# What Determines the Metabolic Cost of Human Running Across a Wide Range of Velocities?

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ABSTRACT

The cost of generating force hypothesis proposes that the metabolic rate during running is determined by the rate of muscle force development ($1/t_c$, $t_c$=contact time) and volume of active leg muscle. A previous study assumed a constant recruited muscle volume and reported that the rate of force development alone explains ~70% of the increase in metabolic rate for human runners across a moderate velocity range (2-4 m $s^{-1}$). **PURPOSE**: We performed a more systematic analysis of the effective mechanical advantage (EMA) of the lower leg over a wide velocity range to determine if we could more completely explain the increase in metabolic rate that human runners are capable of sustaining aerobically. We hypothesized that over a wide range of velocities, the EMA of the lower leg joints would overall decrease, necessitating a greater volume of active muscle recruitment. **METHODS**: Ten high-caliber male human runners (mean $VO_2$ max = 72.7 ± 3.9 $mlO_2$/kg/min) ran on a force-measuring treadmill at 8, 10, 12, 14, 16 and 18 km $hr^{-1}$ while we analyzed their expired air to determine metabolic rates. We measured ground reaction forces and joint kinematics to calculate contact time and estimate active muscle volume. **RESULTS**: From 8 to 18 km $hr^{-1}$, metabolic rate increased 132% from 9.01 to 20.92 W $kg^{-1}$. All subjects completed the speed range with an RER<1.0 and a blood lactate concentration ([La]) <4.0 mmol/L (mean RER at 18 km $hr^{-1}$ = 0.937 +/- 0.04, and mean blood [La] at 18 km $hr^{-1}$ = 3.51 ± 0.31 mmol/L). Contact time ($t_c$) decreased from 0.280 sec to 0.190 sec, and thus the rate of force development ($1/t_c$) increased by 48%. Ankle EMA decreased by 19.7±11%, knee EMA increased by 11.1±26.9% and hip EMA decreased by 60.8±11.8%. Estimated active muscle volume per leg increased 54.1% from 1663±152 $cm^3$ to 2550±169 $cm^3$. **CONCLUSION**: Overall, 97% of the increase in metabolic rate across the velocity range was explained by just two factors: the rate of generating force and the volume of active leg muscle. These results link the biomechanics and metabolic costs of human running and the approach may give greater insight into understanding individual differences in metabolic rate.