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Comparison of the Contributions of Knee and Hip Muscle Strength on Maximum Oxygen Consumption Parameters During Continuous and Constant Test Protocols

Diz ve Kalça Kas Kuvvetinin Kademeli ve Sabit Test Protokolleri Sırasındaki Maksimum Oksijen Tüketim Parametrelerine Etkisinin Karşılaştırılması

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ABSTRACT

Preliminary VO_{2max} verification testing allows to examine the reproducibility of comparable tests in the same participants and helps to verify whether neuromuscular performance is associated with VO_{2max} during different testing conditions. The main purpose of this study was to compare VO_{2max} values obtained using a graded treadmill and cycling protocols and to verify whether the results are also reproducible during the constant time to exhaustion testing protocols. The second rationale of the study was to characterize the contributions of hip and knee muscle strength during four different testing conditions, and to determine how these quantities change when altering the modality of exercise for a given exercise intensity. A repeated measures study design was used. A total of 20 healthy male participants (21.20±2.17 years) underwent preliminary VO_{2max} testing sessions on treadmill and cycling ergometers with 24-h intervals. Isokinetic strength performance of hip and knee muscles was tested at 60°/sec angular velocity. A paired and independent-sample t-test was performed for inter-group and intra-group comparisons. Linear regression was applied to determine the percentage of variation in VO_{2max} testing outputs during either testing modality explained by hip and knee muscle strength parameters. Lower extremity strength characteristics of hip and knee were symmetric between the dominant and non-dominant limb (p>0.05). VO_{2max} and blood lactate concentration were significantly greater during constant testing protocols for either testing modalities (p<0.001). Hip muscle strength performance explained a greater variation in VO_{2max} parameters during incremental (cycling r^2= 0.25, running r^2= 0.24) and constant (cycling r^2= 0.35, running r^2= 0.33) testing protocols for either testing modality compared to the contribution of knee muscle strength performance on VO_{2max} parameters during incremental (cycling r^2= 0.17, running r^2= 0.17) and constant (cycling r^2= 0.23, running r^2= 0.18) testing protocols. The local muscular performance of the hip and knee muscles were strongly related with the changes in running and cycling mechanics and hip muscles had a greater contribution to the VO_{2max} performance during constant protocols than knee muscles. In conclusion, the extent to which contribution of lower extremity muscles during VO_{2max} testing relies more on the mode of the exercise rather than the type of the testing modality.

Keywords: *Oxygen consumption, Exercise intensity, Neuromuscular performance*

ÖZ

Doğrulayıcı VO_{2maks} testi, aynı katılımcılarda karşılaştırılabilir testlerden elde edilen ölçümlerin tekrarlanabilirliğini incelemeye olanak sağlarken farklı test koşulları sırasında nöromüsküler performansın VO_{2maks} ile ilişkili olup olmadığını doğrulamaya yardımcı olur. Bu çalışmanın temel amacı, kademeli koşu bandı ve bisiklet protokolleri kullanılarak elde edilen VO_{2maks} değerlerini karşılaştırmak ve sonuçların sabit hızda uygulanan doğrulayıcı test protokolleri esnasında da tekrarlanabilir olup olmadığını doğrulamaktır. Çalışmanın ikinci amacı ise, kalça ve diz kas kuvvetinin dört farklı test koşulu sırasında VO_{2maks} performansına olan katkılarını karakterize etmek ve belirli bir egzersiz yoğunluğu için egzersiz modalitesini değiştirirken bu miktarların nasıl değiştiğini belirlemektir. Çalışma dizaynı olarak tekrarlanan ölçümler çalışma tasarımı kullanıldı. Toplam 20 sağlıklı erkek katılımcıya (21.20±2.17 yıl), 24 saatlik aralıklarla koşu bandı ve bisiklet ergometrelerinde ön VO_{2maks} testleri uygulandı. Kalça ve diz kaslarının izokinetik güç performansı 60°/sn açısal hızda test edildi. Gruplar arası ve grup içi karşılaştırmalar için eşleştirilmiş ve bağımsız örneklem t-testi uygulandı. Her iki test modalitesinde elde edilen VO_{2maks} test çıktılarının kalça ve diz kas kuvvet parametreleri tarafından açıklanan varyans yüzdesini belirlemek için doğrusal regresyon analizi uygulandı. İzokinetik kalça ve diz kas kuvvet değerleri baskın ve baskın olmayan ekstremite arasında simetrikti (p>0.05). VO_{2maks} ve kan laktat konsantrasyonu, her iki test yöntemi için de sabit test protokolleri sırasında istatistiksel olarak daha yüksek bulundu (p<0.001). Kalça kas kuvvet performansının VO_{2maks} performansına olan katkısı hem artan (bisiklet r^2= 0.25, koşu r^2= 0.24) hem de sabit (bisiklet r^2= 0.35, koşu r^2= 0.33) test protokolleri sırasında diz kas kuvvetinin kademeli (bisiklet r^2= 0.17, koşu r^2= 0.17) ve sabit hızda (döngüsel r^2= 0.23, çalışan r^2= 0.18) gerçekleştirilen testlerden elde edilen VO_{2maks} parametrelerine olan katkısına kıyasla daha büyük bir varyasyonu açıkladı. Bu nedenle, kalça ve diz kaslarının lokal kas performansı, koşu ve bisiklet mekaniğindeki değişikliklerle güçlü bir şekilde ilişkili olduğu görülürken kalça kaslarının sabit protokoller sırasında VO_{2maks} performansına olan katkısı diz kaslarının katkısına oranla daha yüksek bulundu. Sonuç olarak, VO_{2maks} testi sırasında alt ekstremite kaslarının katkısının derecesi, test yönteminden çok egzersiz moduna bağlı olduğu söylenebilir.

Anahtar Kelimeler: *Oksijen tüketimi, Egzersiz şiddeti, Nöromüsküler performans*

INTRODUCTION

The assessment of maximal oxygen uptake (VO_{2max}) is generally accepted to be the best indicator of endurance performance capacity for both professional athletes and sedentary individuals (O'Toole and Douglas 1995; Sleivert and Rowlands 1996). In this regard, this variable is frequently used to determine training intensities in numerous endurance sports such as running and cycling. Studies to date showed that VO_{2max} is highly dependent upon the mode of testing, with the highest values normally attained during treadmill running. These variations have been shown to be associated with the type of the exercise modality and VO_{2max} attained using treadmill protocols tend to produce up to 20% greater values when compared to cycle protocols (Myers et al., 1991; Muscat et al., 2015; Carter et al., 2000; Hill et al., 2003; Jones and McConnell, 1999). Therefore, to optimize the effectiveness of a training program and establish training guidelines in running and/or cycling training, training activities appear to need some specificity with regard to mode, duration and intensity.

Graded exercise testing (GXT) is one of the most common exercise assessment methods used to examine the dynamic relationship between exercise workload and the physical activity-induced responses in cardiovascular, pulmonary, musculoskeletal, and neuropsychological systems (Albouaini et al., 2007). The use of treadmill and cycle ergometry during GXT is the most preferred exercise regimen to evaluate the endurance performance of athletes in this manner (Billat et al., 1998; Albouaini et al., 2007; Millet et al., 2009). Theoretically, the differences in biomechanical properties between two exercise modality and recruitment in muscle contractile patterns may lead to an asymmetric strength distribution in quadriceps, hamstring, and hip muscles during performance and their attribution may also change when altering the modality of exercise for a given exercise intensity. Because of this specific adaptation, runners are generally tested on a treadmill, and cyclists on a cycle ergometer despite lower extremity muscles activate cyclically both during running and cycling (Basset and Boulay, 2000). During both running and cycling, these muscle groups control the movements of the knee and hip joints and the recruitment patterns of quadriceps and hamstring muscles increase with increasing exercise intensities (Camic et al., 2015). In this context, the occurrence of strength discrepancies during these testing modalities may affect all-out exercise performance (Heiderscheit et al., 2011). Rather than the mechanical properties of cycling and running techniques, the strength of the lower extremity muscles affects the exercise performance due to the recruitment of the lower extremity muscles in a manner that leads to muscular fatigue during strenuous activities (Millet et al., 2009). The discrepancies in lower extremity muscles may also be transferable to the mechanics of endurance performance and such conditions can result in poor technique and/or imbalances of force generation (Farrell et al., 2003). These differences may also provoke VO_{2max} due to the varying kinematics of lower extremity muscles during graded and constant testing protocols for either testing modality. The differences between mechanical properties and muscle recruitment patterns during these testing modalities may also be attributed to larger recruitment of exercising skeletal muscle mass, cardiac output (Q) and arteriovenous oxygen difference (a-vO_2 diff), and may yield different results during incremental and constant testing protocols (Okita et al., 1998; Porszasz et al., 2003; Tanner et al., 2014; Yoon et al., 2007).

In addition to the ergonomic and biomechanical differences between these two testing modalities, the selection of the type and characteristics of an exercise test may also influence the precision of VO_{2max} test outputs (Sousa et al., 2015). In addition to that, despite a diminished plateau in cycling is attributed to the increased metabolic cost of the eccentric skeletal muscle activity in treadmill running compared to the concentrically dominant cycle exercise, there is no study that characterize the contributions of hip and knee muscle strength during four different testing conditions and how these quantities change when altering the modality of exercise for a given exercise intensity. With this in mind, the data obtained from the same individual concerning muscular contribution of lower extremity muscles during constant and incremental running and cycling VO_{2max} testing modalities may yield important information for both coaches and athletes to design optimal exercise training prescriptions.

Due to the differences in muscle recruitment patterns between constant and incremental running and cycling VO_{2max} testing, we hypothesized that VO_{2max} performance would also vary, and the participants would yield different VO_{2max} outputs during constant and incremental testing protocols due to the varying activations of either muscle groups. Thanks to the utilization of these verification tests for either modalities, it would be possible to test the reproducibility for the same participants and screen the interaction between the lower extremity strength characteristics of these muscles and VO_{2max} performance. Thus, the purpose of this study was to compare VO_{2max} values obtained using graded treadmill and cycling protocols and to verify whether the obtained results from incremental protocols are also reproducible during constant time to exhaustion testing protocols. The second rationale of the study was to characterize the contributions of hip and knee muscle strength during four different testing conditions, and to determine how these quantities change when altering the modality of exercise for a given exercise intensity.

METHODS

Participants: Volunteers were 20 healthy male collegiate students enrolled in the Faculty of Sports Science between the ages of 18 to 26 (21,20±2,17) years old. The participants were physically inactive and they were not performing any kind of sports at any professional clubs. The anthropometric parameters of participants were (height: 176.35±5.28 cm, weight: 75.99±8.05 kg, lean body mass: 65.35±4.81kg, fat mass: 14.04±4.93 %), respectively. All participants gave written informed consent before participating in the study approved by Institutional Review Board (Protocol number: 2017/92, Date of approval: 04/13/2017) in compliance with the ethical standards of the Helsinki Declaration.

Procedures: Before all testing sessions, participants were informed regarding equipment and familiarized with the experimental procedures. The anthropometric parameters (body fat mass, lean body weight, weight) were assessed using bioelectrical impedance analysis (Tanita 418-MA Japan) before isokinetic strength and VO_{2max} test sessions. Height was measured with a stadiometer in the standing position (Holtain Ltd. U.K.). Isokinetic and VO_{2max} tests were applied with 24-h intervals.

At their first visit to the laboratory, the participants underwent isokinetic knee strength measurements. Twenty-four hours later, they performed isokinetic hip strength measurements to avoid fatigue resulted from the previous testing session. These test were followed by incremental running VO_{2max} testing and constant time to exhaustion testing, each with separated 24-h intervals. Upon completion of 24-h intervals, the participants underwent incremental cycling VO_{2max} testing which followed by constant time to exhaustion testing 24-h post recovery.

Assessment of VO_{2max} parameters using cycle ergometer and treadmill: All participants performed incremental treadmill and cycling tests over a 24-hour interval with two separate visits to the laboratory. In the assessment of oxygen kinetics, participants randomly completed two maximal exercise tests to exhaustion on separate days. To determine minimum exercise intensity and velocity required to perform verification protocol at a constant speed and intensity the participants initially underwent an incremental cycling and running protocol. Cycling incremental and constant verification protocol was performed on Ergoline Ergoselect 100/200 cycle ergometer. In the first visit, athletes underwent an incremental cycling test protocol to determine the minimum intensity at which VO_{2max} elicit. The initial intensity was

50 Watt and participants were asked to pedal between 95-100 rpm on a cycling protocol. Each stage consisted of 2 minutes and 50 Watt load increase was applied at every stage. If the participants could not complete 2 minutes intervals the load of the previous stage was recorded to perform constant verification protocol for the following test session. Before verification protocol, each participant underwent a 10-min warm-up at 60% of their VO_{2max}. Upon completion of warm-up process the participants performed at an exercise intensity at which VO_{2max} elicited during the preliminary tests. After 10 minutes warm-up the intensity progressively increased to the VO_{2max} intensity in 30 s and using verbal encouragement they were told to maintain this intensity until they felt exhausted. The time to exhaustion during verification protocol was recorded as the time from when the exercise intensity was first attained until the point when they were not able to maintain the prescribed cycling frequency of 80 rpm. The test ended when the participants failed to continue the pedaling rate at the required exercise intensity despite verbal encouragement. Gas exchange was measured breath-by-breath in 10-second sampling periods throughout the VO_{2max} with a Masterscreen™ CPX metabolic cart (Germany).

In the assessment of the same VO_2 components, all participants underwent VO_{2max}, and time to exhaustion on treadmill using both progressive and constant exercise protocols. All participants maintained a standing position on a treadmill and were asked to hold the handrails before initializing the device for the test session. Then, the treadmill speed was set to 5 $km \cdot h^{-1}$ (0 % slope) and increased every minute by 1 $km \cdot h^{-1}$. Following this warm-up process, the test was started when the speed reached 8 $km \cdot h^{-1}$. Throughout the tests, participants received verbal encouragement. The test continued until at least two of the following criteria were obtained: a plateau in VO_2 despite an increase in running speed: a respiratory exchange ratio (RER) above 1.1; HR over 90 % of the predicted maximal HR. If the stage of 1 min could not be completed, the velocity of the previous stage was recorded as minimum running velocity at which VO_{2max} elicit and was used for the verification protocol. At the following session, the participants underwent a time to exhaustion test at a constant velocity on a treadmill under the same laboratory conditions. Following a 15-min warm-up period at 60% of VO_{2max}, the speed was immediately increased (in less than 20 s) up to minimum velocity at which VO_{2max} elicited. Then, the participants were encouraged to run to their volitional exhaustion. Blood lactate concentrations were determined using the samples obtained in duplicate from the earlobe at rest and 2 minutes into a seated recovery (Lactate Pro 2 LT-1730, Arkray, Inc., Kyoto, Japan) during all testing sessions. Heart rate (HR) was monitored and recorded using 12-lead ECG during treadmill and cycling testing sessions.

Isokinetic muscle strength assessment: In the assessment of isokinetic knee peak torque strengths, the participants were seated on the Humac Norm Cybex CSMI chair in an upright position. Before the isokinetic test session, the hips and thighs of participants were stabilized with the hips flexed at an angle of 90° using pelvic and thigh straps during the testing session. They initially performed a warm-up test at 60°/s angular velocity and then completed five maximal effort contractions at the same velocity to determine isokinetic peak torque strength parameters. The participants were instructed to exert effort as hard and as fast as possible for all contractions.

Upon completion of the knee strength performance evaluation, participants laid supine on the dynamometer chair with the chair back completely flattened to measure isokinetic hip flexion and extension peak moment strength at an angular velocity of 60°/s. The tested hip was at 0° of flexion, with 90° of knee flexion, and secured into a brace. The tested thigh was strapped to the dynamometer pad at the femur level. The non-tested thigh was stabilized to the dynamometer chair at 0° of hip flexion. The range-of-motion limitations were set beginning from the hip neutrally extended on the table to the hip being maximally flexed. The pelvis and trunk were strapped to the dynamometer chair to prevent undesirable movements throughout the test. They initially performed a warm-up test at 60°/s angular velocity and then completed five maximal effort contractions at the same velocity to determine isokinetic peak torque strength parameters. Gravitational corrections were made before all test sessions to avoid the effect of limb weight on moment production.

Statistical Analysis: Descriptive data are presented as means and standard deviation unless otherwise stated. A paired-samples t-test was conducted to compare knee and hip isokinetic strength characteristics, aerobic exercise energy expenditure between GXT and constant cycling and treadmill protocols. Linear regression was applied to determine the percentage of variation in oxygen consumption parameters of GXT and constant testing protocols outcomes explained by hip and knee muscle strength parameters. The variables for final models were selected based on statistical significance, maximum R^2 values, and distribution of residuals. The level of statistical significance was set at $p<0.05$ and $p<0.001$ for all comparisons. The statistical analysis was performed with SPSS version 20.0 (SPSS Inc., Chicago, IL, USA). GraphPad Software GraphPad Prism 6 was used for graphical expression.

RESULTS

Lower extremity strength characteristics of the participants revealed symmetric distribution between the dominant and non-dominant limb (Table 1).

Table 1

The Comparison of Neuromuscular Strength Characteristics of the Participants (n=20)

Variables	Dominant limb	Non-dominant limb	P-value
Hip extension, Nm	324.81±70.26	319.11±65.15	0.40
Hip flexion, Nm	189.21±29.91	183.82±30.16	0.57
Knee extension, Nm	275.13±38.55	272.28±35.29	0.43
Knee flexion, Nm	153.55±21.18	151.35±23.48	0.39

Note: Values are presented as mean ± SD.

The participants had significantly higher VO2max values during constant testing protocols for either testing modalities ($p<0.001$). VO2max was found 18.22% greater for constant cycling testing protocols while it was 11.61% higher during constant running protocol compared to incremental testing protocols for both running and cycling. Blood lactate concentration following constant testing protocols were also significantly higher compared to GXT testing protocols ($p<0.05$).

Table 2

Comparison of Mean Values of Physiological Variables and Their Significance During GXT and Constant Cycling and Treadmill Testing Protocols

Variable	**Cycling**		**Treadmill**	
	GXT	Constant	GXT	Constant
VO_{2max}, ml/kg/min	51.03±6.55	61.26±10.41**	53.32±8.80	59.89±4.46**
HR, bpm	187.26±7.85	189.87±6.58	184.89±9.09	188.32±8.73
RER	1.13±0.11	1.16±0.25	1.12±0.01	1.13±0.23
Blood lactate pre, mmol/L	1.01±0.21	1.03±0.23	1.00±0.21	1.02±0.38
Blood lactate post, mmol/L	11.32±3.23	12.80±3.05*	11.01±3.22	12.67±3.13*

Note: Values are presented as mean ± SD. Asterisks (*) shows a significance level $p<0.05$. Asterisks (**) shows a significance level $p<0.001$. **VO_{2max}**: maximum oxygen consumption, **HR:** heart rate, **RER:** respiratory exchange ratio

Additionally, linear regression was applied to determine the percentage of variation in VO2max parameters during GXT and constant protocols for either modalities explained by hip muscle strength parameters showed that the combination of hip extension and flexion muscle strength performance explained 35% of the variation in VO2max during incremental cycling protocol compared to a 25% during constant cycling protocol. Similarly, the combination of hip extension and flexion muscle strength performance explained a greater variance during GXT treadmill running (33% of the variation) compared to a 17% during constant treadmill running protocol. The combination of hip extension and flexion muscle strength performance explained a greater variation in VO2max parameters during incremental (cycling r2= 0.25, running r2= 0.24) and constant (cycling r2= 0.35, running r2= 0.33) testing protocols for either testing modality compared to the contribution of knee muscle strength performance on VO2max parameters during incremental (cycling r2= 0.17, running r2= 0.17) and constant (cycling r2= 0.23, running r2= 0.18) testing protocols. The combination of hip extension and flexion muscle strength performance explained greater variance of the variation in VO2max during constant testing conditions for cycling (r2=0.35 vs. r2=0.25) and running (r2=0.33 vs. r2=0.24) protocols compared to incremental testing protocols.

On the other hand, the results revealed that the combination of hip extension and flexion muscle strength performance explained a greater variation in VO2max parameters during incremental and constant testing protocols for either testing modality compared to the combination of knee extension and flexion muscle strength performance (Table 3).

Table 3

The Differences of the Contributions of Lower Extremity Muscle Performance During GXT and Constant VO_{2max} Protocols

Variable	**Knee muscle strength**			**Hip muscle strength**		
	r	**r^2**	**p**	**r**	**r^2**	**p**
Cycling GXT	0.413	0.171	0.560	0.502	0.252	0.328
Cycling Constant	0.482	0.233	0.377	0.588	0.346	0.149
Treadmill GXT	0.409	0.167	0.571	0.485	0.238	0.379
Treadmill Constant	0.429	0.184	0.519	0.571	0.326	0.179

DISCUSSION

Preliminary VO_{2max} testing allows to examine the reproducibility of comparable tests in the same participants and helps to verify whether the athletes performed at their maximum capacity at the required work rate and also neuromuscular performance is associated with VO_{2max} capacity. The main purpose of this study was to compare VO_{2max} values obtained using graded treadmill and cycling protocols and to verify whether the results are also reproducible during the constant time to exhaustion testing protocols. The second rationale of the study was to characterize the contributions of hip and knee muscle strength during four different testing conditions, and to determine how these quantities change when altering the modality of exercise for a given exercise intensity.

The results of the current study show that the rate of energy expenditure is influenced by both bioenergetics and neuromuscular determinants during either incremental and constant cycling and running testing protocols. However, although lower extremity muscles have great importance during these testing modalities it is important to examine the segmental contributions of these muscles to the VO_{2max} performance. As seen in Table 1 the participants demonstrated symmetrical muscle strength performance, whereas it did not result in similar VO_{2max} performance during these testing modalities with the varying mode and intensities.

Therefore, it is important to question the extent to which muscles contribute a superior attribution to the VO_{2max} performance and whether they also demonstrate similar interactions during both incremental and constant testing protocols. Despite similar muscle strength performance between the dominant and non-dominant limb, the participants showed significantly greater VO_{2max} parameters during constant testing protocols for either testing modality. Considering the stride length and frequency is higher during constant protocols than those in incremental protocols the interaction between VO_{2max} testing performance and lower extremity muscle strength may be superior. The previous research showed that increased EMG signal of hip and knee muscles was greater during late swing when step rate is increased (Chumanov et al., 2012; Semciw et al., 2014). Additionally, the hamstrings, and gluteus maximus have been shown to accelerate the hip into extension, while the hamstrings also work to oppose the knee from accelerating into extension during this phase of running (Dorn et al., 2012). The greater activity and force production from these muscles have shown to be related to increased step rate most likely due to increased inertial loads which also leads to a decreased hip and knee joint loads during stance (Heiderscheit et al., 2011; Lenhart et al., 2014; Schache et al., 2011; Souza et al., 2009; Neumann, 2010). The contribution of these muscles was also found superior during constant cycling and running time to exhaustion test protocols than those in the incremental running and cycling VO_{2max} test protocols most likely due to the increased activity of these muscles during constant testing protocols. Linear regression analysis applied to determine the segmental contributions of these muscles to the overall VO_{2max} performance showed that hip muscle strength comprises a great role for VO_{2max} performance during either training modality compared to the knee muscle strength (Table 3). These findings are per another study that reported hip muscle demands during running, whereas those results were obtained during running performed at preferred speed, ranging from 2.4 to 3.8 $m \cdot s^{-1}$, and therefore may not generalize to faster speeds (Lenhart et al., 2014; Heiderscheit et al., 2010; Dorn et al., 2012). Additionally, the repeated transient impact of vertical ground reaction force has been shown to causes an abrupt collision force which is equal to about 1.5- to 3-fold the body weight during running (Lieberman et al., 2010). Furthermore, Aramptzis et al. (1999) reported an increased mechanical power at the knee joint and muscles to be exposed to heavier load with the increase in velocity (Arampatzis et al., 1999; Neumann, 2010). Contrary to the treadmill running, previous research denoted that only concentric muscle actions are involved during cycling (Miura et al., 2000). Shinohara et al. (1997) found a positive relationship between the EMG activity of concentric exercise and the load applied which shows in turn concentric muscle actions dominate during cycling (Shinohara et al., 1997). However, despite the different nature of treadmill and cycle ergometers the results of the current study revealed that the participants did not show negative adaptations to either testing modalities thanks to their symmetrical lower extremity muscle strength performance regardless of the contractile properties of the muscles. Considering the biomechanical aspects of cycling it is possible to assert that the hip flexors contribute the least to pedaling power and cyclists have weaker hip flexors compared to all the primary pedaling muscles such as quads, glutes, calves, hamstrings, and hip extensors. Nevertheless, the results of the linear regression analysis showed that the combination of hip extension and flexion muscle strength performance explained 35% of the variation in VO_{2max} during constant cycling protocol compared to 25% during incremental cycling protocol. Similarly, the combination of hip extension and flexion muscle strength performance explained a greater variance during constant treadmill running (33% of the variation) compared to a 17% during GXT treadmill running protocol. Similarly, the contribution of the knee muscle strength performance to the VO_{2max} performance during constant cycling testing protocol was greater compared to the incremental testing protocol (23% vs. 17%). The contribution of the knee strength performance was also higher during constant testing protocols as opposed to GXT running protocols (18% vs. 15%). On the other hand, the results revealed that the combination of hip extension and flexion muscle strength performance explained a greater variation in VO_{2max} parameters during incremental and constant testing protocols for either testing modality compared to the combination of knee extension and flexion muscle strength performance (Table 3). With this regard, it can be speculated that the contributions of the lower extremity muscles vary depending on the exercise mode regardless of the type of testing modality and hip muscles have great importance to maintain exercise performance at intense and constant exercise modalities compared to the incremental testing procedures. However, the results of another study showed that a simple 10% increase in running step rate while maintaining preferred running speed has been shown to reduce energy absorption at the hip during the loading response while these potentially beneficial alterations to hip mechanics during loading response was accompanied by increased activation of the hamstring and gluteal muscles during the late swing (Chumanov et al., 2012; Heiderscheit et al., 2011). Thus, despite a greater contribution by the hip muscles during either VO_{2max} performance, further analyses are needed to understand the interactions between the VO_{2max} performance and individual muscle performance responses considering the biomechanical differences between incremental and constant testing protocols. These results show that the local muscular performance of the hip and knee muscles are strongly associated with changes in running and cycling mechanics however this variation relies more on the mode of the exercise rather than the type of the testing modality. Taking such repeated impacts into account, it is possible to speculate that the participants with higher local muscle resistance in hip muscles had fewer changes in kinematic variables during either running and cycling compared to the contribution of the knee muscle strength during constant exercise modalities. Owing to their symmetrical hip and knee muscle strength, the participants in this study were able to cope with lower limb muscle fatigue and prolong time to exhaustion during constant testing protocols. Symmetrical strength characteristics appear to be an important indicator for an improved VO_{2max} performance during constant protocols since the participants had greater VO_{2max} parameters compared to incremental testing protocols both during cycling and running VO_{2max} testing.

However, there are some limitations of the current study. Our study consisted of only male participants. The application of isokinetic testing was limited to concentric muscle contractions and one angular velocity. Future researches need to be warranted including athletes with high performance levels, varying muscle contractions at different angular velocities to explain the confounding components in the current study.

CONCLUSION and RECOMMENDADITONS

This results show that VO_{2max} is highly dependent upon the mode of testing, rather than the type of testing modality. The data suggest that constant protocols enable the individuals to produce greater VO_{2max} compared to incremental testing protocols. Thus, coaches may conduct VO_{2max} tests using both treadmill and cycle ergometer since the participants were tend to produce similar VO_{2max} during either testing modality and VO_{2max} attained from either testing modality can be used to monitor the intensity of activities performed using either mode of exercise.

The evaluation of muscle strength performance of hip and knee muscles may offer coaches precise information in understanding the biomechanical mechanisms of either sports performance. Screening these components may be an important factor for them to design enhanced training programs with accurate training loads. Designing optimal training programs and characterizing individual muscle activity patterns during these testing modalities may provide useful insights into muscle function. In this regard, data obtained during these tests may help to minimize potential injury risk factors, and improve exercise performance. Early recognition of these risk factors may help to determine specific neuromuscular demands of the activity to avoid adverse outcomes of excessive training loads or previous injury history.

Author contributions:

1. **Nasuh Evrim ACAR:** Idea/Concept, Design, Data Collection and/or Processing, Analysis-Comment, Article Writing
2. **Gökhan UMUTLU:** Idea/Concept, Design, Analysis-Comment, Article Writing, Critical Review

Information about Ethical Approval

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KAYNAKÇA

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