EFFECT OF SLOPE AND SPEED ON KINETICS OF JOGGING WITH A BACKPACK

Philippe Malcolm[3], Fausto A. Panizzolo[1,2], Jozefien Speeckaert[1,2,4], Jinsoo Kim[1,2], Hao Su[1,2], Giuk Lee[1,2], Ignacio Galiana[1,2], Kenneth G. Holt[5], Conor J. Walsh[1,2]
[1] John A. Paulson School of Engineering and Applied Sciences and
[2] Wyss Institute for Biologically Inspired Engineering, Harvard University, Cambridge, MA 02138, USA
[3] Department of Biomechanics and Center for Research in Human Movement Variability, University of Nebraska Omaha, Omaha, NE, 68182, USA
[4] Department of Movement and Sport Sciences, Ghent University, Ghent, B9000, Belgium
[5] Sargent College of Health and Rehabilitation Science, Boston University, Boston, MA 02215, USA
email: walsh@seas.harvard.edu, web: http://biodesign.seas.harvard.edu/, http://coe.unomaha.edu/brb

INTRODUCTION

Running while carrying a load under different conditions such as slopes and speeds is a part of military training [1], trail running [2], commuting and conditioning exercises [3]. There have been different studies on effects of slope [4–6], speed [7,8] and load [3,9,10] on biomechanics of running. However, only a limited number of studies analyzed the effects of multiple parameters in interaction (e.g. [3]) and, to the best of our knowledge, there has been no study on the effects of slope and speed during jogging with a relevant military load at slow speeds that are likely to occur at such slope and load combinations. Knowledge about the effects of slope and speed on the joint kinetics can be useful for understanding the performance requirements of different types of terrain and for preparing accordingly. Our aim is to study the effects of slope and speed on joint kinetics during slow jogging with a military relevant backpack load. We hypothesize that uphill jogging will increase positive work (mostly at the hip and ankle) [5, 6] and reduce negative work and that faster jogging will increase both positive and negative work (mostly at the hip and ankle) [3,7,8].

METHODS

We tested 10 healthy male participants (29 ± 2 yrs; 76 ± 3 kg; 1.79 ± 0.02m; mean ± s.e.m.) during jogging on a treadmill (Bertec) at 15 combinations of slope (–8, -4, 0, +4 and +8°) and speed (2, 2.5 and 3 m s^{-1}) with a 15kg backpack. We measured joint kinetics using motion capture (Vicon). We calculated rates of positive and negative work for each joint by integrating positive and negative power portions and dividing by stride time. Next, we evaluated the linear, second order and interaction effects of slope and speed on each metric using mixed-model ANOVA with stepwise elimination.

RESULTS AND DISCUSSION

As hypothesized, we found that an increase in slope leads to an increase in positive work rate at the hip and ankle joint (similar to [5] and [6]) and to a decrease in negative work rate mostly at the knee joint and for the sum of all joints (Figure 1). Furthermore, we found that an increase in speed led to an increase in positive work rate at all joints, but at the knee this effect is very small. We also found that an increase in speed led to an increase in negative work rate for all joints. We found significant interactions for the effect of slope and speed in all joints for positive work rate but only in the knee for negative work rate (Table 1).

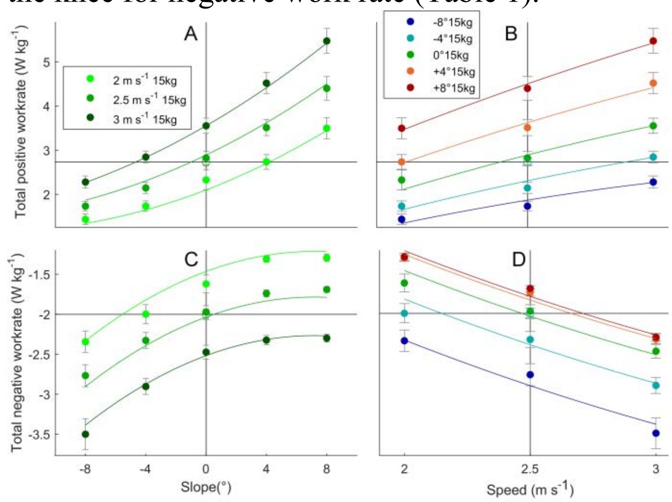

Figure 1: Effects of speed (a,c) and slope (b,d) on total positive (a,b) and negative (c,d) work from the hip knee and ankle. Dots and error bars are mean ± s.e.m. Lines show curve fits from ANOVA.

CONCLUSIONS

These results quantitatively show that fast uphill loaded jogging is strenuous, not only because positive joint work rate increases with slope and speed, but also because the interaction between slope and speed further magnifies these effects. Results also show that the combination of fast downhill jogging leads to high negative work at the knee because of the effect of slope, the effect of speed and that this is further magnified by interaction of slope and speed. Knowledge of these effects can be useful for choosing pacing strategies, course selection, estimating injury risk, optimizing training and rehabilitation and for selecting and developing orthotic or assistive devices. For example, an assistive exoskeleton for running [11] could be programmed to change its assistance magnitude based on the equations in table 1 to mimic human responses to changes in slope and speed.

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Table 1: Coefficients of mixed-model ANOVA for each outcome metric. Only significant terms were retained (p-values < 0.05).
Outcome metric = intercept + a · slope + b · slope^2 + c · speed + d · speed^2 + e · (speed · slope) with slope in ° and speed in m s^{-1}.

	Intercept	a (slope)	b (slope^2)	c (speed)	d (speed^2)	e (speed · slope)	R^2
Positive hip work rate (W kg^{-1})	0.518		0.004	-0.409	0.237	0.034	0.946
Positive knee work rate (W kg^{-1})	-0.684		0.001	0.891	-0.163	0.007	0.689
Positive ankle work rate (W kg^{-1})	-2.195			2.248	-0.330	0.026	0.913
Negative hip work rate (W kg^{-1})	-0.022	0.005	-0.001		-0.022		0.587
Negative knee work rate (W kg^{-1})	0.333	0.029	-0.003	-0.572		0.009	0.901
Negative ankle work rate (W kg^{-1})	1.293	0.014	-0.001	-1.273	0.178		0.883
Total positive work rate (W kg^{-1})	-2.341		0.005	2.731	-0.256	0.066	0.953
Total negative work rate (W kg^{-1})	1.700	0.070	-0.005	-1.938	0.177		0.929