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Lower Leg Anatomical Correlates to Performance and Metabolism from Flywheel-based Exercise

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ABSTRACT

Lower leg exercises are impacted by the anatomy of the triceps surae-Achilles tendon complex. Such exercises may utilize series elastic energy (SEE), temporarily stored within the Achilles tendon, to augment forces exerted by the triceps surae. While SEE's contribution to bipedal jumping and walking have been assessed, other lower leg exercises yet to receive similar scrutiny include seated calf presses done on flywheel-based hardware. Current subjects did two identical calf press workouts on a flywheel ergometer. The following three variables were obtained from workouts─the total work (TW) performed, net energy costs, and peak blood lactate concentration ([BLa$^-$]). With multivariate regression, four variables correlated with each criterion measures' variance─lower leg length (LLL) and cross-sectional area (CSA), as well as the lengths of the triceps surae (ML) and Achilles tendon (ATL). Our predictor variables correlated to significant amounts of TW and net energy cost, but not [BLa$^-$] variance. Univariate matrices showed CSA was the best overall predictor for our criterion measures, while ML and ATL were generally weaker correlates. ATL did not have as great an impact as with other lower leg exercises; likely because the slow rate of ankle joint movement greatly limited SEE activity. The limited degree of foot support for ergometer repetitions was also a factor that likely weakened ATL's impact as a correlate. More research on anatomy's impact on this novel form of exercise is warranted.

Key words: Achilles Tendon Length; Series Elastic Element; Flywheel Ergometer; Triceps Surae; Potentiation

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INTRODUCTION

Flywheel-based exercise hardware are used on manned spaceflights to reduce muscle size and strength losses. NASA also has several versions of flywheel-based hardware now in development (International Countermeasures Working Group, 2010). Currently aboard the International Space Station (ISS) are two resistive exercise devices equipped with flywheels. They include the Advanced Resistive Exercise Device (ARED) which uses flywheels to simulate the sensation of lifting weights in 1-*g*. The ARED abated muscle atrophy and strength losses (Bentley et al., 2006; Loehr et al., 2011). The other is the flywheel exercise device (FWED) sent by The European Space Agency and housed within the ISS

Columbus Module (International Countermeasures Working Group, 2010). The FWED is the in-flight version of a prototype ergometer from which much ground-based data were obtained (Caruso et al., 2015; Caruso et al., 2005; Caruso and Hernandez, 2002; Caruso et al., 2003). Figure 1 shows the FWED aboard the ISS.

Since research noted the prototype ergometer abated mass and strength losses in ground-based human unloading models with only modest increases in net energy costs, their use warrants continued inquiry (Caruso et al., 2005; Caruso and Hernandez, 2002; Caruso et al., 2003). Exercises done on both the FWED and prototype ergometer include the seated calf press (ankle extension), which targets the triceps surae muscle group. This is an important exercise, as the triceps surae incurs among the greatest unloading-induced mass and strength losses of the human body, presumably from a lack of load-bearing activity (Caruso et al., 2005; Reeves et al., 2005). Maintaining triceps surae mass and function with the calf press during spaceflight is a NASA task objective (Human Research Roadmap, 2017).

Figure 1. The flywheel exercise device (FWED) in use onboard the International Space Station.

Prototype ergometer calf presses are impacted by numerous factors that foretell exercise performance. The triceps surae-Achilles tendon complex may utilize the series elastic element (SEE) for various exercises. Temporarily stored in the Achilles tendon as it rapidly lengthens, the SEE augments force output. The SEE dissipates rapidly, and thus must be used quickly if it is to aid performance and reduce the metabolic cost of exercise (Caruso et al., 2003; Hunter et al., 2011; Hunter et al., 2015; Sugisaki et al., 2011). For instance during exercise with high-speed ankle movement, the SEE created by the lengthened Achilles reduced metabolic costs by up to 50% (Alexander, 1984). The level of SEE activity, and subsequent reductions in metabolism, relate to triceps surae-Achilles tendon anatomy (Hunter et al., 2015; Kongsgaard et al., 2011).

Prior to strain and stiffness measurements, anthropometric measurements helped predict performance for exercise that involved the Achilles tendon (Del Prado-Lu, 2007; Hunter et al., 2011; Hunter et al., 2015; Reeves et al., 2005). FWED and prototype ergometer workouts may each be impacted by lower leg anatomy, as persons with longer tendons may rely on more SEE involvement to enhance performance and limit energy costs for the calf press exercise (Hunter et al., 2011; Hunter et al., 2015). The prototype ergometer's (YoYo Inertial Technologies, Stockholm, Sweden) flywheels (radii 23 cm) provide a large inertial load that requires users to exert large forces and offers a stimulus that abates triceps surae mass and strength losses for the calf press exercise. As exertion of the triceps surae's concentric forces exceed the inertial load, the flywheels rotate at rates commensurate to the forces exerted. Upon completion of the concentric phase, the direction of flywheel rotation reverses as subjects' feet remain against the footplate; this lengthens the Achilles tendon and increases the SEE. Higher concentric forces may heighten subsequent SEE activity. Thus, in addition to lower leg anatomy, SEE activity relates to the work done on the ergometer during the concentric phase that in turn impacts the degree of Achilles tendon lengthening for the subsequent eccentric phase (Caruso et al., 2005; Cavagna et al., 1968).

It is thus important to ask what impacts calf presses done on flywheel-based hardware more—Achilles tendon length, or other anatomical variables? Since it is the FWED prototype, responses to ground-based ergometer workouts may impact deployment of in-flight countermeasures by foretelling (1) the impact Achilles tendon length has on the calf press exercise and metabolism done on flywheel-based hardware, and (2) crewmember selection based on lower leg anatomy. Each is important, as in-flight exercise must impart intense mechanical loads while it limits energy costs (Matsuo et al., 2012). Our study assesses Achilles tendon length and other lower leg anatomical variables, as correlates to performance and metabolism from calf presses done on the prototype ergometer. We hypothesize Achilles tendon length as a sole predictor, and also when combined with three other lower leg anatomical indices, will correlate significantly to (1) the total volume of work, (2) net energy costs, and (3) peak blood lactate concentrations derived from workouts.

MATERIALS AND METHODS

Subjects

Our protocol was approved in advance by The University of Tulsa's Institutional Review Board. Subjects (16 men, 14 women) provided written informed consent before they participated. They came to our laboratory three times. Per subject, visits were spaced 7-14 d apart and all three were completed within a 22 d time-frame. First visits entailed a series of anatomical measurements and familiarization to our procedures. The last two visits required subjects to perform identical seated calf press workouts on the prototype ergometer. Data from each visit was used to test our study's hypotheses. In addition, data collected at the final two visits were used to assess the reliability of our measurements.

First Visits

To begin data collection, subject heights, body masses, and body fat percentages were recorded as they stood barefoot in an upright posture. Heights were measured with a stadiometer (Detecto, Webb City, MO, USA). Body mass and body fat percentage were recorded with a calibrated bioimpedance scale (Model BF-350, Tanita, Tokyo, Japan). Subjects then submitted to lower leg anatomical measurements. Most of the biometric data were recorded with a cloth tape in accordance to established methods (Del Prado-Lu, 2007; International Standards for Anthropometric Assessment, 2001). To prevent inter-rater variability, only one researcher (J. L. Martin), who had prior experience measuring anthropometric data in the principal investigator's laboratory, collected that data. Anatomical values were recorded in triplicate.

Left lower leg length equaled the distance from the mid-popliteal fossa to the floor. Along the mid-sagittal line of their lower left leg's posterior surface, the triceps surae and Achilles tendon lengths were measured. To begin those measurements, left lower leg was palpated to ascertain triceps surae and Achilles tendon lengths. Muscle length equaled the distance between the mid-popliteal fossa and inferior border of the superficial (medial gastrocnemius) triceps surae, even if the muscle's shape and contours ultimately led it to deviate from the mid-sagittal line. Achilles tendon length equaled the distance from the medial gastrocnemius' inferior border to its insertion point on the calcaneus. Our coefficient of variation (CV) data showed lower leg, muscle, and tendon lengths measured in triplicate each varied < 1% (Caruso et al., 2005). Thus they were averaged and used for analysis.

Next, subjects had their cross-sectional area (CSA) estimated at the left lower leg location with the largest visible girth. Our CSA estimates are valid assessments of muscle mass changes over time (Caruso et al., 2005; Moritani and De Vries, 1980). The same researcher who measured lower leg, muscle, and tendon lengths also obtained CSA data. Circumference and skinfold data were collected with a cloth tape measure and skinfold calipers, respectively. To calculate CSA, four skinfolds were taken 90^o apart at the circumference site, averaged, and subtracted from the lower limb's radius to correct for subcutaneous fat. The corrected values were used to estimate CSA with the following formula: $(r^2 - r^1)^2\ \pi$, whereby r^2 and r^1 equaled circumference and skinfold thickness values, respectively. Like the lower leg length data, intraclass correlation coefficients showed our CSA estimates varied < 1% (Caruso et al., 2005). Subjects then pedaled a stationary bicycle (Ergotest; Stockholm, Sweden) at 75-90 W for five minutes, followed by calf presses (repetitive ankle extension/flexion as knees remained extended; concentric forces were exerted as the ankle extended) done at a submaximal level of effort on the ergometer. The first visits lasted 20-25 min.

Second and Third Visits

To limit data variability per subject, their second and third laboratory visits occurred at the same time of day and were preceeded by consumption of the same meal.. To begin the second and third visits, the subject's body masses were recorded, and the subjects were then requested to sit for five minutes. Next blood lactate concentration ($[BLa^-]$) was measured with a calibrated analyzer (Accutrend, Hawthorne, NY, USA). With a spring-loaded lancet, blood (~15 μL) was sampled from the index finger of subjects' right hands. Once a pre-exercise $[BLa^-]$ was obtained, they did a warm-up identical to the one at their first visit to limit their risk of injury.

Subjects then sat on the ergometer as their O_2 uptakes were measured by a metabolic cart (CPX MedGraphics, St. Paul, MN, USA) that provided breath-by-breath gas values. After 10 min, during which their O_2 uptake rates stabilized, they did a 4-set, 15-repetitions/set protocol with 2 min rests between sets. Verbal encouragement was provided. Oxygen was measured during workouts and, until uptake rates returned to pre-exercise levels, after the protocol ended. Due to the way the ergometer operates, kinetic energy generated by concentric forces imparts substantial resistance that the triceps surae lengthens against. This evoked a large degree of eccentric work and potentiated SEE activity. Yet ankle movement occurred at slower rates than for other lower leg activities (walking, jumping, etc.). Only the most distal portion of the foot's plantar surface was supported, and only then by a movable footplate that displaced commensurate to the concentric work exerted per repetition. The ergometer was interfaced with software (National Instruments, Austin, TX, USA) to quantify flywheel rotation rates at 10 Hz. Such a sampling frequency is appropriate based on the slow rates that current study repetitions occurred (Caruso et al., 2005; Caruso et al., 2002; Caruso et al., 2003). The total work (TW), a measure of the exercise bout's rigor previously used to assess performance, was summed for each current study set (Caruso et al., 2005; Caruso et al., 2002; Caruso et al., 2003). Figure 2 depicts data collection during workouts.

One minute after set two ended, a mid-exercise $[BLa^-]$ value was obtained. After subject O_2 uptake rates returned to baseline values, they were disconnected from the metabolic cart. Post-exercise $[BLa^-]$ data were obtained at 0, 5, and 15 min after set four concluded. On a per minute basis, net energy costs were calculated as the difference among average exercise and baseline O_2 uptakes derived from non-steady state activity. Net energy costs, in liters of O_2 consumed, were summed for each minute O_2 uptake rates were above baseline values, and multiplied by five for a non-steady state estimate of kilocalorie expenditure (Caruso et al., 2002; Caruso et al., 2003; Dudley et al., 1991). The second and third visits lasted 45 min.

Figure 2. Configuration of the prototype flywheel ergometer and metabolic cart as current study seated calf press repetitions were performed.

Statistics

Dependent variables from the second and third visits (i.e., the absolute values) were compared for reliability with CV analyses. If a given CV value was less than those typical for biological systems, they were averaged and used for analysis (Stokes, 1985). Next our data were examined for compliance to ANOVA assumptions (normality, independence, equal variances). To test our hypothesis we employed multivariate regression. Based on large effect sizes for resistive exercise, as well as α and ß values of 0.05 and 0.80, respectively, our sample (n = 30) allows examination of up to four predictor variables per criterion measure (Soper, 2017; Kraemer et al., 1991). For our multivariate analyses, data from male and female subjects were pooled, as prior research noted muscle strength was a far better predictor of Achilles tendon properties than gender (Morrison et al., 2015; Muraoka et al., 2005). Furthermore, intra-gender analyses would not permit usage of as many independent variables as were examined in the current study (Soper, 2017). We performed three separate multivariate regression analyses with each of the following criterion variables─TW, net energy costs, and peak [BLa$^-$]. The following variables attempted to predict the variance per criterion─lower leg length (LLL), triceps surae muscle length (ML), Achilles tendon length (ATL), and lower leg cross-sectional area (CSA). A $P \leq 0.05$ denoted significance per multivariate analysis.

RESULTS

No subjects were injured from their participation and they completed all laboratory visits. CV data (range 1-12%) exhibited acceptable levels of reproducibility and less than those typical to biological systems (Stokes, 1985). Thus, values from second and third visits were averaged and used for subsequent analyses. Data met all ANOVA assumptions. Table 1 displays the descriptive statistics for our criterion and predictor variables, as well as height and body mass values. Table 1 values are presented as male, female, and total subject values.

Per multivariate regression analysis, the same four lower leg anatomical correlates attempted to account for our criterion measure's variance. Colinearity values for those four lower leg anatomical correlates appear in Table 2. Multivariate regression results, with TW as the criterion, appear in Table 3. Collectively, the four lower leg anatomical correlates predicted a significant (r = 0.66) amount of TW variance. The Table 3 univariate matrix shows the best single predictor of TW variance was CSA (r = 0.50); conversely, ML and ATL correlated with small (r = 0.15-0.16) amounts of the criterion measure's variance.

Table 1. Descriptive statistics for current study criteria and predictor variables, as well as height and body mass values. Data are presented by gender and total (n = 30) subject values.

Variable (units)	Male subjects		Female subjects		Total subjects	
	$\bar{x} \pm$ sem	range	$\bar{x} \pm$ sem	range	$\bar{x} \pm$ sem	range
TW (joules · 10^3)	19.4±1.1	11.2-29.3	14.4±1.5	8.9-25.6	17.0±1.0	8.9-29.3
net energy cost (kcals)	26.7±1.5	15.4-36.7	17.6±1.5	8.6-28.6	22.4±1.3	8.6-36.7
[BLa$^-$] (mmol · L^{-1})	5.5±0.4	3.0-8.5	4.7±0.4	2.8-8.1	5.1±0.3	2.8-8.5
LLL (cm)	51.0±0.6	45-56	46.0±0.6	43-50	48.6±0.7	43-56
ML (cm)	22.0±0.4	20-25	22.0±0.6	18-26	22.0±0.4	18-26
ATL (cm)	29.0±0.7	25-34	24.0±0.9	19-29	26.6±0.7	19-34
CSA (cm^2)	94.0± 3.8	75-130	71.0±3.4	48-93	83.1±3.3	48-130
Height (cm)	179.0± 2.0	168-187	169.0± 2.0	160-182	174.0± 2.0	160-187
Body mass (kg)	79.9± 4.1	71-111	65.4± 2.5	48-92	72.01± 2.6	48-111

TW: total work
[BLa$^-$]: peak blood lactate concentration
LLL: lower leg length
ML: muscle length
ATL: Achilles tendon length
CSA: lower leg cross-sectional area

Table 2. The degree of colinearity among the current study predictor variables.

	LLL	ML	ATL	CSA
LLL	1			
ML	0.26	1		
ATL	0.87	-0.25	1	
CSA	0.69	-0.06	0.72	1

LLL: lower leg length
ML: muscle length
ATL: Achilles tendon length
CSA: lower leg cross-sectional area

Table 3. Univariate matrix, r, r^2, and prediction equation values for our multivariate regression analysis with total work (TW) as our criterion variable.

	LLL	ML	ATL	CSA	TW
TW	0.22	0.15	0.16	0.50	1

r = 0.66 ($P < 0.05$); $r^2 = 0.43$
TW′ = 1864.9 - 4.5(LLL) + 2.4(ML) + 4.1(ATL) + 0.8(CSA)
LLL: lower leg length
ML: muscle length
ATL: Achilles tendon length
CSA: lower leg cross-sectional area

Table 4 shows our multivariate regression results for net energy cost as the criterion. Our predictor variables correlated with significant (r = 0.75) amounts of net energy cost variance. The Table 4 univariate matrix shows LLL, ATL, and CSA each individually correlated with considerable (r = 0.57-0.67) amounts of net energy cost variance. Yet ML correlated to less (r = 0.20) of the criterion's variance. Peak [BLa^-] multivariate regression results appear in Table 5. Collectively, the predictor variables correlated with non-significant (r = 0.49,P = 0.12) amounts of [BLa^-] variance. Univariate Table 5 shows LLL, ATL, and CSA individually correlated with moderate (r = 0.30-0.39) amounts of peak [BLa^-] variance. Yet ML was a weak univariate predictor (r = 0.17) of peak [BLa^-] variance. Tables 3-5 show univariate matrices, r, r^2, and prediction equation values. No prediction equation appears in Table 5 since the multivariate analysis of peak [BLa^-] did not reach statistical significance.

DISCUSSION

Lower leg exercises attempt to abate triceps surae mass and strength losses during actual and simulated spaceflight (Akima et al., 2003; Reeves et al., 2005; Trappe et al., 2009). Six months aboard the ISS, with exercise that imparted less triceps surae mechanical loading than flywheel-based hardware, evoked significant muscle atrophy (Trappe et al., 2009). It was concluded more intense mechanical loads were needed, such as that provided by flywheel-based hardware (Trappe et al., 2009). During a 90-day bed rest study, subjects either performed concurrent calf presses on flywheel-based hardware every third day, or served as untrained controls (Reeves et al., 2005). Compared to pre-unloading values, there was significant mitigation of losses (~37-38%) to the exercise group than bed rested (~57-58%) controls (Reeves et al., 2005). It was implied that the intervention may have had more benefit with a greater number of workouts, since lower leg

Table 4. Univariate matrix, r, r^2, and prediction equation values for our multivariate regression analysis with net energy cost as our criterion variable.

	LLL	ML	ATL	CSA	net energy cost
net energy cost	0.67	0.20	0.57	0.67	1

net energy cost´ = -32.1 + 1.9(LLL) - 0.7(ML) - 1.6(ATL) + 0.5(CSA)
$r = 0.75$ ($P < 0.05$); $r^2 = 0.56$
LLL: lower leg length
ML: muscle length
ATL: Achilles tendon length
CSA: lower leg cross-sectional area

Table 5. Univariate matrix, r and r^2 values for our multivariate regression analysis with peak blood lactate concentration ([BLa⁻]) as our criterion variable.

	LLL	ML	ATL	CSA	[BLa⁻]
[BLa⁻]	0.38	0.17	0.30	0.39	1

$r = 0.49$ ($P = 0.12$); $r^2 = 0.24$
LLL: lower leg length
ML: muscle length
ATL: Achilles tendon length
CSA: lower leg cross-sectional area

muscles routinely engage in high-frequency load-bearing activity (Reeves et al., 2005). In support of this suggestion, triceps surae mass and strength were preserved over a 20-day bed rest in which subjects concurrently performed 16 resistive exercise workouts (Akima et al., 2003; Reeves et al., 2005). Our four lower leg anatomical correlates predicted significant amounts of TW and net energy cost but not peak [BLa⁻] variance. Thus, our hypothesis whereby the lower leg anatomical indices would correlate with significant amounts of variance from the calf press performance and metabolic data, was affirmed by two of three multivariate analyses. Yet we also hypothesized ATL as a sole predictor would correlate to significant amounts of variance for each variable. We cannot affirm the hypothesis that ATL as a sole predictor would correlate with significant amounts of performance and metabolic data variance, as Tables 3-5 univariate matrices show CSA was the best overall predictor of the variance seen in our three criterion measures, while ATL generally had weaker correlations. Our data show that the variable with the most direct impact on force output (CSA) correlated to more of the variance seen in our three criterion measures than those (ML and ATL) related to SEE. It is important to discuss (1) why ATL had less impact than in prior studies and (2) the influence of CSA on our results.

ATL had less impact on our three criterion measures than were observed previously (Hunter et al., 2011; Hunter et al., 2015). Reasons may include differences in the exercise modes examined, as well as the speed of ankle-joint lengthening, and SEE potentiation. Flywheel ergometer repetitions, unlike exercises assessed previously (e.g., walking, jumping), entail slower rates of Achilles tendon lengthening. SEE potentiation enhances performance when ankle joint movement rates and musculotendinous lengthening increase (Cavagna et al., 1968). On the ergometer, the degree of musculotendinous lengthening relates directly to the concentric work done by the triceps surae as it shortens during the prior phase of each repetition. It appears slow rates of movement during the current study ergometer repetitions offset the large degree of Achilles tendon lengthening and SEE potentiation, to cause ATL to be a weak correlate.

Yet disparities in exercise modes may have also contributed to inter-study differences. Walking entails that the entire plantar surface comes in contact with, and lower leg forces applied against, a stable surface (Hunter et al., 2011; Hunter et al., 2015). In contrast only the most distal portion of the plantar surface is supported for ergometer repetitions, and only then by a footplate that is displaced by the concentric work exerted per repetition. When triceps surae lengthening forces are exerted rapidly against a stable surface, a longer ATL enhances SEE potentiation and exercise economy (Hunter et al., 2011; Hunter et al., 2015; Malvankar and Khan, 2011). ATL was examined for its impact on walking economy on flat and inclined surfaces, as well as isometric plantar flexion, in African American and European American women (Hunter et al., 2011). There were significant inter-racial differences for flat surface walking. Differences were attributed to ATL, which was inversely related to net O_2 uptake (Hunter et al., 2011). African American women had significantly longer ATL than their European American counterparts. Yet inter-racial O_2 uptake differences were reduced when ATL was taken into account (Hunter et al., 2011).

Differences between flat and inclined surface walking were attributed to disparities in SSE activity (Hunter et al., 2011). Versus flat surface walking, inclined surfaces limit eccentric activity at the ankle joint and reduce SEE potentiation (Hunter et al., 2015). Our results are not unlike those for inclined walking (Hunter et al., 2011), as current ATL data were, at best, moderately correlated to criterion measures. As the ankle extends against a stable surface (e.g., jumping, walking), a brief amortization phase occurs whereby forces and SEE potentiation are applied isometrically to overcome inertia provided by a person's body mass (Davis et al., 2003; Earp et al., 2011; Fouré et al., 2011; Morrison et al., 2015). When the foot's plantar border is supported by stable surfaces, the Achilles tendon is well positioned to exert isometric force (Hunter et al., 2011; Hunter et al., 2015; Muraoka et al., 2005; Sugisaki et al., 2011). This was difficult to affirm, as ATL impact on performance was more often assessed for activites in which the plantar surface was supported rather than unsupported (Davis et al., 2003; Earp et al., 2011; Fouré et al., 2011; Morrison et al., 2015). Since limited data exists on ATL impact for exercise in which the plantar surface is largely unsupported, this concept must be considered speculative until it can be affirmed.

Like our studies, prior research observed significant correlations between lower leg CSA and exercise outcomes, as muscle mass is a good performance predictor. They include studies that estimated CSA the same way as our investigation and noted calf CSA (r = 0.78), and type II fiber calf CSA (r = 0.63) were significantly correlated to strength (Regensteiner et al., 1993). In addition a significant correlation (r = 0.41) was noted between calf muscle strength and peak walking times (Regensteiner et al., 1993). To identify correlates to lower leg exercise, 169 women (Runge et al., 2004) and 23 men (Davis et al., 2003) had their calf CSA assessed for its impact on jump performance. Results included significant correlations between calf CSA and peak jumping power for both studies (Davis et al., 2003; Regensteiner et al., 1993). A significant correlation was noted for calf girth and vertical jump height in (Zhang, 2010). Also in support of our outcomes, Zhang (2010) reported the ATL had univariate correlations to exercise outcomes (r = 0.15-0.18) similar to the ATL-TW univariate correlation for our study. Finally, data from a training study, which used the same ergometer as our investigation, saw a positive trend between lower leg CSA and performance (Caruso et al., 2005).

Our exercise device is a prototype of the FWED used onboard the ISS. It was theorized that our results might predict (1) the energy costs for triceps surae exercise done on flywheel-based devices and (2) astronaut selection criteria based on lower leg anatomy. While other research noted differences in ATL impacted walking performance and its metabolic indices (Hunter et al., 2011), current results show CSA, but not ATL measured at rest, was the best correlate to our criterion measures. Due to the differences the impact ATL had on current and prior (Hunter et al., 2011) studies, it is premature to make inferences about metabolic responses to in-flight triceps surae exercise done on flywheel-based hardware or astronaut selection criteria. To answer such questions, more research on the impact lower leg anatomical correlates have on exercise done on this novel form of hardware is warranted.

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