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EFFECT OF FATIGUE ON MASS EXPONENTS AND POWER IN ALL-OUT INTENSITY REPEATED SPRINTS ON A NON-MOTORIZED TREADMILL IN SEDENTARY ADULTS

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Repeated sprint exertions are common in team sports and more sedentary adults are pursuing team sports on a recreational basis. The values of the mass exponents in allometric scaling of functional exercise capacities are fundamental to the accurate interpretation of changes in physiologic parameters during exercise, with exercise training. Apparently, the effect of fatigue on allometrically-derived mass exponents in relation to power output generated during all-out intensity repeated sprints in sedentary adults is not understood. The aim of the study was to establish if acute exercise fatigue caused by repeated sprint efforts affected the value of the derived b or mass exponent in allometric scaling of power in sedentary adult subjects. Twenty male and female sedentary adult subjects performed four 10-s all-out intensity sprints on a non-motorized treadmill (NMT), on three separate sessions with the rest intervals between each sprint at 60-s, 90-s or 120-s, respectively. A dual energy X-ray absorptiometric (DXA)-determined lower limb muscle mass (LLMM) was the best body size descriptor for 1-s peak power (PP), derived from the NMT. Results showed that the b exponents in relation to PP were altered (range 0.87-1.58) in repeated sprints that were separated by different rest intervals. It was necessary to establish beyond sample-specific mass exponents, a trial-specific mass exponents in the allometric scaling of all-out intensity repeated sprints in sedentary adult subjects, for appropriate comparisons in NMT-derived PP that was size-independent and dimensionless.

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Introduction

More sedentary adult subjects are participating in team sports as recreation. Repeated sprint exertions are a common characteristic of team sports such as soccer, basketball, rugby, hockey and netball. In Singapore, these team sports are gaining in popularity among young adults (SSC Survey, 2006). Less is known about the repeated sprint performance of sedentary adults compared to athletes. Research attention on the repeated sprint performance of sedentary adults will buttress the existing data pool, which is relatively scarce in the literature and will also lead to a better understanding between trained and sedentary cohorts. Comparisons in exercise performance, which is influenced by body size across different subject cohorts, are facilitated when differences in body size are taken into account by appropriate statistical treatments of the data sets.

There is growing concern amongst investigators that ratio-scaling, either over- or under-corrects for physiologic measurements and also power measurements. This concern is valid as the extant literature has shown that ratio-scaling did not completely eliminate the effect of body size in relation to exercise or physiologic parameters (Armstrong

& Welsman, 1994; Nevill, Ramsbottom & Williams, 1992; Winter, 1992) as previously thought because the relationship between a physiological variable and the body size descriptor might not be a linear relationship (Welsman & Armstrong, 2000), where the slope of the linear regression line passed through the origin (Batterham & Birch, 1996). Research evidence (Armstrong & Welsman, 1994; Nevill *et al.*, 1992; Winter, 1992) suggest that ratio-scaling could create a new variable that was no better, in terms of controlling for body mass, than no adjustment at all (Vanderburgh, Mahar & Chia, 1995). It is necessary to challenge the conventional use of ratio-scaling in the normalization of exercise data in relation to body size and select the most appropriate scaling method to normalize exercise data so that the performances of groups, that is independent of body size can be appropriately compared and discussed.

Allometric scaling as a preferred scaling method

In a non-linear relationship between a physiologic or exercise performance and body size (e.g. peak power and muscle mass) allometric scaling is the proposed method to determine the relationship between a performance variable and body size. The relationship is expressed as $Y = a \cdot X^b$ where b is the exponent describing the curvature of the line and the influence of the body size variable upon the performance measure in question. In cases where the dependent variable, Y increased at a slower rate than the increase in the independent variable, X , a mass exponent of less than 1.0 is expected. The converse holds true. In ratio-scaling, however, it is assumed that the dependent variable,

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increased proportionally with the independent variable. In such a case the exact mass exponent is 1.0. In many cases, the relationship between a physiologic or measurement variable (such as power output) and a body size indicator (such as body mass or muscle mass) is seldom exactly 1.0. (Armstrong & Welsman, 1994).

A review of 16 performance test results on strength and power by Jaric (2002) showed that 14 had an allometric parameter b of less than 1.0. This implied that had ratio-scaling been applied in these studies, the dependent variable was over-corrected. Conversely, the use of ratio-scaling would have penalised the heavier individuals whilst advantaging the lighter ones (Winter, 1992). Therefore, allometric scaling appeared to be an appropriate scaling model for exercise performance measures, where the relationship between performance and body size is proportional, but not necessarily linear (Welsman & Armstrong, 2000).

The value of the mass exponent is fundamental to the accurate interpretation of changes in the physiologic or measurement parameter. A mass exponent of 0.67 has been suggested, based on the concept of geometric similarity and the surface law in relation to power generated by exercise in the Wingate Anaerobic Test (WAnT) (Chia, 1998).

Geometry similarity theory uses the analogy of two isometric (identical in inherent quality) cubes, with one cube, proportionally larger than the other. Their corresponding surface areas are thus related in the same proportion, squared. Similarly, their volumes are related to the value of the same proportion, to the power of three. In essence, Surface area \propto length²; Volume \propto length³ and Surface area \propto volume ^{2/3} (Jaric, 2002). According to Jaric (2002), as muscle force is increased because of an increase in muscle cross sectional area, in order to obtain an index of muscle strength that is independent of body size, the recorded strength was divided by any body length squared or a body-volume related index to power two-thirds.

Geometric similarity in allometric scaling

Even though allometric scaling presented researchers with the opportunity to uncover new relationships through manipulation of the scaling component, there are critiques (Armstrong & Welsman, 1997; Chia, 2003) that the assumption of geometric similarity is not valid and hence the use of a mass exponent of 0.67 in relation to certain exercise parameters was inappropriate in the absence of sample-specific empirical confirmation (Batterham & Birch, 1996). Indeed, in small sample sizes ($N < 50$), the theory of geometric similarity in relation to exercise variable and body size is seldom defensible (Chia, 2003), and therefore sample-specific mass exponents that are empirically derived from the subject group is recommended.

The use of allometric scaling with mass exponent of 0.67 assumes that the component of mass has the same physiologic importance and that the composition of body mass was similar among individuals of different body sizes. In human subjects, this assumption is not always fulfilled.

Of certainty, the qualitative state of muscle function is also one of the determinants of exercise performance (Rowland, 1996). Therefore changes in the inherent quality of the muscle such as adaptations to training in the longer term and acute or chronic muscle fatigue in the shorter term, will affect the quality of the muscle, and therefore affect exercise performance. Because repeated sprints causes acute fatigue in exercising muscles, and alters the energy substrates within the muscles (Bogdanis *et al*, 1998), this will influence the power generating capability of the muscles during subsequent exercise. Moreover, the recovery in power output following prior sprints that are separated by different recovery intervals in untrained adults has apparently not been studied. The aim of this study was therefore to explain how acute fatigue in muscle, caused by repeated sprint efforts that were separated by 60-s, 90-s and 120-s would affect power and the calculations of the b exponent using allometric scaling. Results of the study will help researchers understand if different b exponents should be used to compare power in repeated sprint performances of untrained male and female adults, within sprint trials, so that the performance is independent of body size.

Methods

Subjects and anthropometric measurements

Institutional ethical approval was granted to conduct the study and written informed consent was obtained from all subjects. Twenty participants, male ($N=10$) and female ($N=10$) sedentary adults, were recruited. Standing height and weight, as was age of each subject, were recorded. A dual energy x-ray absorptiometric (DXA) scan (QDR 4500 Hologic model, Waltham, MA, USA, V8.23A.5) was used to assess body mass, lower limb body mass and fat-free mass. The scanning procedure required subjects, clad in exercise attire, to lie supine and motionless on the scanning table, arms by the side and with the palms pronated. The hips were internally rotated till both toes touched. The scan for each subject took about seven minutes. Subsequently, body mass (BM), lean muscle mass (LMM) and lower limb muscle mass (LLMM) for each subject were derived from the DXA scan.

Repeated sprints on a non-motorised treadmill

A standardized warm-up was performed- five minutes of pedalling on the cycle ergometer at approximately 60 revolutions per minute that were interspersed with four all-out intensity sprints each lasting four to six seconds. This was followed by general static stretching for the groin, quadricep and hamstring muscles for another five minutes. On three separate visits to the exercise physiology laboratory, over a two-week period, subjects sprinted at an all-out intensity for 4 x 10 s on a calibrated non-motorised treadmill, NMT (SPRINT CLUB™ 2000, Médical Développement, Andrézieux-Bouthéon, France), with a consistent intra-session recovery period (randomly assigned as 60s, 90s or 120s at the start of the session). During the recovery period, the participant walked on the NMT at a self-selected pace. 1-s peak power (PP) was recorded for each of the four repeated sprints.

The reliability of PP and 10-s mean power (MP) in repeated sprints (Lim and Chia, 2007) and concurrent validity of power output derived from the NMT in sedentary adults (Chia and Lim, in press) were previously established.

Statistical treatment

All data were stored and processed using SPSS for Windows (version 11.5). The best body size descriptor for allometric scaling was obtained through application of step-wise linear regression to the data sets with age, stature, body mass (BM), lower limb muscle mass (LLMM) and lean muscle mass (LMM) were systematically entered in turn, as the covariate.

To correct for skewness and to reduce the effects of outliers, the data and the selected body size descriptor were first natural-logarithms (Ln) linearised in accordance to the recommendations of Nevill and Atkinson (1997). Following which, a univariate analysis of variance was performed to obtain the b or mass exponent. The dependent variable entered was the natural-logarithms linearised power output, the fixed variable was sex and the covariate was the identified natural-logarithms linearised best body size descriptor.

An interaction was performed between sex and the natural-logarithms linearized body size descriptor to derive a common b exponent for the sexes. A non-significant ($p > .05$, which was obtained) relationship allowed a common b exponent to be used for both sexes. The principle of allometric scaling suggests that the relationship between the performance variable and the selected body size descriptor is curvilinear and also passes through the origin. Therefore at zero size, there was no physiological response (Vanderburgh et al., 1995). To confirm that the scaled variable b was devoid of any relationship to LLMM, a non-significant correlation ($p > .05$) was indeed observed between the scaled physiological variable (i.e. PP) and the body size (i.e. LLMM) variable (Liu & Schutz; 2003; Nevill et al., 1992).

Results

Anthropometric measurements of the subjects

The anthropometric measurements of the twenty subjects (10 male and 10 female adults) who participated in the study

are summarized in Table 1. Male subjects were significantly taller and had greater body and muscle mass than the female subjects.

Peak power for male and female subjects

Figure 1 shows the pooled PP output for each sprint for the subjects. It was observed that the 60-s recovery registered the largest decrease in PP after four sprints.

PP was allometrically scaled to the best body size descriptor. Results showed that for all cases LLMM, when raised to the appropriate b exponent, was the best body size descriptor for PP. In all cases, there were no significant difference ($p > .05$) in the interaction between LnLLMM and Sex. Hence a common b exponent was used for both sexes. The changes in the b exponents with each 10-sprint in the different recovery trials are depicted graphically in Figure 2.

Figure 2 shows a gradual decline in b exponent (PP) with 60-s recovery. This was less pronounced in the 90 and 120-s recovery durations.

Relationships between the allometrically scaled PP in Sprint 1 and the LLMM showed a non-significant ($p > .05$) correlation, indicating that the influence of body size had been eliminated with allometric scaling for the unfatigued muscles.

Discussion

There are apparently no studies so far that focus on the effect of repeated sprints that are separated by different recovery intervals on the identified mass exponents in relation to peak power that is derived from the NMT in sedentary adults. This neglected area is in need of research attention as more sedentary adults participate in team sports as a form of recreation. While there are numerous studies on trained adult athletes using the NMT, this is apparently the first to be conducted on untrained healthy adults using a repeated sprints research design.

Results of the present study revealed that the best body size descriptor for the scaling of power output was LLMM, more so that LBM. This is somewhat surprising since sprinting on the NMT involves both lower limb and upper

Table 1. Anthropometric characteristics of the sedentary adult subjects

	Male adults (n = 10) (Mean \pm SD)	Female adults (n = 10) (Mean \pm SD)	Male & Female adults (N = 20; pooled data) (Mean \pm SD)
Age (yr)	26.0 \pm 4.4	24.7 \pm 4.2	25.4 \pm 4.7
Stature (m)	1.71 \pm 0.05*	1.62 \pm 0.06*	1.67 \pm 0.07
Body mass (BM) (kg)	66.7 \pm 10.6*	52.8 \pm 6.1*	59.7 \pm 11.0
Lean muscle mass (LMM) (kg)	54.0 \pm 5.9*	38.5 \pm 3.6*	46.2 \pm 9.3
Lower limb muscle mass (LLMM) (kg)	18.7 \pm 2.4*	12.8 \pm 1.5*	15.8 \pm 3.6

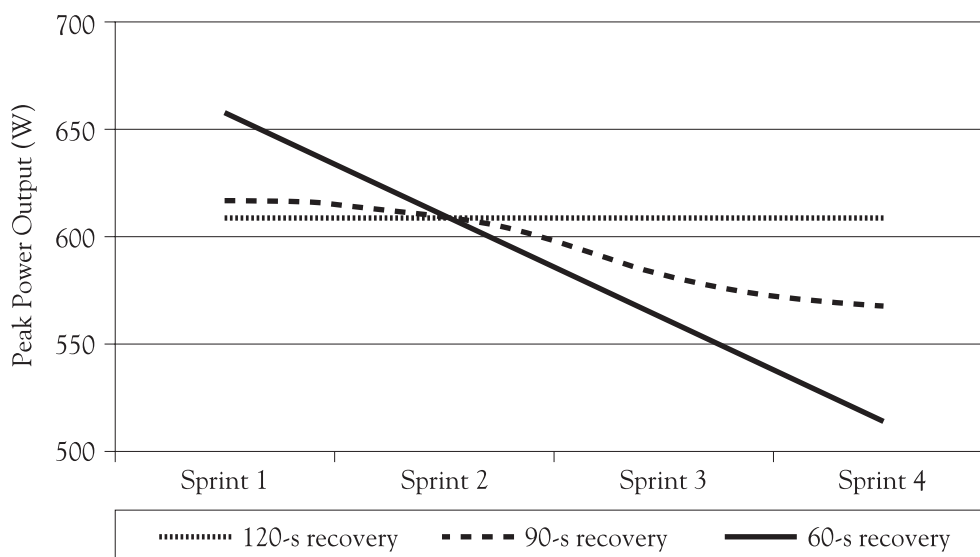


Figure 1. Peak power output for different recovery durations

Note: This was pooled data of male and female sedentary adults. Male adults (n = 10) and female adults (n = 10). Peak power in each sprint was measured as the highest recorded power output (integrated over 1-s) in that specific 10-s sprint.

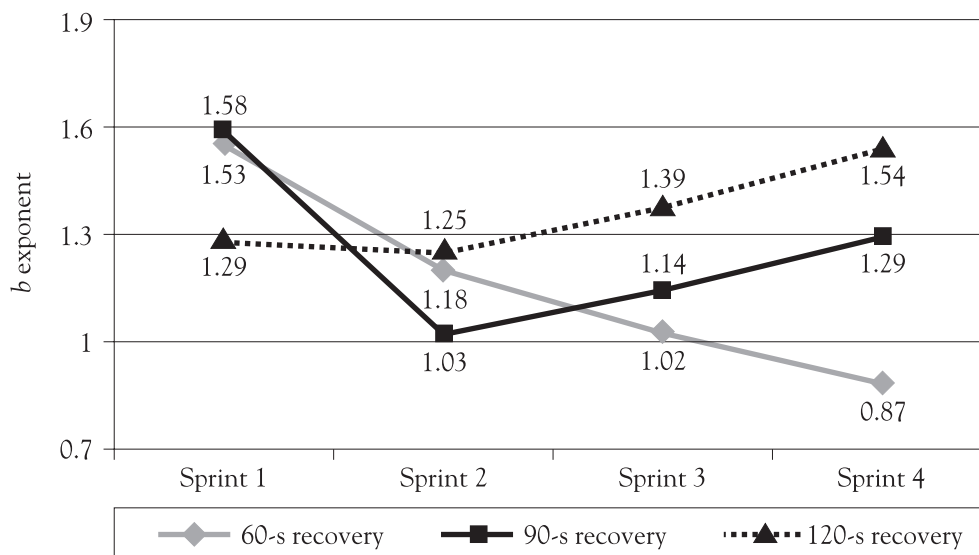


Figure 2. b exponents for PP in repeated sprints for different recovery durations

Note: Pooled data of male and female sedentary adults. Male adults (n=10) and female adults (n= 10). There was no significant difference ($p > .05$) in the interaction between LnLLMM & Sex; therefore common b exponent was used for both sexes. The best body size descriptor was lower limb muscle mass (LLMM). The sprint duration was 10-s on the non-motorised treadmill with intra session rest interval of 60s, 90s and 120s. Peak power was the highest power output over the 10s sprint, integrated over 1s.

limb muscle mass. Nonetheless, the statistically derived *b* exponent in relation to the NMT generated PP was neither 0.67 nor 1.0, as predicted by geometric similarity theory or the assumption or condition for the use of ratio-scaling, respectively. Indeed in 11 of the 12 sprints performed in the study, the *b* exponents identified for PP were greater than 1.0.

The graphical representation of the changes in *b* exponents for PP in the repeated sprint in Figure 2 revealed a trend; that there was a decreasing *b* exponent value in relation to PP in the repeated sprints with 60-s recovery. This was in comparison to the 90-s recovery duration where the decrease in the *b* exponent was less pronounced. The *b* exponent in the 120-s recovery duration, on the other hand, registered an increased value instead. The pattern of change

in *b* exponents for each sprint during intermittent exercises was difficult to explain, as it appears that the comparative literature on the matter is very scarce. However, it is plausible that given that each all-out intensity sprint was 10 seconds, the predominant source of energy during each sprint would be adenosine triphosphate (ATP) and creatine phosphate (CP) (Bogdanis et al, 1998). These energy substrates would be utilized and replenished to different extents during the four repeated 10-s sprints that were separated by recovery intervals of 60s, 90s and 120s. Hence indirectly, the identified *b* exponents would indirectly reflect the metabolic quality of the muscle during the different sprint trials with different recovery intervals. However, further direct evidence of this assertion is necessary perhaps using non-invasive methods such as magnetic resonance spectroscopy (MRS) to affirm the relationship between generated PP, muscle energy

metabolism and the mass exponent.

Data from the literature provides no explanation of the effect of fatigued muscles on the b exponent. Previous studies (Armstrong & Welsman, 1997; Santos *et al.*, 2002) that analyzed power output using allometric scaling performed the analyses on data sets derived from a single sprint and on exercised but unfatigued muscles. Hence results of the present study provided precedence the application of allometric scaling to fatigued and unfatigued muscles in during all-out intensity NMT repeated sprints in sedentary adult subjects.

Several important outcomes are noteworthy in the results of the study. Firstly, it is necessary to derive exact sample-specific mass exponents, using the allometric scaling approach for each cohort of subjects rather than to apply a common presumed scaling factor of 0.67. This important point was reinforced as different values of the b exponents were obtained for the same cohort on different test days, even under the same test conditions. In the current study, variation in values of the b exponents for unfatigued muscles in Sprint 1 of the various recovery durations varied up to 0.29. It is therefore recommended that in addition to sample-specific scaling, researchers should also consider obtaining trial specific b exponent for similar subjects in future studies.

Secondly, fatigued muscles resulted in a change of the derive b exponent in relation to PP in the repeated sprint. Given that the mass of the muscles did not change between sprints, it was highly probable that the identified b exponent across the sprints reflected the qualitative changes in the power generating capabilities of the muscles.

However it was difficult to quantify and standardize fatigue to verify if this hypothesis is tenable. Direct measurement of the kinetics of ATP and CP breakdown and resynthesis are extremely difficult as these are very fast processes and seconds could elapse between sampling and halting the biochemical events in the muscle sample (Scott *et al.*, 1990). Moreover, it would be difficult to determine the total mass and the activities of the all muscles involved in the NMT sprint. A small sample of muscle biopsy is not a good representation of all the muscles involved in the sprint and it would only provide information on relative concentrations rather than absolute concentrations (Scott *et al.*, 1990).

This relationship between PP generated by fatigued muscles and the derived mass exponent is still speculative at the present. The use of allometric scaling assumed that the component of mass had the same physiologic importance and hence the composition of body mass was similar among individuals (Rowland, 1996). This fundamental assumption was violated on two counts in fatigued muscles. Firstly, the power generating capabilities of the same muscles were different during the subsequent repeated sprints, despite testing the same cohort of subjects. This meant that the physiological importance of the same muscle mass in contributing to power output varied, and was dependent on whether the muscles were fatigued or unfatigued or less

fatigued and was thus not identical in all the four sprint attempts. Secondly, even within the same subject, different muscles would fatigue to a different extent after an all-out intensity sprint. In the current study where LLMM was the best descriptor, the degree of fatigue amongst the major muscle groups in the lower limbs might have been different dependent on its contribution to the sprint effort. If this were so, it would again violate the principle assumption for the use of allometric scaling. It is important to note that in allometric scaling, the identified b exponent is clearly a data-dependent variable (Liu & Schutz, 2003).

Conclusion

In conclusion, the evidence from the study showed that the b exponents in relation to PP were altered in repeated sprints that were separated by different rest intervals. Therefore it was necessary to establish the derived b exponent that is not only sample-specific but also trial-specific, in relation to PP that was generated in repeated sprints on the NMT in sedentary male and female adults. Results also showed that with the same subjects, test results in repeated sprint trials with different recovery intervals between sprints, resulted in different allometric b exponents in relation to PP. The application of allometric scaling to fatigued muscles was attempted in the study. An apparently decreasing trend of b exponents was observed when the recovery interval between sprints was less than 120 s or 90 s. Future work in the area should focus on qualifying and quantifying fatigue, either in absolute or relative terms, in muscle during repeated sprints and further examine how power generated by fatigued muscles could be appropriately compared using allometric scaling to derive a dimensionless variable that is size independent.

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