# THE MECHANICS & ENERGETICS OF HUMAN WALKING & RUNNING: A JOINT LEVEL PERSPECTIVE

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## INTRODUCTION

The links between the metabolic and mechanical demands of human locomotion have been studied extensively. Attempts to explain trends in the metabolic cost of transport (COT) based on the overall positive mechanical work done and the time available for generation of forces applied to the ground have most recently concluded that both factors are similarly important determinants of the COT [1]. However, much of the work contributing to this conclusion calculated positive mechanical work as the energy required to raise and accelerate the body's centre of mass (COM) and limbs. This approach exhibits considerable redundancy as this work is the net result of work done by each of the lower limbs which is, in turn, the net result of work done at individual joints.

Joint level data would reveal how power production is distributed among joints and how this distribution varies with speed and gait. In tasks such as incline running (where net positive work is done), power output is redistributed and a greater contribution to total power output is apparent at the hip [2]. This also occurs when switching from running to sprinting [3]. Steady speed locomotion never requires net work but moving faster involves greater positive work per stride. This may require redistribution of power output among joints.

Muscle groups acting at proximal joints within the leg typically have long fascicles with short tendons and small pennation angles. This may make them less efficient than their distal counterparts that are able to recycle energy in compliant tendons and contract with slow fascicle velocities. Thus, if power output shifts proximally (i.e. to the hip) this might affect the overall efficiency of positive work and might contribute to changes in metabolic COT with speed and gait.

Our study aimed to test the hypothesis that changes in overall mechanical power with locomotion speed would primarily be modulated through adjusting hip power output. We also hypothesised that increasing the hip joint contribution to power output would decrease the efficiency of total positive work.

## METHODS

Ten participants (six male, four female) walked at four speeds (0.75, 1.25, 1.75, 2.0 $m \cdot s^{-1}$) and ran at four speeds (2.0, 2.25, 2.75, 3.25 $m \cdot s^{-1}$) on a split-belt treadmill instrumented with bilateral force platforms embedded under the belts (BERTEC, USA). Kinematic data were recorded for the right leg and pelvis using an eight camera motion analysis system (VICON, UK; 120 Hz) and a modified Helen Hayes marker set. Ground reaction forces (980 Hz) and kinematic data were combined in an inverse dynamics analysis to calculate ankle, knee and hip average power outputs. Individual joint powers were summed to calculate total mechanical power and each joint's percentage contribution to the total was determined. Participants walked or ran for seven minutes at each speed, during which time their oxygen consumption was measured using a portable metabolic system (OXYCON MOBILE, GERMANY) so as to calculate their rate of metabolic energy consumption and COT. Efficiency of positive work was calculated as the ratio of total average mechanical power to metabolic power.

## RESULTS

Individual joint average power as a percentage of total average mechanical power did not change as a function speed for walking or running (Fig 1). Walking at 2.0 $m \cdot s^{-1}$ utilised a significantly ($P = 0.02$, repeated measures ANOVA) greater percentage contribution from hip joint power and lesser contribution from ankle joint power to total mechanical power than running at the same speed (Fig 1).

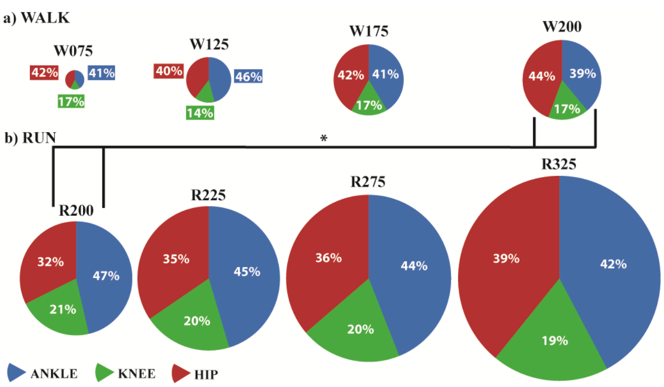


**Fig 1.** Pie charts showing the percentage of total average positive power contributed at the hip (red), knee (green) and ankle (blue) joints. The total area of each pie represents the total average positive power relative to the other conditions. *Indicates a significant difference ($P$ = 0.02, repeated measures ANOVA) in ankle and knee joint contributions.

COT was minimised for walking at 1.25 $m \cdot s^{-1}$ and then increased with walking speed, but remained relatively constant across running speeds (Fig 2). Efficiency of positive work decreased at faster walking speeds but increased again after switching to running gait at speeds above 2.0 $m \cdot s^{-1}$ (Fig 2).

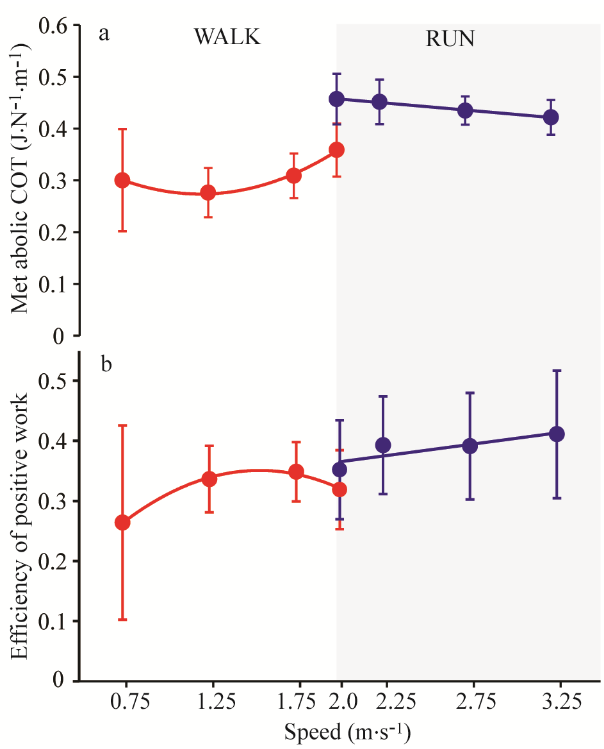


**Fig 2.** COT (a) and efficiency of positive work (b) at all walking (red) and running (blue) speeds.

## DISCUSSION

The increase in total average positive mechanical power that occurred with speed was achieved by systematically increasing power output at the hip, knee and ankle joints for both walking and running. Thus, the proportional contributions from each joint did not change with speed but, these did change when switching from walking to running gait, with a significant shift in the distribution from the hip to the ankle joint (Fig 1). Interestingly, this redistribution of power output coincided with a change in the trend for efficiency of positive work. Efficiency was decreasing at faster walking speeds but after switching to running at 2.0 $m \cdot s^{-1}$ began to increase again (Fig 2). Therefore, as hypothesised a change in the distribution favouring the use of distal joints over the hip may be linked to increased efficiency. Actually, 2.0 $m \cdot s^{-1}$ is approximately the preferred walk to run transition speed for humans and therefore we propose that switching to running may be a strategy to maximize efficiency of locomotion by utilizing distal muscle groups more than proximal. Such a theory is dependent on the assumption that more distal muscle groups generate positive power more efficiently than proximal muscles. It also assumes that increases in distal joint power outputs represent increased power output of distal muscle groups and not increased transfer of power from proximal groups via biarticular muscles. Therefore, direct measurements of in-vivo muscle fascicle and series elastic component behavior are required to support this hypothesis. This is now possible with ultrasound imaging techniques.

## REFERENCES


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