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Comparison of Peak Torque and Aerobic Capacity Asymmetries in the Lower Limbs

Original Research

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Abstract

Introduction: Although lower limb muscle strength asymmetries are well documented, the existence of muscle aerobic capacity asymmetries and the potential relationship with muscular strength asymmetries has yet to be determined. The purpose of this investigation was to quantify lower limb dominance and non-dominance for muscular strength and aerobic capacity and determine if asymmetries in muscle strength were related to asymmetries aerobic capacity.

Methods: Fifteen young, healthy adults performed unilateral knee extensor peak torque at 60º, 180º, and 300º/s for each limb. Single-leg cycling tests were performed with dominant limb (DL) and non-dominant limb (NDL) to determine VO_2 peak and VO_2 at ventilatory threshold (VT). Limb symmetry index (LSI) was used to determine asymmetry= [(1-NDL (Nm) /DL (Nm))*100]. Paired Samples T-tests were utilized to compare dependent variables between DL and NDL while Pearson R correlations assessed for relationships between strength and aerobic capacity LSI.

Results: Limb asymmetry existed for mean peak torque (DL = 89.5±34.8 Nm, NDL = 82.0±30.8 Nm, P=0.002). However, there were no differences for DL and NDL VO_2 peak (DL = 34.0±5.1 ml/kg/min, NDL = 34.4±8.1 ml/kg/min, P=0.679), or VO_2 at VT (DL = 17.4±4.6 ml/kg/min, NDL = 16.5±3.8 ml/kg/min, P=0.296). LSI relationships for mean peak torque and aerobic capacity outcomes were not strongly correlated (P≤0.05), (VO_2 peak, R= 0.374, and VO_2 at VT, R= 0.062).

Conclusions: Although there were asymmetries in muscular strength, they are not strongly correlated with aerobic capacity asymmetries in young, healthy adults.

Key Words: limb symmetry index, single-leg cycling

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Introduction

Individuals commonly prefer one side of the body when performing a motor control task, which may lead to lower limb asymmetries [1,2]. Lower limb asymmetries historically refers to differences between the dominant limb's (DL) and non-dominant limb's (NDL) ability to produce force or power, as indicated by plyometric jumping or resistance exercise [3]. Isokinetic testing is one method commonly used as a tool to determine muscular strength limb asymmetries, which, if present, may increase risk for injury [4,5]. Leg dominance along with muscle fatigue and decreased knee proprioception are several factors that increase the risk for noncontact ACL injuries. In addition, lower limb muscular strength asymmetries which are often recorded in individuals after anterior cruciate ligament (ACL) reconstruction [6,7] increase the likelihood for an ACL re-tear [8]. Thus, strength testing guidelines for return to play have recommended 10% or less muscular strength limb asymmetry between the injured and non-injured limbs [9].

Despite the vast literature on limb asymmetries for maximal power and muscular strength, only a few investigations have evaluated limb specific asymmetries in aerobic activities such as running and cycling

[5,10-13]. Carpes and colleagues reported that during a cycling time trial the DL had a greater crank torque compared to the NDL at a sub-maximal intensity, but the crank torque differences were reduced as the exercise intensity increased [13]. In a follow-up investigation single-leg cycling was performed in both trained and untrained cyclists. During submaximal single-leg cycling there were no differences in muscular activation or oxygen uptake between the two limbs [10,11]. With regards to maximal oxygen uptake, Larson and colleagues reported individuals with multiple sclerosis had limb specific asymmetries in both muscular strength and peak oxygen uptake[5]; however, there is no research published on maximum oxygen consumption limb asymmetries in healthy individuals.

Therefore, the purpose of this investigation was two-fold – (1) evaluate differences between DL and NDL for muscular strength and aerobic capacity, (2) determine if lower limb muscular strength peak torque asymmetries were associated with lower limb aerobic capacity asymmetries (VO_2 peak, VO_2 at ventilatory threshold (VT), or time to fatigue) during single limb cycling. The central hypothesis was limb specific asymmetries will be observed for both muscular strength and aerobic capacity measures and will have significant positive relationships with one another. Specifically, the limb that produced greater force will be more aerobically fit potentially due to composition of muscle fibers.

Methods

Participants

Kent State University Institutional Research Board approved all procedures and all participants were informed of all risks of the research and signed the consent form prior to participation. 15 young, healthy adults (9F/6M, 23±3 years of age, 72.1±14.4 kg, 1.7±0.1 m) were recruited for this study. Inclusion criteria included individuals 18-39 years of age who were physically active at least three days per week, involved in recreational to competitive athletics, and free of lower limb injuries for a minimum of three months. In addition, all participants had low cardiovascular risk based on the American College of Sports Medicine guidelines [14]. Twenty-four hours before a visit, participants were instructed to refrain from strenuous exercise, consume their normal diet, and abstain from alcohol and caffeine. Four hours prior, participants were asked to refrain from food or beverage other than water to ensure more stable substrate utilization for single-leg aerobic capacity testing. These criteria were orally confirmed at the start of each visit.

Protocol

This cross-sectional experiment design involved two visits with 2-7 days separating each visit. During each visit a maximal knee extension muscular strength test and a maximal single leg aerobic capacity test were administered to determine lower limb specific muscular strength and limb VO_2 peak, VO_2 at VT, and time to fatigue. To avoid fatigue across the two protocols, maximal strength was assessed on one leg while aerobic capacity was assessed on the contralateral limb on visit one. On the second visit the participants performed the assessments with the opposite legs.

The participants warmed up on the Monark ergometer (Vansbro, Sweden) at a self-selected pace using standard pedals for 10 minutes. Next, lower limb muscular strength was assessed using a Multi Joint System 3 Dynamometer (Biodex Medical Systems, Shirley, New York, USA). Participants were positioned per manufacturer's recommendations to perform maximal isokinetic knee flexion and extension protocol. Following a familiarization trial at each velocity, participants were instructed to perform five maximal isokinetic knee extensor and flexion movements each at 60º, 180º, and 300º per second (deg/s). Between each set, participants had a three minute recovery period. Peak torque was the highest muscular force output at any moment during a repetition. The limb that produced the greatest mean knee extension peak torque across the three velocities was deemed the DL. The opposing limb was the NDL.

The single-leg cycling test was performed on a modified Monark ergometer (Vansbro, Sweden) with SRM Powermeter (SRM International, Germany). Participants were fitted with clipped in cycling shoes from Trek Bontrager (Waterloo, Wisconsin, USA). Shimano SPD mounted cleats and pedals (Sakai, Japan) were utilized to help prevent the subjects from slipping off the pedals. Similar to previous investigations [15], the single cycling test utilized a 9 kg counterweight attached to the unoccupied crank arm. The counterweight simulated the weight of the opposing limb resulting in a smoother pedal stroke technique similar to double limb cycling [16]. A safety foot platform device was utilized allowing the participants to rest their non-active limb on the platform next to the cycle (Image S1). The protocol began at 30 watts for minute one and increased 8 watts per minute for females, and 10 watts per minute for males. The difference in watts per stage based on sex accounted for differences in muscular strength [4,17] thereby allowing the ramp protocol to last 10-14 minutes regardless of sex.

Throughout the test participants were instructed to maintain the desired cadence 80±5 revolutions per minute (RPM). Participants were encouraged to continue cycling until they reached volitional fatigue. Expired air was analyzed and averaged every 20 seconds with a Parvo Medics metabolic cart (Sandy, Utah, USA) to determine VO_2, VCO_2 and VE while a Polarlink® HR monitor (Kaohsiung City, Taiwan) was used to monitor heart rate which was also recorded in 20 second intervals. The maximum watts cycled and time to fatigue were recorded at the end of the cycling test. Tests were terminated following ACSM clinical exercise testing guidelines [14], or when the subject could no longer maintain a pedaling rate above 70 RPM.

The parameters assessed for aerobic capacity test were VO_2 peak, VT and time to fatigue. VO_2 peak was determined as the maximum VO_2 (20 second interval mean) achieved during the test. VT was determined through two separate methods [18-20]. Specifically, the V-slope method calculated VT at the point of deflection of VCO_2 compared to VO_2 [18]. The second method, ventilatory equivalents, calculated as the point at which VE/VO_2 reached its lowest point and started to rise without a concomitant rise in VE/VCO_2 [18-20]. Two independent exercise physiologists determined VT for both methods and then calculated the mean VT. Finally, time to fatigue was the duration in which the participant cycled to volitional fatigue. Aerobic outcomes were matched to the DL and NDL associated strength measures. Mean peak torque was calculated by averaging peak torque for 60º, 180º, and 300º per second (deg/s).

Statistical Analysis

All statistical analyses were performed using statistical analysis software (SPSS, Version 23.0, Chicago, IL). The level of significance was set a priori at $P \leq 0.05$. Paired Samples T-tests were used to determine if differences or asymmetries were present between DL and NDL greatest mean peak torque, VO_2 peak, VO_2 at VT, and time to fatigue. LSI was used to calculate the index between the DL and NDL. LSI=[(1-(NDL)/(DL))*100]. Pearson R correlations were performed to evaluate the LSI relationships between mean peak torque and VO_2 peak, VO_2 at VT, and time to fatigue. All data met normality and equal assumptions and are reported as mean ± SD.

Results

Five participants were removed from analysis because they had a difficult time coordinating the tasks, and therefore their data were not reliable. There was a statistically significant difference in limb-specific mean peak torque. Specifically, mean peak torque of the DL was 7.5 Nm higher than NDL (9.1±8.7% difference). However, there were no statistical differences in limb specific aerobic capacity outcomes including VO_2 peak, VO_2 at VT, or time to fatigue (Table 1). In addition, there were no statistically significant relationships between mean peak torque LSI and VO_2 peak LSI (R=0.374, P=0.169), VO_2 at VT LSI (R=0.062, P=0.827) or time to fatigue LSI (R=-0.172, P=0.541) in Figure 1A, B, C.

Table 1. Muscular strength and aerobic limb dominance measures comparison

Variable	DL	NDL	P-value
Mean peak torque, Nm	89.5 ± 34.8	82.0 ± 30.8	P= 0.002
VO_2 at VT, ml/kg/min	17.4 ± 4.6	16.5 ± 3.8	P= 0.296
VO_2 peak, ml/kg/min	34.0 ± 5.1	34.4 ± 8.1	P= 0.679
Time to fatigue, minutes: seconds	11:19 ± 4:11	11:56 ± 2:8	P= 0.468
Maximal heart rate, bpm	170 ± 12	166 ± 16	P= 0.414

Mean peak torque included 60, 180, 300 deg/s. VT was calculated as mean of V-slope and ventilatory equivalents methods. Values indicate mean ± SD.

Figure 1

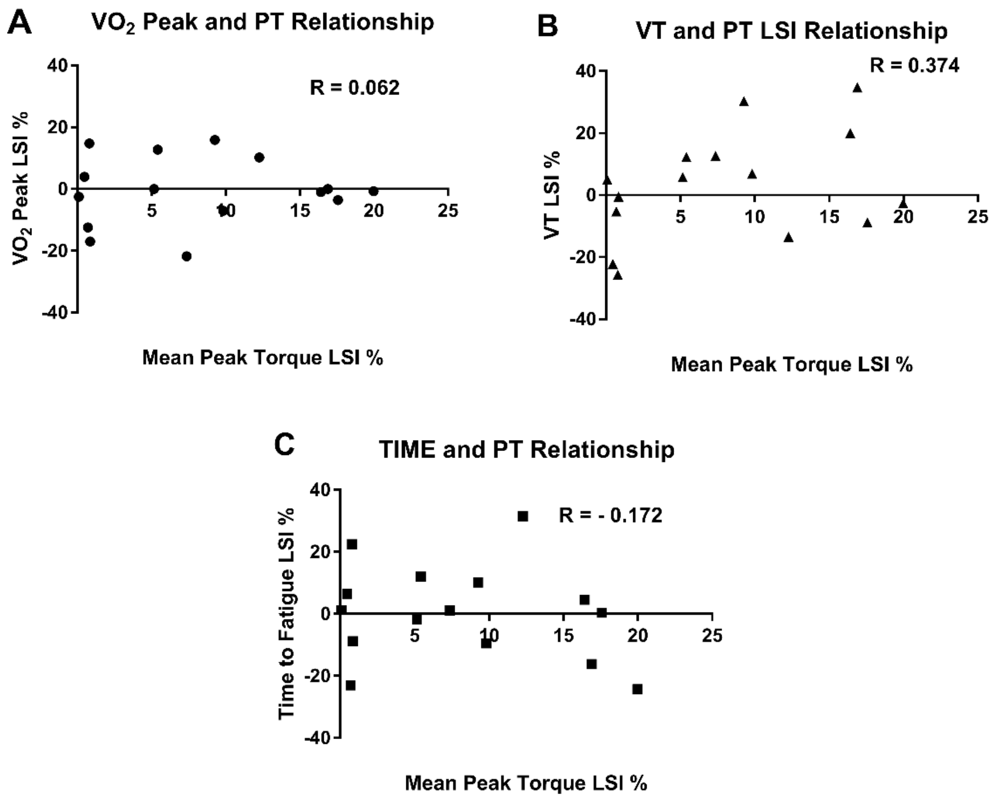

Figure 1A, B, C. Pearson R correlations compared dominant and non-dominant limb asymmetry relationships between aerobic capacity variables: VO2 peak (A), VO2 at VT (B), time to fatigue (C) to mean knee extensor peak torque.

Discussion

Although the concept of lower limb muscular strength asymmetries is well-known there is no information on limb specific aerobic capacity asymmetries. The purpose was to investigate the differences between DL and NDL for muscular strength and aerobic capacity and determine if lower limb muscular strength peak torque asymmetries were associated with lower limb aerobic capacity asymmetries. To our knowledge, this is the first investigation that compares lower limb strength and aerobic capacity asymmetries. These data indicate that mean peak torque lower limb DL and NDL asymmetries existed in this young healthy adult population, however aerobic capacity asymmetries were absent. In addition, muscular strength and aerobic capacity relationships were not significantly associated to one another.

Lower limb aerobic capacity asymmetries were evaluated by VO_2 peak, VO_2 at VT, and time to fatigue during a maximal single-leg cycling test. These results indicated no significant differences between DL and NDL for these aerobic outcomes. Whether lower limb aerobic asymmetries existed was unknown, although some researchers have investigated muscular strength and cycling outcome relationships. In fact, there is a reduced magnitude in asymmetry relationship between seated sprint cycling and knee extensor muscular strength [21]. However, lower asymmetries at the knee and hip during cycling were potentially due to lower overall joint torques associated with faster joint velocities during sprint cycling compared to isolated knee extension exercise [22]. This is supported by previous findings that indicate higher cycling cadences reduce asymmetries [10]. In contrast, Smak et al., found that cycling at relatively higher cadence may increase asymmetries potentially due to increased coordination required at the higher cadences [23]. Furthermore, coordinating patterns of the ankle may increase asymmetries between limbs [21]. Although lower limb aerobic asymmetries did not exist in young healthy adults, they may exist in other populations including those with previous orthopedic injuries.

The null hypothesis was accepted as limb specific asymmetries were observed for muscular strength, but not aerobic capacity measures. Overall, there were weak non-significant positive relationships between peak torque LSI and LSI for VO_2 peak, VO_2 at VT and fatigue. We hypothesized a positive relationship between muscular strength and aerobic capacity simply due to greater overall daily dependence on the dominant limb and previous reports that indicate the dominant limb has more type I slow twitch muscle fibers in resistance trained males [24].

Despite the fact that there were no aerobic asymmetries in this healthy population, lower limb aerobic capacity asymmetries may be more prevalent in certain athletes, individuals who have suffered musculo-skeletal injuries as well as at risk groups such as older adults with functional limitations and individuals with neurodegenerative disease. Thus, future research should investigate the presence of muscle aerobic capacity asymmetry in athletes predisposed to a large limb asymmetry such as soccer players and hurdlers. This additional asymmetry test should also be utilized when determining baseline and 'return to play' guidelines for those who have suffered lower limb injuries as it would help identify limb specific fitness loss and recovery. Finally, knowing the presence of aerobic capacity asymmetries in the lower limbs may help guide physical therapy programs for older adults and those with neurodegenerative diseases.

Media-Friendly Summary

Although there were significant asymmetries in mean peak torque in the lower limbs, these differences were not related to lower limb aerobic capacity asymmetries. This investigation addresses lower limb muscular strength and aerobic capacity relationships in healthy, young adults.

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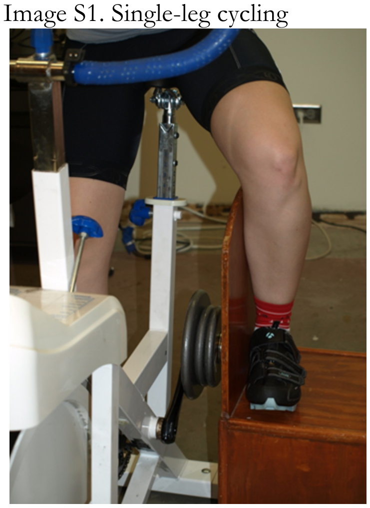
Author Disclosure Statement

The authors declare no conflict of interest.

Supplementary Materials

Image S1. Single-leg cycling



The safety foot platform device displayed allowed participants to place their non-exercising lower limb on the platform next to the stationary ergometer. Thus, the platform also acted as a shield protecting the participant from the rotating counterweight.

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