Acute effect of continuous running or cycling exercise on subsequent strength performance

- A concurrent training study

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Abstract

Aim

Aerobic exercise may interfere with subsequent responses to strength training. The aim of this research was to examine the acute effects of cycling or running on subsequent leg strength performance. It was hypothesized that eccentric contractions induced by running would impair strength performance more than the cycling mode of exercise, which consist mainly of concentric muscle actions.

Method

In order to investigate if continuous running or cycling affected following strength performance, 6 healthy individuals (5 males, 1 female) were subjected to a randomized cross-over design. Subject characteristics were age (year) 25,5 ± 2,1, height (cm) 180,5 ± 6,4, and body weight (kg) 83 ± 3,4. The experimental sessions included three protocols: strength protocol (S) which included 3 repetitions measuring peak power followed by 3 sets to muscular failure at 80% of 1RM in the squat exercise; and continuous running (RS) and cycling (CS) conditions (40 minutes at 80% of maximal heart rate), followed by the S protocol. Peak power performance and total work volume was measured.

Results

Average peak power attained between the three protocols were CS = 1639± 444Watts (W), RS = 1633± 422 and S = 1565 ± 349. No significant differences were observed between the three conditions (P = 0,817). No differences across the three protocols was observed for highest peak power attained by each subject (P = 0,619). Total work volume performed (main effect P = 0,027) revealed a significant difference between CS = 2559 kg and S = 3715 kg (P=0,037), and CS and RS = 3345 kg (P=0,037) due to the lower loads lifted in CS.

Conclusions

There were no differences observed between the three training protocols regarding peak power performance. When cycling exercise was performed prior to the strength session, the total volume lifted was lower than when performing the strength test alone. Thus, it is concluded that cycling exercise, but not running, interferes with subsequent strength training performance.

Sammanfattning

Syfte och frågeställningar

Uthållighetsträning kan leda till försämrad styrkeprestation. Syftet med denna forskning var att undersöka de akuta effekterna från cykling eller löpning på efterföljande benstyrka. Hypotesen var att löpning, som omfattar excentriska muskelaktioner, skulle leda till en större försämring av efterföljande styrkeprestation jämfört med cyking, som främst omfattar koncentriska muskelaktioner.

Metod

För att undersöka om kontinuerlig cykling och löpning påverkade efterföljande benprestation, undersöktes 6 deltagare (5 män, 1 kvinna) i en randomiserad cross-over design. Försökspersonernas karakteristika var ålder (år) 25,5 ± 2,1, längd (cm) 180,5 ± 6,4, vikt (kg) 83 ± 3,4. Försökspersonerna utförde tre experimentella protokoll: styrka (S), vilket bestod av 3 repetitioner av maximal kraftutveckling efterföljt av 3 set till muskulär utmattning på 80% av 1RM i benböj; och löpning (RS) samt cykling (CS) protokoll (40-minuter på 80% av maximal hjärtfrekvens), efterföljt av S protokollet. Data för maximal kraftutveckling och total arbetsvolym samlades in.

Resultat

Den genomsnittliga maximala effekten som uppnåddes mellan de tre protokollen var: CS = 1639 ± 444 Watt (W), RS = 1633 ± 422W och S = 1565 ± 349W. Inga signifikanta skillnader observerades mellan de tre förhållandena (P=0,817). Högst uppnådda effekten för varje deltagare mellan de tre förhållandena visade ingen skillnad (P=0,619). Totala arbetsvolymen (tidseffekt: P=0,027) visade signifikanta skillnader mellan CS = 2559 kg och S = 3715 kg (P=0,037), och CS och RS = 3345 kg (P=0,037) på grund av lägre vikt lyft vid CS.

Slutsats

Ingen skillnad observerades mellan de tre förhållandena angående maximal styrkeprestation. Den totala volymen vikt som kunde lyftas var dock lägre när cykling utfördes innan styrketestet. Slutsatsen är därför att cykling, men inte löpning, hindrar maximal träningsprestation vid ett efterföljande styrkepass.

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1 Introduction

For thousands of years humans have been training with the goal to increasing muscle mass and strength. The skeletal muscle has allowed us to fulfill various physical demands due to its phenotypic profile and the combination of different muscle fibers. Development of strength is essential when training for specific demands. For example, various sports require athletes to attain high levels of maximal strength, power, and speed with control and technique. The aim for a resistance training regimen may not solely be to develop muscular adaptations but also to decrease the risk of injuries and promote overall health in recreational and sport settings. Indeed, resistance exercise is beneficial for the general population and has become a very popular method not only to promote health and fitness in elderly and sedentary people but also for injury prevention.

The primary approach to increase muscular strength in humans across populations for many years has been by utilizing resistance training (Peterson et al., 2005; Wernbom et al., 2007). Although resistance training has been studied and performed for so long, there are still controversies regarding the ideal recommendations of training variables such as intensity, volume, frequency and rest periods to achieve optimal adaptations (Ratamess et al., 2009). From an athletic standpoint, the resistance exercises may vary from heavy loading for prime physiological adaptations in powerlifters to explosive adaptations in track and field runners.

1.2 Acute responses to resistance exercise

The short-term increase in strength elicited by resistance training is mainly due to neural adaptations during the initial periods of training (Sale, 1988; Phillips, 2000). These adaptations increase maximal voluntary contraction by promoting recruitment and activation of motor units, which result in greater force producing capacity (Sale, 1998; Phillips, 2000; Gabriel et al., 2006). During heavy resistance training, the muscular fibers are recruited in a specific order depending on the size of the motorneuron (Henneman et al., 1965). According to this size principle, fibers with lower force production (type I) are recruited before higher force producing fibers (type II) take over the increasing force demands (Henneman et al., 1965).

The acute response to resistance training occur during or shortly after the bout is completed. The immediate response is fatigue-induced metabolism, which results in increased acidity and energy depletion (MacDougall et al., 1977). The body compensates for this by increasing blood flow to match the oxygen demands from working muscles (MacDougall et al., 1977;

Egan & Zierath, 2013). Despite the high force and power requirements, the energy cost is relative low even when larger muscle groups are involved (Dudley et al., 1991). Regardless of the energy demand, resistance training employed to promote muscle and strength gains generates major metabolic events such as increased protein synthesis. If performed regularly, chronic adaptations of skeletal muscle, i.e. increased muscle size, will occur and persists for a longer period of time.

1.3 Chronic responses to resistance training

When performing resistance exercise regularly, the cross-sectional area of the muscle will increase and eventually the muscle is capable of exerting greater force (Ikai et al., 1968). Strength and power improvements during initial training period are mainly reliant on neural factors as mentioned above. However, these adaptations are eventually exceeded by the growth in muscle fiber diameter, a process called hypertrophy (Costill et al., 1979; Gollnick et al., 1983). The enlargement of muscle fibers occurs when protein synthesis is greater than protein degradation over time. The synthesis is stimulated by regular resistance training and from important amino acids through nutrition (Hulmi et al., 2010). Likewise, for growth, the skeletal muscle fibers can shrink in diameter if disused for a prolonged period of time causing muscular atrophy (Booth et al., 1997; DeRuisseau et al., 2005; Schiaffino et al., 2013). Enhancement of muscular strength and growth can also occur if the muscle fibers increase in number resulting in hyperplasia (Gonyea, 1980). However, the explanations are scarce and diffuse of what elicits hyperplasia because it has been witnessed in both bodybuilders and untrained muscle (MacDougall et al., 1984).

Contrary for power and strength training, (DeLorme, 1945; Tesch, 1988; Narici et al., 1989), endurance training increases the capillary and mitochondrial density (DeLorme, 1945; Andersen & Henriksson, 1977; Holloszy & Coyle 1984) which is important in activities demanding more stamina rather than power and strength.

1.3.1 Hypertrophy

The skeletal muscle experience microscopic damages from traumatic stress induced by resistance training. In order for the muscular fibers to grow, the protein synthesis must exceed the protein breakdown (Behm, 1995). This process is the natural response augmented by the muscles to overcome increasing workloads, causing muscular hypertrophy. However, it is not known when hypertrophy surpasses the neural adaptation for primary strength contribution. Early investigations reported only 4 weeks (Moritani, 1979) before seeing fiber enlargements, and Sale (1986; 1988) reported neural adaptations to be surpassed by hypertrophy after 6-10 weeks of regular resistance training. However, a recent study found hypertrophic adaptations to occur in less than 4 weeks (Seynnes et al., 2007).

Despite overabundant investigations regarding resistance training, the debate continues about favorable training regimens to improve strength. Existing recommendation advocates heavy loads, >80% of 1RM, for optimal intensifications in strength (ACSM, 2010) while research has fairly challenged these guidelines (Carpinelli, 2008; Burd et al., 2012). Additionally, strength training to muscular fatigue is recommended to optimize hypertrophic responses in trained individuals (Willardson, 2007; Nóbrega & Libardi, 2016).

2 Concurrent training

It is common for individuals in athletic and recreational settings to participate in training regimens that involve both endurance training and resistance training. As already indicated, resistance training is important for stimulating skeletal muscle strength, size and power while aerobic training is effective for improving the cardiorespiratory fitness and promoting fat utilization. A tendency frequently seen in both athletes (Reilly et al, 2009) and fitness enthusiasts (Garber et al, 2011) is the performance of aerobic training followed by a bout of resistance training in the same exercise session.

The combination of incorporating endurance and strength training in one session is currently known as concurrent training (Hickson, 1980). Although concurrent training is commonly exerted, existing research have shown equivocal results for the development of power and strength performance when combined with aerobic or anaerobic training (Dudley & Djamil., 1985; Hennessy & Watson., 1994; Kraemer et al., 1995; Leveritt et al., 1999; Balbinis et al., 2003; De Souza et al., 2007; Davis et al., 2008)

Hickson's influential study was the initial investigation that examined the possible hampering effect of endurance training on strength adaptations. Hickson reported that performing solely resistance training improved maximal strength gains more than performing endurance training incorporated with resistance training. This was termed an "interference effect" (Hickson, 1980). The interference effect was also confirmed by Dudley et al, (1985) who reported that endurance training concurrently interfered with strength adaptations if the aerobic portion was extended or too intense (Dudley et al., 1985). In other studies, muscular adaptations to concurrent aerobic and resistance exercise were compatible (McCarthy et al., 2002; Balbinis et al., 2003). Thus, depending on selected training variables, it seems as endurance training may either diminish muscle hypertrophy, power and endurance when equated to strength training alone (Häkkinen et al., 2003; Glowacki et al., 2004; Izquierdo et al., 2005), or result in similar adaptations across exercise modes (Leveritt et al. 1999).

2.1 Interference effect

Several studies have investigated potential mechanisms for this phenomenon termed interference effect. The commonly researched areas involve:

- Neuromuscular adaptations and specificity of training (Hickson, 1980; Dudley et al., 1985; Hennessy & Watson, 1994; Kraemer et al., 1995).
- Mammalian target of rapamycin (mTOR) and activated protein kinase (AMPK) signaling (Hawley, 2009; Kimball, 2006; Winder et al., 2006, Lundberg et al., 2012).
- Accumulated fatigue to acute concurrent training (Abernethy, 1993; Bell et al., 2000; de Souza, 2007; Häkkinen et al., 2003; Kraemer et al., 1995; Vincent, 2005).
- Overtraining (Hickson, 1980; Dudley & Djamil, 1985; Dudley & Fleck, 1987; Bell et al., 2000).

However, new methods and techniques have been developed and led to increased interest behind molecular interference to combined training. (Nader, 2006; Hawley, 2009).

2.1.1 Overtraining

The definition of overtraining is well explained by Lehmann et al., (1993) as "an imbalance between training and recovery, exercise and exercise capacity, stress and stress tolerance" (Lehmann et al., 1993). Overtraining can be observed in individuals performing a combination of both aerobic and resistance exercises. Specifically, when intensity, duration or frequency of training becomes excessive, muscular adaptations to concurrent training can be impaired (Dudley & Fleck, 1987). There is insufficient evidence to support this theory and one reason could be the common methodology in early research. Majority of concurrent training studies involve at least 3 different groups: one group performing an isolated strength protocol, the second group performing only endurance exercises and lastly, the third group performing a combination of both. Following this design, the latter group performs the same amount of work as strength and endurance combined, hence explaining the overtraining observations.

The overtraining interference was first documented by Hickson (1980) who reported reduction in strength gains for the concurrent training group. However, this suggestion was rightfully challenged by Dudley and Djamil (1985) arguing that the result of overtraining from concurrent exercise cannot be the main reason in diminished power and strength developments. They used 3 different groups to investigate this theory, similar to Hickson's study, but the total workload was significantly lower. Despite of exerting a lower training volume, one outcome variable of Dudley and Djamils' (1985) study illustrated similar results compared to Hickson (1980) which is questionable considering the lower volume during the training programme. Besides, if overtraining resulted in attenuation of strength and endurance performance when concurrently training, the same affects would have been observed in the exercise modalities alone (Leveritt et al., 1999).

2.1.2 Residual fatigue and glycogen depletion

Following a bout of aerobic exercise, muscle force development is decreased during a subsequent resistance exercise bout (Chromiak et al., 1990; Craig et al., 1991; Bentley et al., 2000). Specifically, force production of exercised muscles is diminished for a minimum of 6 hours after endurance training is conducted (Leveritt et al., 1999; Bentley et al, 2000; Sporer et al., 2003). This suggests that endurance exercises would restrict the muscular force production and thereby limit subsequent strength performance (Sale, 1987).

Residual fatigue accumulated by endurance exercise may also have a reducing effect on the volume of work performed throughout subsequent resistance training (Sporer et al, 2003). In addition, residual fatigue has been associated with the depletion of muscle glycogen content (Jacobs et al., 1981; García-Pallares et al., 2009). Scarce research to-date that has examined this association directly with the interference effect, but support for this statement exists as strength performance have presented diminished effects on individuals experiencing a decrease in muscle glycogen content (Hepburn et al., 1982). Therefore, it might be of great importance to allow time for muscle recovery between exercise bouts in order to develop satisfactory adaptations to concurrent training.

2.1.3 Neurological factors

Attenuation of force production development and explosive strength has explicitly been reported by several studies after concurrent training (Dudley et al., 1985; Hunter et al., 1987; Hennessy et al., 1994; Chtara., 2008; Wilson et al., 2012). More specifically, studies showed inhibited pure torque, force measurements and vertical jump performance when concurrent training was applied, suggesting a neural interference (Dudley et al., 1985; Nelson et al., 1990; Abernethy et al., 1993; Häkkinen et al., 2003). In support for this statement, a 21-week study conducted by Häkkinen et al (2003) reported improvements in muscular power and agonist muscle activation in subjects performing isolated strength training. The group performing concurrent training showed lower neural adaptations, indicating that combined training may indeed result in neuromuscular interference and hence compromise strength development. Similar outcomes can be seen in additional research during a shorter period of time, 12-weeks (Cadore et al., 2012) respectively 8-weeks (Santtila et al., 2009).

3 Problem area

The acute effects of concurrent training are dependent of several variables as mentioned previously. However, an important factor to consider in the acute interference hypothesis is the mode of aerobic exercise performed. The most common aerobic exercises performed prior strength training are bouts of cycling and running, which both have been shown to impair performance in subsequent strength performance (Abernethy, 1993; Bentley et al., 2000; Sporer & Wenger, 2003; de Souza et al., 2007). Although both exercise modes may alter subsequent strength performance, the distinct differences between the modalities is the type of muscle actions used to generate force. In contrast to cycling where the concentric actions are dominant, during running the contribution of the concentric phase declines and the eccentric muscular actions become more important (Bijker et al., 2002). Comparing the two, running has shown to cause greater muscular damage when performed for a prolonged period of time (Koller et al., 1998) and when equated for intensity or duration (Leepers et al., 2000; Millet et al., 2003). The reason for this could be that eccentric actions progressively overstretches the sarcomeres, beginning with the weakest successively to the strongest, and resulting in damaged fibers over a series of contractions (Proske & Allen, 2005). Muscular damage is also considerably higher in running since the movements itself create shock waves throughout the lower limbs. Although the explanation is satisfactory regarding the muscle fiber damages created by eccentric actions, further research is required to fully understand the mechanisms behind these events.

Gaining more insight about effects of different exercise modes on subsequent strength performance could benefit coaches and practitioners to construct a training program in order to minimize interference in strength adaptations. It is possible that acute fatigue induced by eccentric actions like running, causes superior interference to subsequent strength performance since the muscular damage is greater as compared to concentric actions when cycling. However, existing research in this area is limited and divergent. For example, one study investigated acute fatigue induced by high-intense intermittent aerobic modalities on subsequent strength performance and found reduction in repetitions from both cycling and running (Panissa et al., 2014). The running condition resulted in decreased strength performance in the first set only and the cycling condition resulted in decreased strength in the first and second set, suggesting that cycle ergometry induces greater interference. However, a meta-analysis conducted by Wilson et al., (2012) compared running to cycling and found that strength training concurrently with running reported a greater muscular interference to hypertrophy and strength than cycling. The suggestion was that concentric contractions involved with cycling dampens the interference compared with the greater reliance on eccentric actions with running. They also suggested that cycling per se, minimizes muscular damages since there is no body weight to carry as when running. Nonetheless, since the empirical evidence is limited, more research needs to be conducted before any conclusions can be drawn.

Despite the different results from the studies, it could be argued that when aerobic exercises are conducted for a longer period of time, the interference could be exaggerated even further. Specifically, since the muscular damage elicited by eccentric contractions increases as the contractions continue, the suggestion might be that continuous running would show greater interference on acute leg strength performance compared to continuous cycling. Surprisingly, no research to my knowledge has examined continuous running and cycling on acute leg strength performance. Therefore, the aim of this investigation was to compare how a continuous bout of cycling and running influenced acute leg strength performance in healthy individuals.

4 Aim and Hypothesis

The aim of the present study is to investigate the effects of prolonged continuous exercise induced by cycling or running on acute strength performance in healthy individuals.
The hypothesis was that a prolonged bout of running would diminish acute leg strength performance compared to cycling due to the eccentric contractions involved when running.
It was also hypothesized that combined training, regardless of exercise modes, results in greater interference in strength performance than when performing strength training alone.

5 Methodology

5.1 Experimental Approach to the Problem

This randomized cross-over study was designed to compare the effects of prolonged continuous cycling and running on subsequent leg strength performance. In order to investigate if running and cycling exercise affected strength performance, all participants were subjected to four experimental sessions. During the first week, the maximal heart rate elicited by running and cycling ergometer was obtained and the one repetition max (1RM) was measured in order to set the correct training intensities. The remaining three weeks consisted of three training interventions separated by 7 days apart in order to minimize any carry-over effects.

5.2 Pre Participation

Before included in the study, the participants were asked to fill out a questionnaire regarding their health history and physical activity assessment. They were informed about the procedures, potential risks and benefits both verbally and in writing. Subjects then gave their written informed consent to participate. Upon inclusion, the participants were asked to refrain from any physical activity and nutritional supplemental substances 48 hours prior testing and were asked to continue their normal daily routines regarding sleep, medication and diet.

5.3 Subjects

Six healthy participants (5 males, 1 female) were recruited for the study (table 1). They had at least 2 years of experience with strength and aerobic training. All subjects were free from any health issues that could possibly affect their performance and participation in the study.

Table 1. Descriptive characteristics of the 6 subjects.

Age (years)	25,5 ± 2,1
Body Weight (kg)	83 ± 3,4
Height (cm)	180,5 ± 6,4
Back Squat 1RM (kg)	121,25 ± 14,9
MHR, Cycling GXT ($b \cdot min^{-1}$)	175,5 ± 6,7
MHR, Running GXT ($b \cdot min^{-1}$)	191 ± 5,8

MHR = maximal heart rate. GXT = graded exercise test. Data represented are average ± standard deviation.

5.4 One Repetition Max Test

The maximal repetition attained in the squat exercise was assessed by using a Smith machine (Cybex International, Medway, MA, USA). The strength testing began with a warm-up of 5 minutes on a cycle ergometer. Each subject then selected a voluntary weight and completed 8-10 repetitions before the weight successively increased until no more than one repetition could be accomplished, following the National Strength and Conditioning Association guidelines for 1RM testing (Baechle & Earle, 2008). To make sure each participant descended to the correct angle at the knee joint, the bar was lowered until it touched a safety gadget, which demonstrated each individuals' 90° at the knee joint and was used throughout the study. An acceptable lift involved lowering the bar with control until it briefly touched the safety gadget before ascending to a fully extended knee. The subjects had 3 trials to achieve the 1RM load with 2-minutes resting period for each trial.

5.5 Maximal Cycling test

The participants performed an incremental test to voluntary failure on a cycle ergometer (Monark 828e, Varberg, Sweden). The incremental test started with a load of 0,5 kilopond (kp) and increased with 0,5kp per 1-minute stage until the subject no longer could continue.

The revolutions per minute (RPM) were consistent at 65 throughout the test. Rated perceived exertion and heart rate was measured using a Polar heart-rate monitor (Polar Electro OY, Kempele, Finland) during the test and recorded 10s before increasing the load. MHR was determined when the subject reached fatigue and no longer could continue. The maximal load by kp reached was defined as maximal intensity attained. The seat height was set for each individual to express an angle of 15-20° at the knee joint and was kept constant throughout the study. Also, they were not allowed to stand up while pedaling in order to eliminate weight bearing aid.

5.6 Maximal Running Test

The running incremental test was conducted using the same design as the cycling test. The participants began with a warm-up at a voluntary intensity for 7 minutes. The initial running ergometer (Cybex International, Medway, MA, USA) test started at $8km \cdot h^{-1}$ and successively increased by $1km \cdot h^{-1}$ during each 1-minute stage until voluntary fatigue. Heart rate (Polar Electro OY, Kempele, Finland) and rated perceived exertion was measured and taken at the end of each 1-minute stage. MHR was determined when the subject reached fatigue and could no longer continue the test. The maximal velocity reached was expressed as the maximal intensity attained.

5.7 Training Intervention

The training intervention consisted of four experimental sessions including the above mentioned maximal measurements during the first week. The following three weeks consisted of three experimental sessions applied in randomized order with 7-days apart:

1) A bout of continuous cycling followed by acute leg squat performance (CS).
2) A bout of continuous running followed by acute leg squat performance (RS).
3) Isolated leg squat performance (S).

5.7.1 Endurance Exercise

The endurance cycling and running interventions lasted for 40-minutes at an intensity of 80% of MHR. If the estimated intensity did not match the target HR, the work load was either increased or decreased in order to reach the 80% MHR. Supervision was strictly required to accomplish this. The cycling cadence remained at 65 RPM throughout the intervention.

A 10-minute recovery period was given after each endurance bout before the intervention continued onto the strength performance testing.

5.7.2 Strength Performance

The intervention of acute leg strength was firstly conducted by warming-up at an intensity of 50% of the 1RM for 8-10 repetitions. Secondly, the peak power performance (MuscleLab, Langesund, Norway) was measured in watts (W) involving 3 repetitions separated by 1 minute. Each repetition started from the individuals' 90° angle on a smith machine using the safety gadget. When ready, the subjects forced the barbell rapidly upwards without lifting the feet from the floor.

After resting for 1 minute after the last peak power repetition, the final strength exercise in this protocol included 3 sets to muscular failure. They completed the maximal number of repetitions in each set and recovered for 2-minutes between the sets. In order for all repetitions to count, they needed to lower the bar in a controlled fashion until it touched the safety gadget before extending fully at the knee joint. The sets were terminated when the subjects no longer could perform a full extension at the knee joint due to fatigue. The load remained at 80% of 1RM during the study.

6 Ethics

Since the present research was conducted within the framework of higher education, no formal ethical approval was necessary to complete the study. However, some guidelines (Vetenskapsrådet, 2002) are mandatory to adhere by and in accordance to the information requirement, the participants were informed about the purpose, procedures and risks of the study. In accordance to the informed consent requirement, the participants were informed about their voluntary participation of the study and the ability to withdraw at any time. A written informed consent was signed and no guardian consent was required since the subjects were over 18 years of age. In accordance to the confidentiality requirement, details of all participants in the research must be preserved with the utmost confidentiality and personal data should be stored in such a way that unauthorized individuals could not access them.

In accordance to the data requirement, data collected from the participants may be used for research purposes only, unless the individual gives special permission otherwise.

The participants were informed about the potential risks involved when determining maximal repetition and maximal heart rate. They were also informed about potential risks and benefits from the training protocols. The participants were insured through the university.

7 Reliability and Validity

In order for collected data to have any value, the test must measure what it is supposed to measure and include reliability (Domholt, 2000). The measurements of peak power were conducted from a device manufactured by MuscleLab (Langesund, Norway) with intention to calculate velocity, power and force exerted from a Smith machine. To validate this system, an optoelectronic 3D motion analysis with two cameras (OQUS 4, Qualisys AB, Gothenburg, Sweden), operating at 100 Hz, was used for sampling frequency of spherical reflective markers (19 mm diameter). The two cameras were positioned in different angles to target the coronal plane of the smith machine and the participant. The spherical reflective marker was positioned on the top side of the barbell.

Following the setups, we asked a participant to perform 10 peak power repetitions replicating the present study at 80% of 1RM (90kg). The optoelectronic motion system measured each acceleration collectively with the MuscleLab software used in the study. The observational differences in values from both systems were deviated and presented as root-mean-square-error (RMSE). RMSE equated in 0,03 m/s using an external weight at 90 kg with force acceleration at 9,81 m/s^2. Average differences in maximum power development between the two systems is thus $0,03 \cdot 90 \cdot 9,81 = 26,49$ Watts.

8 Statistical Analysis

Peak and average power over the 3 attempts in the strength test were compared using one-way repeated-measures ANOVA analysis with three different factors for conditions: Cycling + Strength (CS), Running + Strength (RS) and Strength only (S). Further, the total volume lifted (kg) in the subsequent 3-set test was compared across the three conditions (CS vs. RS vs. S). Data were summarized in Excel (Microsoft Corporation, USA) and all statistical analysis was subsequently performed using the SPSS Software (Chicago, IL, USA). The significant alpha-level was set to 5% ($P<0,05$). Data is presented as mean ± standard deviation.

9 Results

Effects on Peak Power

Average peak power across conditions were CS = 1639 ± 444 W, RS = 1633 ± 422 W and S = 1565 ± 349 W (Figure 1). No differences were observed between the conditions (P=0,817).

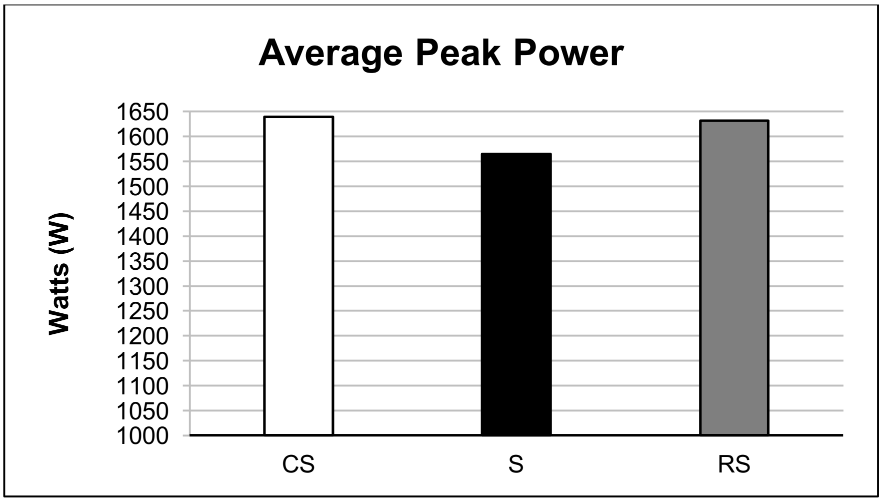

Figure 1 – Average Peak Power. CS = Cycling + Strength. S = Isolated Strength. RS = Running + Strength.

There was no difference across the three conditions when examining the highest peak power reached for each individual for the three conditions (Figure 2, P=0,619).

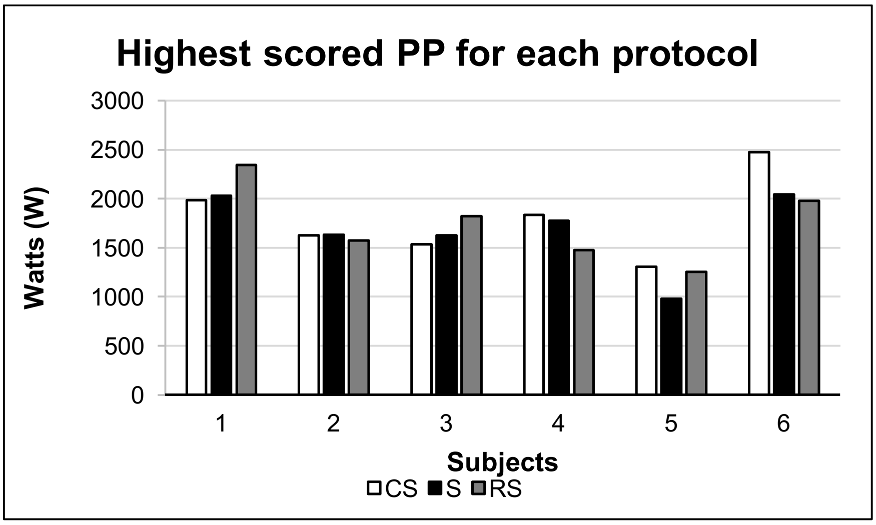

Figure 2 – Highest measured peak power between training protocols for each subject. CS = Cycling + Strength. S = Isolated strength. RS = Running + Strength.

Effects on total volume lifted

The ANOVA analysis revealed a significant main effect of condition (P=0,027, F=5,27) for total volume lifted in the 3 sets carried out after the peak power test (Figure 3). This was because CS resulted in lower loads lifted (2559kg) than both RS (3345kg, P=0,018) and S alone (3715kg, P=0,037). No difference was observed between the RS and S conditions.

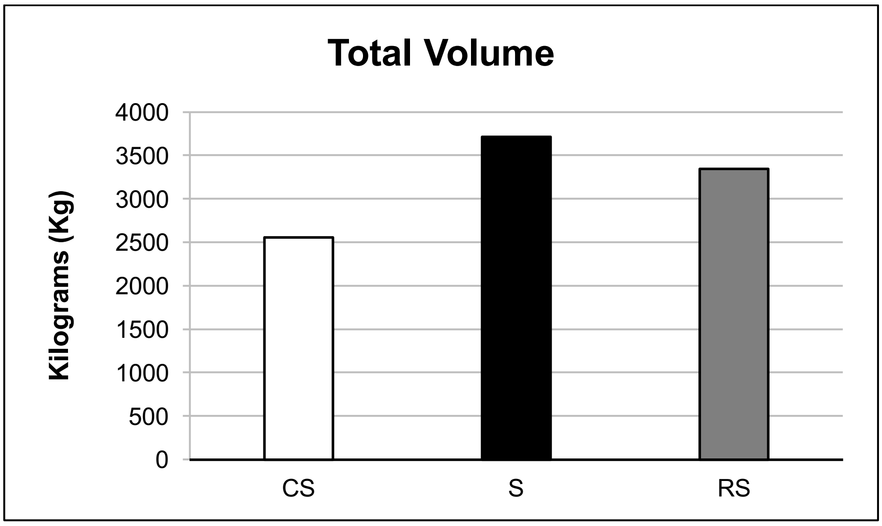

Figure 3 – Total work volume performed. CS = Cycling + Strength. S = Isolated strength. RS = Running + Strength. Total work volume was calculated: sets · repetitions · 80% of 1RM (kg).

A closer look on the average repetitions managed in each set for the three conditions is displayed in Figure 4. It is clear that the decline in performance is greater in S and RS, since the performance is already low in CS during the first set.

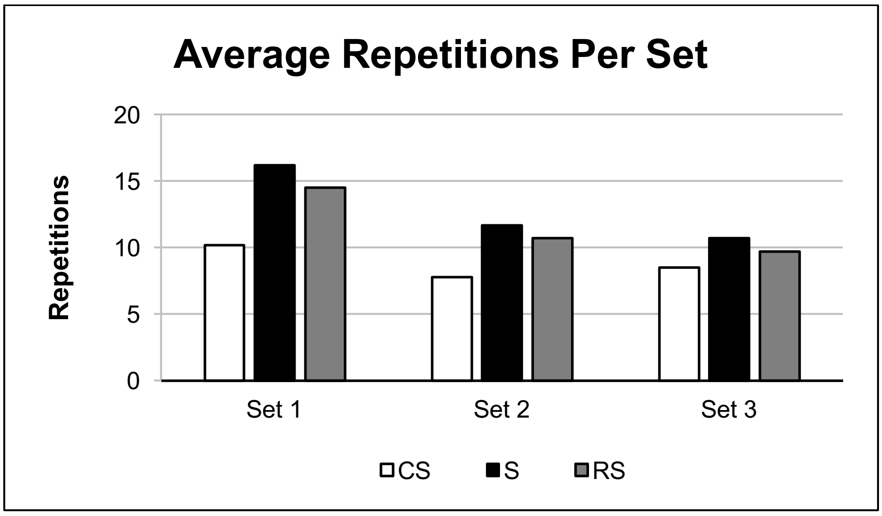

Figure 4 – Average repetitions performed in each set. CS = Cycling + Strength. S = Isolated strength. RS = Running + Strength.

10 Discussion

The purpose of this research was to examine two frequently used endurance modalities recommended to promote health and performance benefits and its impact on acute leg strength performance. The specific goal was to investigate if the physiological characteristics induced by running and cycling respectively affected subsequent leg strength performance. Based on the scarce published research, it was hypothesized that continuous running would result in greater interference to subsequent leg strength performance due to the eccentric muscle actions involved as compared to cycling, which consists of primarily concentric muscle actions. Thus, the purposed hypothesis disagreed with current results.

The observed outcome regarding peak power did not result in any significant differences between the three training protocols. It was proposed that running would eventually result in attenuated peak power performance compared to cycling. However, no such observations were made in the present research. The reason for this could be due to the contractile activity in previous running and cycling exercises. Force production decrease because of the repeated muscular activation, eventually resulting in neuromuscular fatigue (Rassier et al., 2000). Although the induced fatigue serves to diminish force production, the contractile history can facilitate subsequent force production, resulting in a post activation potentiation (Sale, 2002). This physiological phenomenon is typically seen in maximal or near maximal voluntary activation (Sale, 2002; Sale, 2004). This was observed in a previous study where specific exercises caused a short term increase in neural activation, encouraging maximal voluntary contraction in strength-speed performances in upper and lower extremities (Güllich & Schmidtbleicher, 1996). Thus, although the subjects of the present study performed endurance exercise rather than close to maximal exercises, it is perhaps possible that post activation potential counteracted some of the fatigue induced by the endurance exercise bouts, resulting in similar peak power performance across conditions.

The other interesting discovery was that the performance in total volume lifted by the participants was compromised when cycling was carried out before the strength session. Thus, comparing the two modalities, running resulted in greater total work performed compared with cycling, suggesting a larger interference when continuous cycling was conducted prior strength. Interestingly, the total repetitions managed between each set seemed relatively constant after cycling, showing very little attenuation in muscular endurance. This was not the case for continuous cycling and isolated strength, where the biggest drop occurred between the first and second set but not the third (Figure 4). The findings from present study is in line with previous studies examining endurance modalities on strength performance. Although examining high intensity endurance training on acute subsequent strength performance, the observations from Panissa et al (2012) reported a greater interference in cycling rather than running as currently hypothesized. They assigned 10 physically active males into three experimental interventions: intermittent running and cycling followed by strength exercise and one control group. The intermittent cycling and running groups were exposed to 15 1-min bouts at an equalized maximal intensity, separated by 1-minute resting periods. 15-minutes after the endurance, they were submitted to a strength protocol consisting of 4 sets to concentric failure at 80% of 1RM in the squat exercise. The results indicated that the total volume performed was lower in both modalities as compared to strength alone. These results are in accordance to present study where the total volume was superior in strength only and greater in running as compared to cycling.

An explanation for why cycling could induce more interference in acute strength performance than running could be that cycling accumulates greater local muscle fatigue than running, which induce more systemic/central fatigue. This suggestion is in accordance to previous research investigating energy distribution in both cycling and running, which reports higher accumulation of anaerobic components in cycling (Scott et al., 2006). However, the intentions were not to measure energy metabolism contribution, although further research should be considered regarding this matter.

During a running exercise, the muscles are forcibly lengthening which is the characteristics of eccentric contractions, and eccentric actions promote greater muscle damage than concentric actions. The contractions also deviate from one another in the perspective of strength loss and the period to recover from exercise induced muscle damage. The recovery of strength after concentric contractions occur rapidly after exercise, but this is not the case for eccentric exercises where damages can be seen up to 7-days post training (Eston et al., 1995). In present study however, the running bout did not seem to cause any degradation in total volume compared to cycling. The possibility is that muscular damages induced by running do not occur immediately, but instead escalate over time. Comparing to concentric muscular damages, the damages in eccentric induced actions are minor immediately following exercise and gradually expand resulting in greater deleterious observations 24-48 hours post-exercise. This is known as delayed onset muscle soreness (Newham et al., 1983). Applying this theory to present study, the 10-minute recovery period between running and strength was possibly not extensive enough to witness greater interferences in running when compared to cycling. Implementing a longer recovery period between exercise modes could lead to greater strength interference and research should investigate this proposal for future references.

Noteworthy to mention is that cycling mostly exhausts quadriceps muscles while the running does not. This might affect the results of a test that is precisely based on quadriceps strength such as squat.

The largest limitation in this study was the number of subjects included in the study. Only 6 participants showed interest to volunteer and the same individuals were accepted for this investigation. The subject number was smaller than desired, which reduced the possibility to detect small yet potentially important differences concerning peak power performance.

10.1 Conclusion

There were no differences observed between the three training protocols regarding peak power performance. When cycling exercise was performed prior to the strength session, the total volume lifted was lower than when performing the strength test alone. Thus, it is concluded that continuous cycling exercise, but not running, interferes with subsequent strength training performance.

10.3 Practical Application

Strength and conditioning coaches constantly strive towards optimizing training programme for strength and endurance adaptations. This study suggests that endurance training can be combined with strength training without any detrimental effect on peak power performance. However, performing cycling exercise prior to strength training may reduce training performance since lower loads can be lifted during the subsequent strength session. Thus, the coach could either implement longer rest periods between cycling exercise and strength training, or prescribe the strength training before the cycling exercise.

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