FORCE-VELOCITY RELATIONSHIP OF LEG MUSCLES ASSESSED BY MOTORIZED TREADMILL TESTS

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We aimed to explore the properties of the F-V relationship of leg muscles exerting the maximum pulling F within a wide range of V set on a standard motorized treadmill. Subjects exerted maximum horizontally pulling F while walking on a treadmill set to 8 different V (1.4 - 3.3 m/s). The obtained F-V relationships proved to be linear and strong (all R > 0.84), while their parameters depicting the leg muscle capacities for producing maximum F, V, and power (i.e., the maximum product of F and V) were highly reliable (0.84 < ICC < 0.97; 6.4 < CV% < 19.3). Moreover, when obtained from only the lowest and highest V the F-V relationships revealed virtually identical outcomes. We conclude that the evaluated procedure could be developed into an ecologically valid and reliable protocol for routine testing of the F, V, and P-producing capacities of leg muscles.

KEY WORDS: power, test, linear regression, reliability

INTRODUCTION: While the force-velocity (F-V) relationship of isolated muscles has been known to be hyperbolic (Hill 1938), multi-joint functional tasks (e.g., jumping, running, cycling, lifting, pushing, throwing) typically reveal strong and approximately linear F-V relationship patterns (see Jaric 2015 for review). Specifically, a manipulation of the external load provides a range of externally exerted F and V of the tested movement that allow for applying a linear regression model that reveals the maximum F, V, and power (product of F and V) producing capacities of the tested muscles. There are apparent advantages of such an approach over the standard testing procedures typically conducted under a singe set of mechanical conditions. Namely, the approach based on the obtained F-V relationship of tested muscles not only discerns among the F, V, and power (P) producing capacities of the tested muscles, but also has the property of a high ecological validity. However, despite apparent importance of testing gait function within both the athletic and clinical settings, the F-V relationship of the muscles performing gait has not been properly evaluated yet. Namely, although attempts conducted on non-motorized treadmills revealed an approximately linear F-V relationship (Jaskolska et al. 1999), such an approach does allow for a proper control of the F and V outputs as the standard motorized treadmills do. To address that gap in the literature, we designed a protocol for evaluation of the F-V relationship of leg muscles from a standard motorized treadmill within a wide range of the treadmill's V that covers the natural V of both walking and running.

METHODS: Young and physically active males and females (N=13+15) were tested on exerting the maximum pulling F at the pre-set treadmill V ranging from 1.4 to 3.3 m/s (Figure 1). The average F exerted over 5 s of maximum pulling was recorded. In line with a number of previous studies (Jaric 2015), the range of the obtained F and pre-set V data allowed for applying a linear regression model $F(V) = F_0 - aV$ that provided 4 parameters of apparent physiological meaning. Specifically, F_0 (i.e., the F-intercept) revealed the maximum F producing capacity of the tested muscles, V_0 (V-intercept) revealed their maximum velocity producing capacity, P_0 (equals $F_0V_0/4$) depicted the maximum muscle power producing capacity, while the slope a (equals F_0/V_0) revealed the balance between the F and V producing capacities. Two consecutive tests provided the data for estimation of the reliability through the intraclass correlation coefficients (ICC) and coefficients of variation (CV%). Finally, the parameters obtained from the linear regressions applied on all 8 applied V were compared with the same parameters obtained from the line drawn through only the lowest and highest V (two-point method; Jaric 2016).

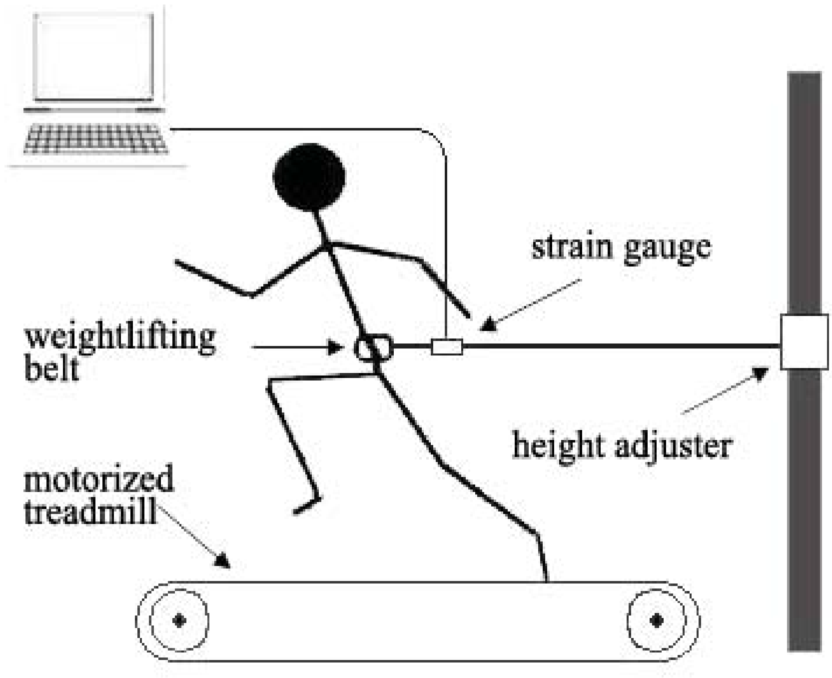

Figure 1: Illustration of experimental conditions. Subject exerts the maximum horizontal pulling force while walking at a pre-set velocity on a motorized treadmill.

RESULTS: Figure 2 shows the F and V data of each group averaged across the subjects. As expected, males revealed markedly higher F at the same V than the females. The presented regression method provided the F-V relationship parameters F_0, V_0, P_0, and *a* to be 385 N, 8.16 m/s, 785 W, and 47.2 Ns/m in males, and 236 N, 6.70 m/s, 395 W, and 35.2 Ns/m in females, respectively. However, of utmost importance is that despite the relatively wide interval of the applied V, the regression method revealed nearly perfect linear F-V relationships in both subject groups. When individual F-V relationships were analysed, the F-V relationships again proved to be high (R = 0.880 - 0.990). In addition, the 2 consecutive tests revealed high reliability of the obtained F-V relationship parameters. In particular, across both groups and all 4 parameters (i.e., F_0, V_0, P_0, and *a*) the ICC ranged from 0.84 to 0.97, while their CV% ranged from 6.4% to 19.3%.
Of interest here is also the comparison of the parameters obtained from all 8 applied V and from only the lowest and highest V (the two-velocity method). The results revealed no significant different between the same parameters observed by the 2 methods, while the relationships between them proved to be high (R = 0.890 - 0.986).

DISCUSSION: The main finding of the present study are that (1) the observed F-V relationships are strong and fairly linear within a wide range of the applied V, (2) the relationship parameters depicting distinctive mechanical capacities of the tested muscle are highly reliable, while (3) virtually the identical outcomes can be obtained from only 2 tested V. Both the strength and shape of the observed F-V relationship are not only in line with the previous results obtained from leg muscles tested using partly different methods (Jaskolska et al, 1999), but mainly in line with the findings observed from other functional movement tasks (Zivkovic et al, in press; Jaric, 2015). In addition to high reliability, one could even argue that the observed F-V relationships also provide valid indices of the mechanical capacities of the tested muscles. Namely, although the values of F_0 (388 N in males and 238 N females) could be somewhat below the maximum isometric puling F that one leg can exert

in horizontal direction, the magnitudes of V_0 (8.59 m/s and 6.86 m/s) closely correspond to maximum sprinting V of young and physically active males and females, respectively, while P_0 (810 and 396 W) is similar to maximum P directly recorded in similar tests (Jaskolska et al. 1999). Therefore, the present study adds to the evidence that not only the F-V of functional multi-joint tasks is strong and linear, but also that it provides reliable and valid indices of the F, V, and P producing capacities of the tested muscles.
Finally, in line with other functional tasks (Zivkovic et al, in press), the present results show that only 2 tested V can provide an almost identical F-V relationship as a number of tested V recorded for the purpose of regression modelling. Therefore, similar to the 'two-load method' applied to the tasks that allow for manipulation of external loading (Jaric 2016), the 'two-velocity method' applied in the tested task can be employed both in research and routine testing. It arguably shortens and simplifies the testing procedure and allows it to be fatigue-free, while still revealing an elaborate set of information regarding the mechanical properties of the tested muscles typical for F-V relationships observed from a number of either loads or V applied. Nevertheless, further research should address limitations of the present study by exploring the same phenomena within different ranges of treadmill velocities and in different athletic and non-athletic population, as well as further evaluate the validity of the observed relationship parameters.

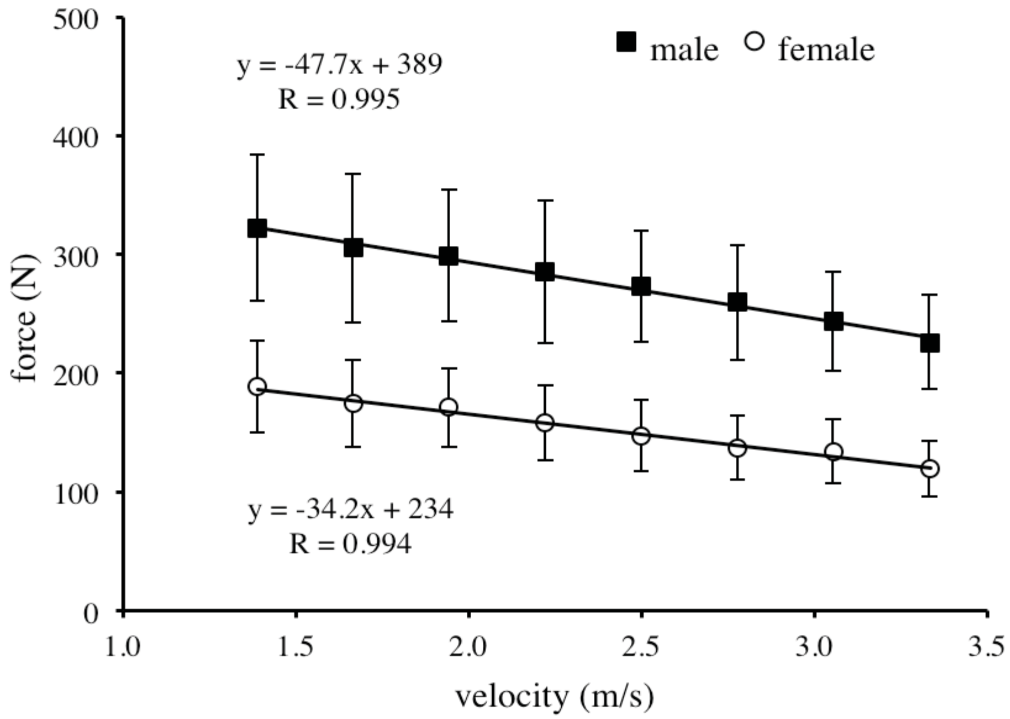

Figure 2: Averaged across the subjects pulling forces (means and SD error bars) and treadmill velocities that served for the assessment of F–V relationships of leg muscles of males (squares) and females (circles). The regression lines are shown with the corresponding equations and correlation coefficients (R).

CONCLUSION: The present results suggest that the F-V relationship of leg muscles tested by a motorized treadmill through the maximum pulling F at different V could be strong and linear, while its parameters could be highly reliable and valid. Moreover, a virtually identical relationship can also be obtained from only 2 distinctive treadmill V that allow for a relatively quick and fatigue-free testing procedure through the two-velocity method. Therefore, the evaluated procedure could be developed into a relatively simple, reliable, and ecologically valid routine procedure for comprehensive testing of different mechanical capacities of leg muscles.

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