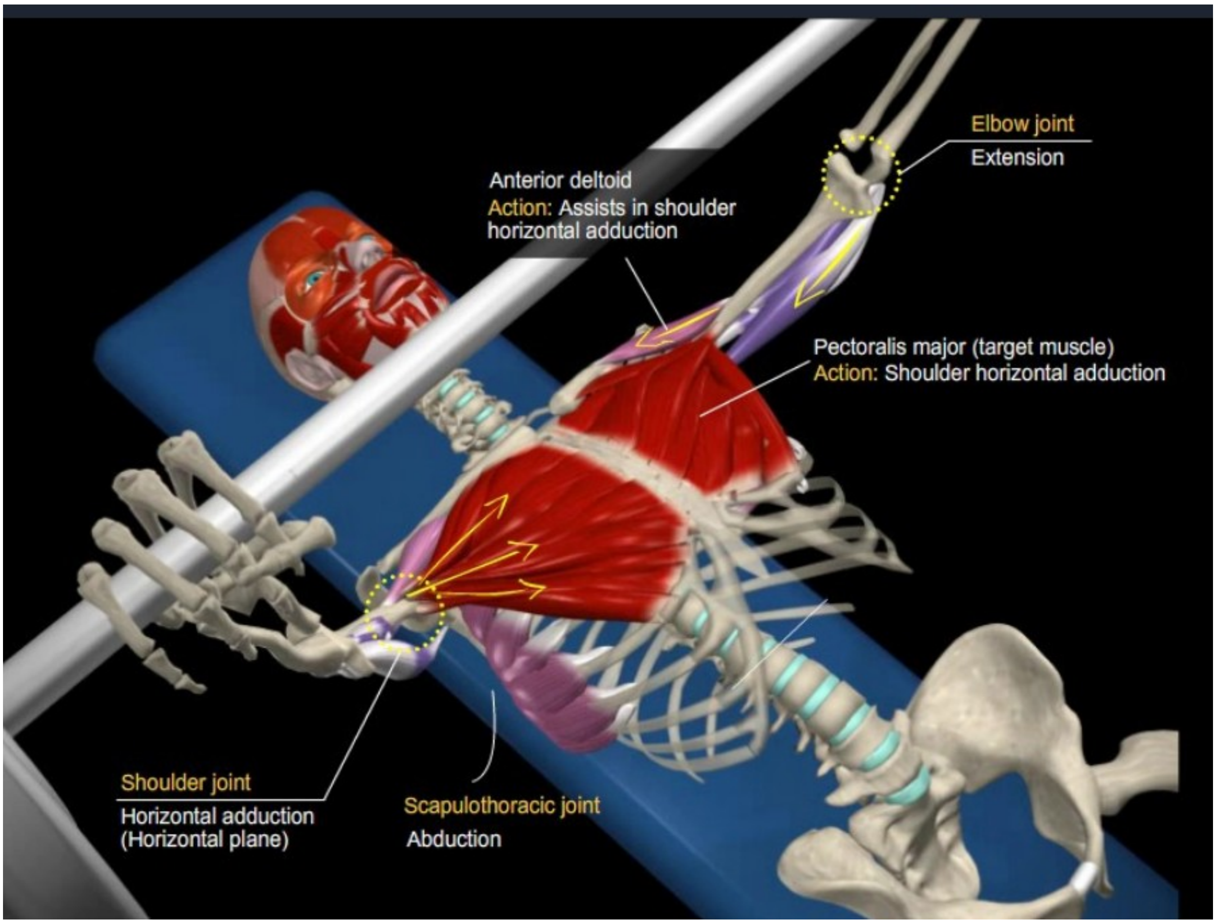

FIGURE 23. Bench press exercise. https://vimeo.com/393978106

Link to educational video https://app.strength.muscleandmotion.com/exercise/86

8.5.12 Barbell bent over rows

Target muscles are latissimus dorsi, posterior deltoid and erector spinae.

Synergist muscles are teres major, trapezius, rhomboids and posterior deltoid.

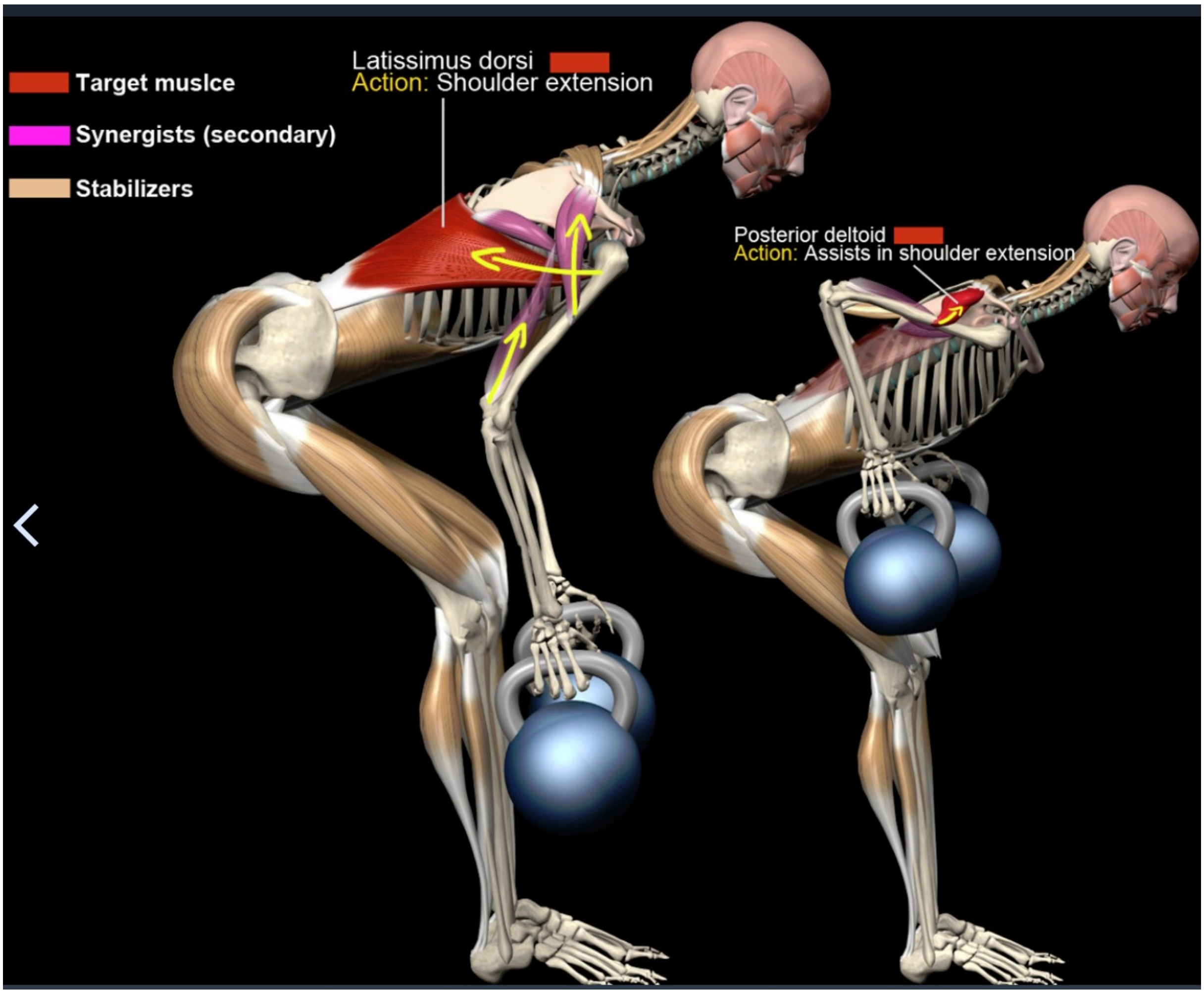

FIGURE 24. Barbell bent over rows exercise. https://vimeo.com/393978156

Link to educational video https://app.strength.muscleandmotion.com/exercise/682

This move can also be done with dumbbells or kettle balls.

Partly this move is isometric hold of superficial back line chain, additional target muscles are gastrocnemius, hamstrings and erector spinae.

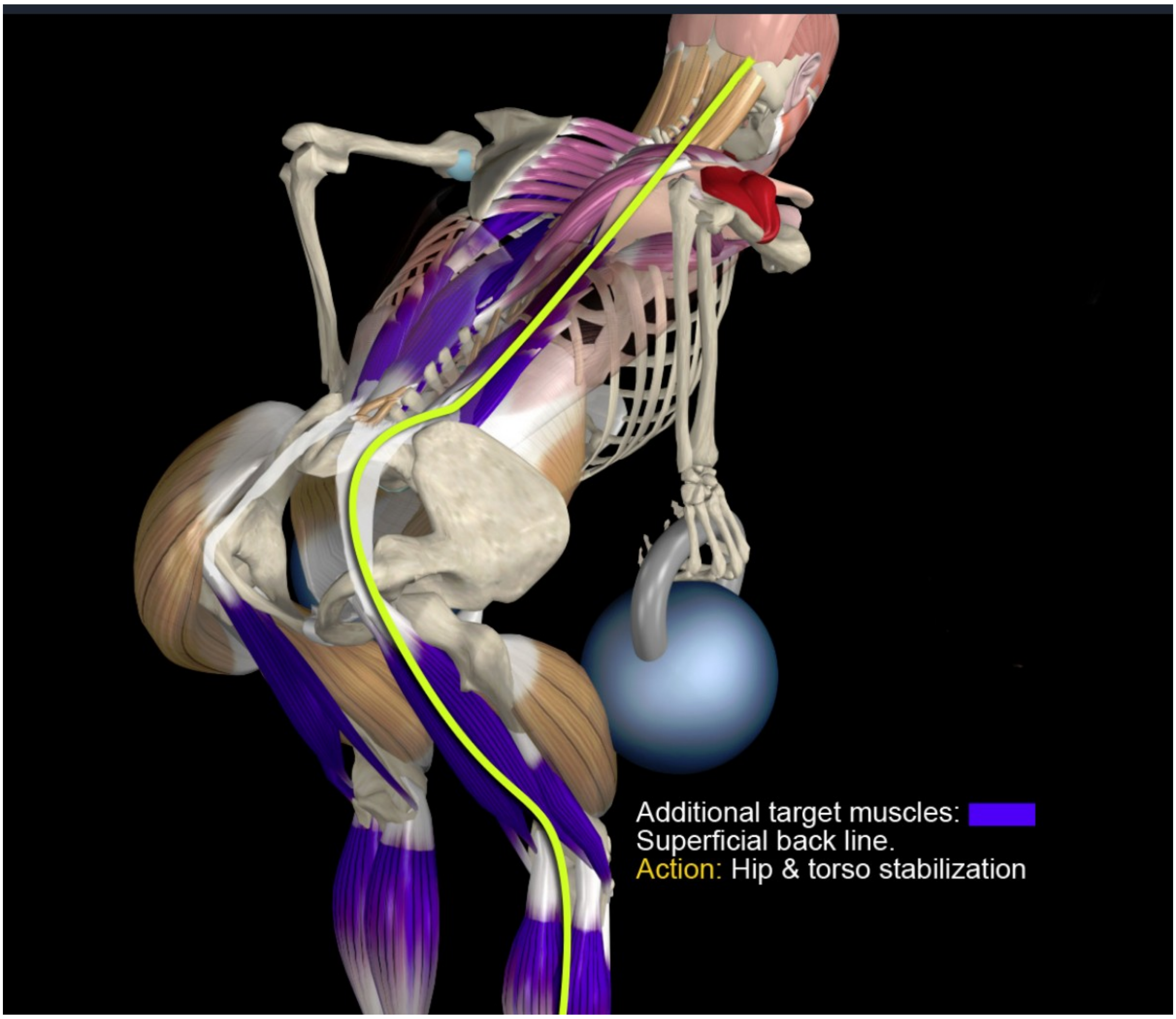

FIGURE 25. Barbell bent over rows exercise. https://vimeo.com/393978156

Link to educational video https://app.strength.muscleandmotion.com/exercise/682

8.5.13 Barbell bicep curl

Target muscles are biceps brachii. Synergists are brachialis, brachioradialis and pronator teres.

When performing this move, keep your elbows attached to your body and don't move front/backwards. Only your arms are supposed to move.

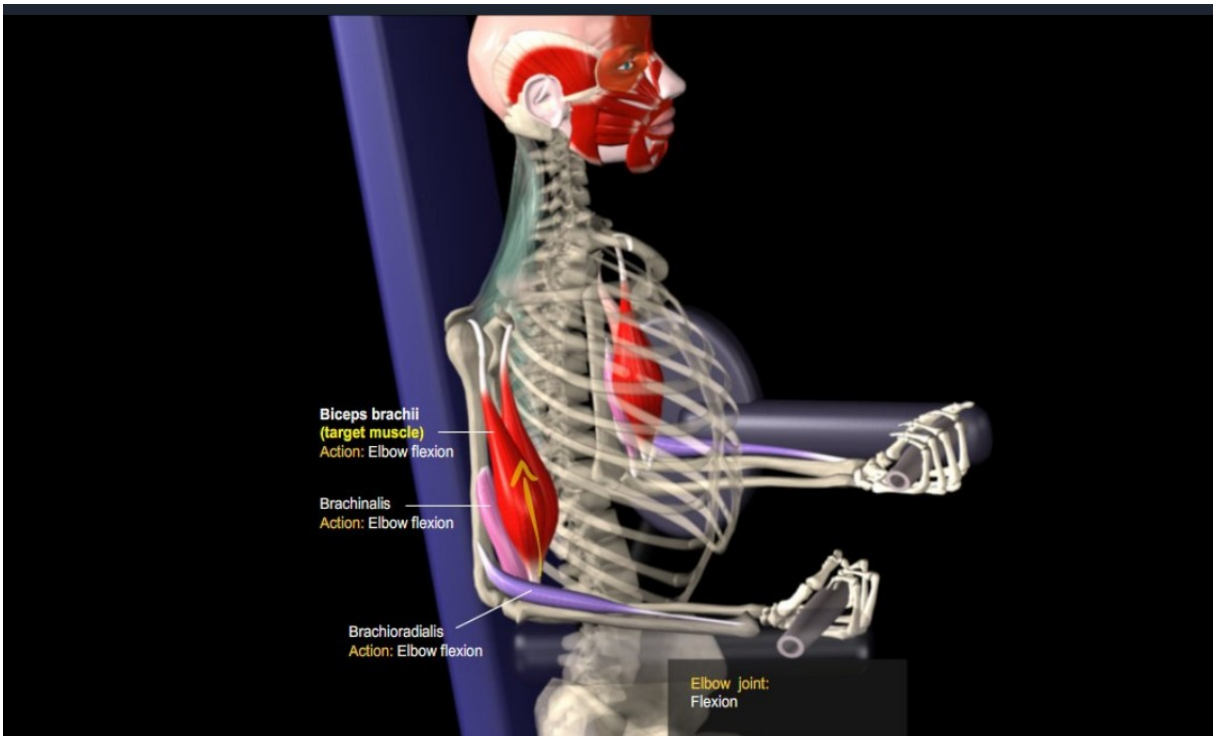

FIGURE 26. Barbell bicep curl exercise. https://vimeo.com/393978192

Link to educational video https://app.strength.muscleandmotion.com/exercise/40

8.6 Statistical analysis

Data was analysed with IBM SPSS Statistics for Windows, Version 26.0. (IBM Corp, Armonk, NY, USA:). Data was checked to be normally distributed.

Descriptive statistics (mean and SD) were calculated for subject weight and test measurements (RPE, HR, lactate). Statistical significance was checked by paired t-tests from start test to end test (RPE, HR, lactate).

Additionally, lactate data was analysed with repeated measures Anova to find out statistically significant inverse changes within start or end test. Alpha was chosen $p < 0,05$ for all statistical comparisons. Data are expressed as mean values in result graphs.

9 RESULTS

Explosive strength training did improve running economy and development was visible also in bicycle ergometer. Lactate values became lower, test group could run further time and to next treadmill speed level.

9.1 Anthropometric measurements

Test persons were measured anthropometric before start and end tests. These tests were performed in daytime after one or even two meals so Inbody results are not reliable. Average weight was 82,3kg in both tests.

9.2 Rating of perceived exertion

In figure 27 is presented the rating of perceived exertion development from start test to end test in all measuring points. Paired T-test analysis showed statistically significant change in first 4 running points. It is also visible that post 4 value change is positive.

In running points 4-16 minutes average RPE change was -6,9% ±1,4%. In individual measuring points percent change varied between 5,4% and 8,2%.

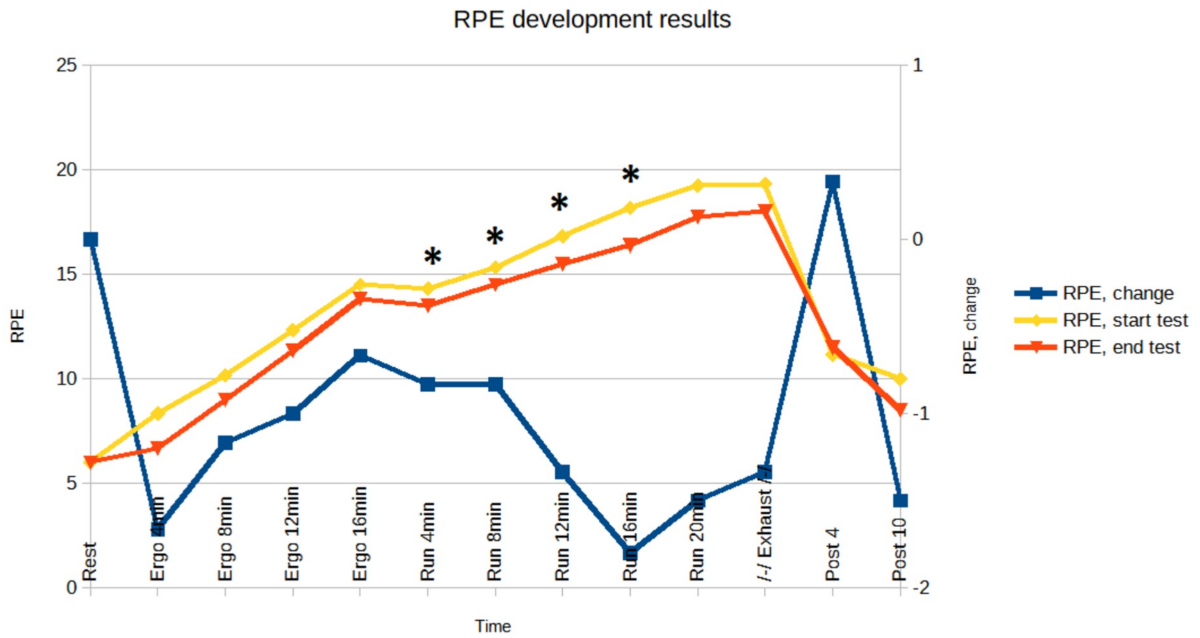

FIGURE 27. The rating of perceived exertion change in bicycle ergometer and run after 2 minutes transition time (T2). * = p < 0,05. X-axis is time in minutes, left y-axis is RPE in, right y-axis is RPE change.

9.3 Heart rate

In figure 28 is presented heart rate development from start test to end test in all measuring points. Paired T-test analysis showed no statistically significant change. Though it is visible that post value changes are positive.

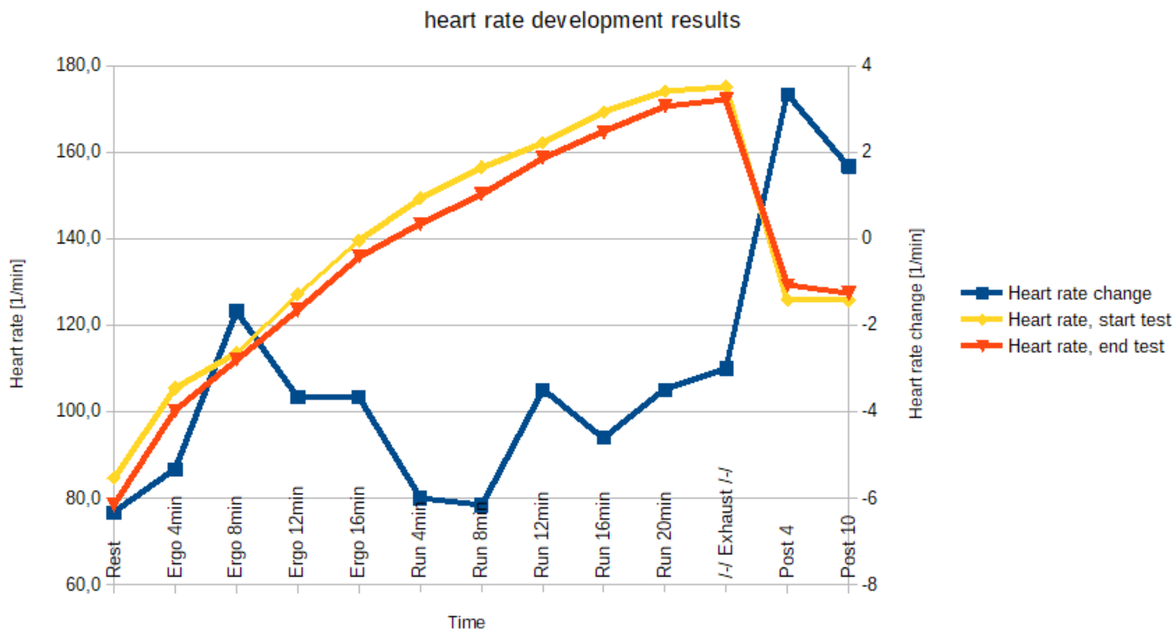

FIGURE 28. Heart rate change in bicycle ergometer and run after 2 minutes transition time (T2). * = p < 0,05. X-axis is time in minutes, left y-axis is heart rate in 1/min, right y-axis is heart rate change in 1/min.

9.4 Lactate

In figure 29 we can see results of lactate measurements. In bicycle ergometer last 16 minutes measurement point lactate change was 7,5% ±17%, average lactate values lowered from 3,7 mmol/l to 3,3 mmol/l ±0,5 mmol/l (p > 0,05). Earlier bicycle ergometer time from 0 to 12 minutes was guided warm-up phase.

In treadmill 0-20 minutes time average run lactate change was -17,8% ±7,5%. In individual measuring points percent change varied between 13,6% and 20,8% and largest change was seen in last measuring points. Statistical significance in running measuring points 4, 12, 16 minutes and exhaust (p < 0,05).

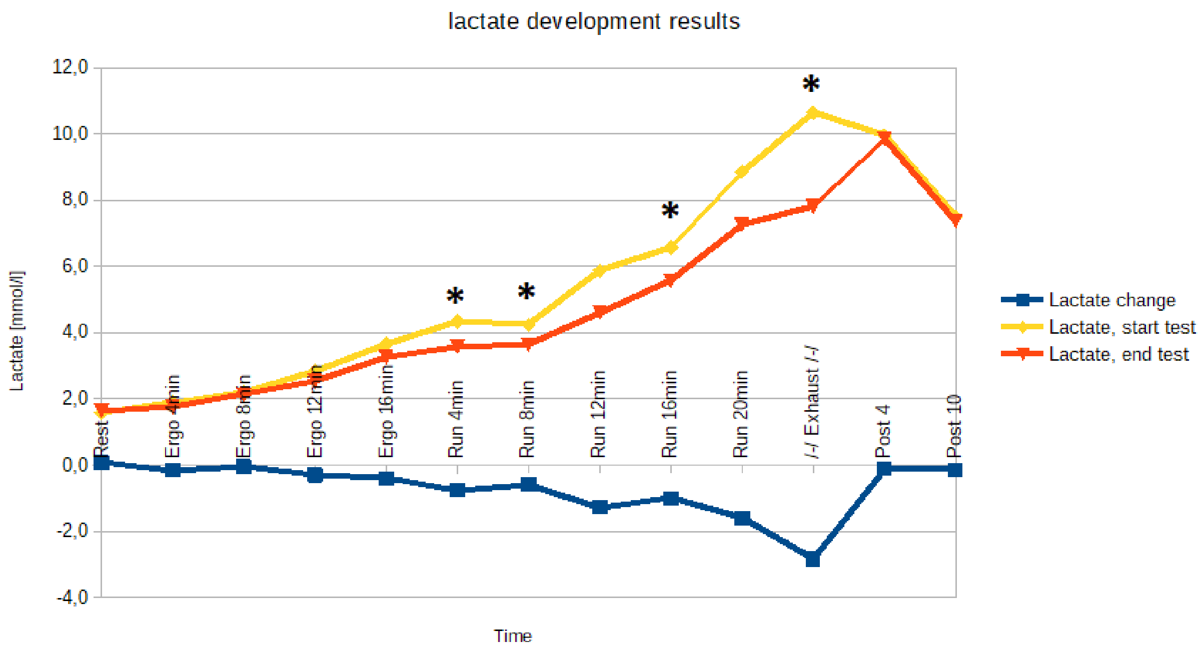

FIGURE 29. Lactate change in bicycle ergometer and run after 2 minutes transition time (T2). * = p < 0,05. X-axis is time in minutes, y-axis is lactate in mmol/l.

From graphs it can be seen that post 4 and post 10 lactate values are quite similar and there is no change in lactate deacidification.

RM Anova analysis revealed that in start test bicycle ergometer there were statistical significance changes ($p < 0,05$) in all four measuring points. In end test there was statistical change only in last 16 minutes measuring point. This inverse analysis method could mean statistically valid development, although there was no statistical significance in paired t-tests analysis.

In treadmill start test repeated measures Anova analysis told that significant change was visible in time points 34 minutes (4. run measuring point after 16 minutes of running) and 38 minutes (5. run measuring point after 20 minutes of running). In end test significant change was not found in these measuring points but from exhaust value. Significant change had been delayed.

9.5 Treadmill time and speed development

In the start test average run time to exhaustion was 20 minutes 23 seconds. After exercise program test persons could run average 3 minutes 22 seconds further ±01:59 until average 23 minutes 45 seconds, 16,6% percentage development. Extended treadmill time is statistically significant ($p < 0,05$).

Maximal treadmill speed development was 1,0 km/h from average 13,2 to 14,2 km/h ±1,5 km/h, this means significant 7,6% development. Maximal treadmill speed development is statistically significant ($p < 0,05$).

9.6 Exercise technique development

In this research we could see some development in gym exercises. For example ability to maintain reasonable rowing pace, rowed distance increased from 1500m → 2000m in 10 minutes. Some test persons even wanted to row 2500m for warm-up. Small amounts of extra weight was possible to add in most exercises. Speed development on barbell exercises was noticeable, for example squat changed towards barbell squat jump.

10 DISCUSSION

The aim of this research was to determine how explosive-strength training intervention affects triathlon running economy with novel triathlon exercise test.

Main finding was that triathlon running economy improved statistically significantly. In triathlon end test measured lactate curve lowered, test group could run longer time and maximum speed increased.

Explosive-strength training improved both bicycle ergometer and run phase of triathlon test. Possibly because of faster muscle power production ability, bicycle phase did not create same level of fatigue in end test so test group could start run phase in more recovered state and final run fatigue delayed (Linnamo et al., 2000; Van Cutsem et al., 1998). This gave chance of improving running time and maximal run speed. Here was seen decreased lactate levels in bicycle phase and this perhaps improved lactate oxidation in slow muscle cells and delayed fatigue in running phase. Behind maximal fatigue there are chemical phenomenons, e.g. Ca^{2+} cannot act any more in muscle, fatigue is catastrophic at peripheral side of neuromuscular system.

As Linnamo pointed out, explosive-strength training increases hormonal responses in men (Linnamo et al., 2005). I think this mostly effect fast muscle cells and their ability to produce energy and force. As we know, fast muscle cells work glycolytic, produce energy anaerobic and produce lactate as a result. So when we measure high lactate levels in treadmill, it means fast muscle cells have been in heavy use.

Faster power production ability could improve running economy also from biomechanical side, however we did not measure this separately.

Lactate measurement was performed in four minutes steps. This is different from common sport test protocol where 3 minutes including stopped blood sample time is normal step. Because we performed also NIRS-device testing, pause time in run phase between steps was 1 minute, and exercise time was 3 minutes. 3 minutes running time was long enough to achieve steady-state condition, this was clearly seen in heart rate after 2,5 minutes.

Increased jumping power can also be one important part of increased running economy, in theory it can be behind RE development (Taipale et al., 2010). Our exercise program included drop jumping which is explosive training and when performed from high heights changes towards maximal strength training (*Verkhoshansky Site*, 2020). Occasionally performed maximal strength training may also be involved in improved running economy. Plyometric training can also effect on elastic properties of body and improve SSC function.

There was not physical overload seen in results (RPE, HR) (Meeusen et al., 2013). 35% 1RM weights are light enough that athlete can recover.

It is possible to estimate improved VO_2max oxygen consumption if test person can run to next speed level in the end test. Oxygen consumption improvement would mean better RE (Paavolainen et al., 1999). Our test maximal running speed improvement is 1,0 km/h. This means approximately 3 ml/kg/min improvement (Londeree, 1986).

Multi-joint barbell moves were very effective in loading neuromuscular system and this I believe was one of the keys to success. Another was drop jump. Altogether these gave enough stress for neuromuscular system. I remember first times when performed drop jumps from 60cm height, after training directly had to go sleeping. This shock method load to nerve system was significant. Normal endurance athletes may not have experience of this kind of load. Jumping ability improved in 2 months training program. Even continuous barbell squat jumping was possible.

My novel maximal triathlon exercise test turned to be very suitable test for triathletes. They liked nice 16 minutes bicycle part which did heat them until lactate levels even 5 mmol/l, and fast 2 minutes T2 was like normal race situation. So they got needed measured lactate information about start running speed and how their body can tolerate after bicycle load. Some athletes could recover in first running loads. Some had chosen a little bit too fast running start speed so their lactate levels rose rapidly. This was very educational to all test persons to get precisely measured information of bicycle load and how they could handle it in run phase.

I think this explosive training took its place inside weekly training hours, because hobby athletes have limited amount of time for training so they cannot add extra training hours.

10.1 Limitations of the study

In next research it could be wise to measure breathing gases for precise oxygen and energy consumption. Also test persons 3-5RM tests would be good to perform to directly evaluate 35% 1RM loads to exercise program. By this we could also measure how explosive-strength training effects to maximal performance. Run technique development could also be measured e.g. acceleration sensor device. And most importantly, it would be educational to measure jump heights so jumping power ability development could be analysed. Also it would be informal to combine EMG and NIRS measurements e.g. m. Vastus Lateralis to deepen knowledge in neuromuscular system behaviour in explosive events. And blood glucose and hormone measurements could be also be informal to evaluate final cause of fatigue, is it neural or peripheral, or peripheral efferent inhibition to spinal level that shuts motor units down even without cortical command. There could have been control exercise group with no training.

10.2 Practical applications

For endurance athlete it is advisable to include explosive-strength training occasionally in training program as a 4-8 weeks period to improve motor unit recruiting and to activate fast type muscle cells, so they do not change to slow type when aging.

It was beneficial to test persons to freely choose their start running speed after bike so they gathered experience about suitable running start speed and could also learn valuable information about muscle acidification situation around simulated T2 situation. When lactate was near anaerobic threshold, around 3-4,5 mmol/l, it is about sprint or olympic distance situation. If test person would perform test again in future, it would be educational to choose different running start speed to find out metabolic adaptation to different loading.

Because of simultaneous NIRS-device measurements, we had one minute sample taking pause, 4 minutes loading steps. This 3 minute effective loading time was long enough to achieve solid steady-state condition. This was very visibly seen in treadmill. Four minutes testing steps could be used more in sport laboratory test, it gives solid results. Of course it takes more time to perform but it could be performed perhaps once or twice year for professional athlete.

Test persons got feedback from their race situation thresholds, usually aerobic threshold was on bike and anaerobic on run. Because of some fatigue from bike, run anaerobic threshold was different from normal situation when maximal test is performed in run.

10.3 Acknowledgement

It was a pleasure to plan and perform this “explosive powerlifting with drop jumping” training program for myself and triathlon athletes. We were dedicated to train properly and did achieve very good results. Lactate levels were lower, so running economy improved. Also test group could run further and to next treadmill speed level so we could estimate also improved VO_2max.

I would like to give many thanks to teachers Jarmo Piirainen, Olli Ohtonen and Vesa Linnamo for comprehensive sport science theory and laboratory lessons, it was a pleasure to improve these skills after long personal sport history.

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12 ATTACHMENTS

12.1 Educational training videos

- Link to triathlon test video, laboratory setup: https://vimeo.com/394368240
- Link to triathlon test video, bicycle ergometer: https://vimeo.com/394368294
- Link to triathlon test video, treadmill run: https://vimeo.com/394368259
- Rowing exercise https://vimeo.com/393977636
- Sit-up exercise https://vimeo.com/393977681
- Lifting legs exercise https://vimeo.com/393977718
- Back extension exercise https://vimeo.com/393977757
- Drop jump https://vimeo.com/393978225
- Depth jump https://www.youtube.com/watch?v=4P1A2R2nT-A&feature=youtu.be
- Full squat exercise https://vimeo.com/393977879
- Deadlift exercise https://vimeo.com/393977912
- Deadlift with straight legs exercise https://vimeo.com/393977958
- Standing calf raise exercise https://vimeo.com/393977995
- Barbell high pull and push exercise https://vimeo.com/393978070
- Bench press exercise https://vimeo.com/393978106
- Barbell bent over rows exercise https://vimeo.com/393978156
- Barbell bicep curl exercise https://vimeo.com/393978192

Extra video: 8 weeks development from squat to squat jumping

- Barbell squat jumping https://vimeo.com/447415091

12.2 Educational anatomy motion internet links

- Sit-up https://weighttraining.guide/exercises/decline-sit-up/
- Lifting legs https://weighttraining.guide/exercises/lying-straight-leg-raise/
- Back extension https://weighttraining.guide/exercises/hyperextension/
- Drop jump https://app.strength.muscleandmotion.com/exercise/721
- Full squat https://app.strength.muscleandmotion.com/exercise/322
- Deadlift https://weighttraining.guide/exercises/barbell-deadlift/
- Deadlift with straight legs https://app.strength.muscleandmotion.com/exercise/437
- Standing calf raise https://app.strength.muscleandmotion.com/exercise/196
- Bench press https://app.strength.muscleandmotion.com/exercise/86
- Barbell bent over rows https://app.strength.muscleandmotion.com/exercise/682
- Barbell bicep curl https://app.strength.muscleandmotion.com/exercise/40

12.3 Triathlon test videos

- Link to triathlon test video, laboratory setup: https://vimeo.com/394368240
- Link to triathlon test video, bicycle ergometer: https://vimeo.com/394368294
- Link to triathlon test video, treadmill run: https://vimeo.com/394368259