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## Short Communication

# The role of lower extremity joint powers in successful stair ambulation

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## ABSTRACT

Ascending stairs is an important functional activity that is affected by lower extremity pathology including amputation. Although several studies have demonstrated stair ascent is more challenging than level ground walking, our understanding of the mechanics remains limited. The purpose of this study was to determine the association between lower extremity joint power generation and vertical COM acceleration ( $COM_A$ ) during stair ascent. Twenty-two healthy individuals underwent a biomechanical gait assessment while walking up a 16-step instrumented staircase. The association between the peak joint powers and peak  $COM_A$  during stance were assessed with respect to timing and magnitude. With respect to timing, peak ankle joint power was highly correlated with peak  $COM_A$  ( $R^2 = 0.93$ ), while peak knee and hip joint powers demonstrated limited association with  $COM_A$  ( $R^2 = 0.41$  and  $0.08$ , respectively). Only the magnitude of peak ankle power was associated with peak  $COM_A$  ( $R^2 = 0.3$ ).

Significant temporal and magnitude associations between peak ankle joint power and peak  $COM_A$  suggest ankle power is a key contributor to  $COM_A$ . Although peak knee joint power and  $COM_A$  are temporally associated, the association is weaker and the occurrence of peak joint knee power is nearly 10% after peak  $COM_A$ , suggesting knee joint power plays a lesser role in  $COM_A$ . These combined findings indicate the role of trail limb ankle plantarflexors should be recognized in the stair ascent cycle definition and demonstrate the potential importance of a power generated by the ankle plantarflexors to normalize stair ascent performance following lower extremity amputation.

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## 1. Introduction

Ascending stairs is a common and important functional activity that is affected by a range of conditions including lower extremity amputation [1]. Although several studies have demonstrated ascending stairs is more challenging than level ground walking, and performance is limited by pathology, our understanding of stair ascent mechanics remains limited [1–4].

As with early definitions of the gait cycle for level ground walking, the stair ascent (SA) gait cycle is subdivided into phases based on the current understanding of the role of the limb in successful activity performance. The stair ascent cycle definition first proposed by McFadyen et al. [5] includes the actions of weight acceptance, pull-up, forward continuance, foot clearance, and foot placement and emphasized the role of the leading limb knee extensors in pulling the individual up the step [5]. This framework was modified by Zachazewski et al. [6] by replacing the pull-up phase with the term vertical thrust. Although the role of the lead limb in successful stair ascent has been emphasized, the relative

contributions of lower extremity joint powers, to include relative timing and magnitude have not been previously explored.

The aim of this study was to investigate the role of lower extremity musculature on elevation of the body, by assessing the temporal and magnitude relationships between vertical COM acceleration ( $COM_A$ ) and lower extremity joint powers. We hypothesized the trail limb ankle plantarflexors play an important role given their recognized importance in the performance of other ambulatory activities [7].

## 2. Methods

Twenty-two healthy individuals (13 male, 9 female) between the ages 18 and 45 with no current pain or history of major lower extremity injury volunteered to participate in this study. Subjects were on average  $21 \pm 4$  years old with a mean body mass and height of  $74 \pm 15$  kg and  $1.71 \pm 0.08$  m, respectively. Following written informed consent, all subjects participated in a biomechanical gait assessment during stair ascent walking. A total of 55 markers were used to track whole body motion while subjects walked up a 16-step instrumented staircase (AMTI, Inc., Watertown, MA) at a controlled cadence of 80 steps per minute (Fig. 1). Kinematic data were collected at 120 Hz using a 26 camera optoelectronic motion capture system (Motion Analysis Corp., Santa Rosa, CA).

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Fig. 1. Photograph of instrumented staircase.

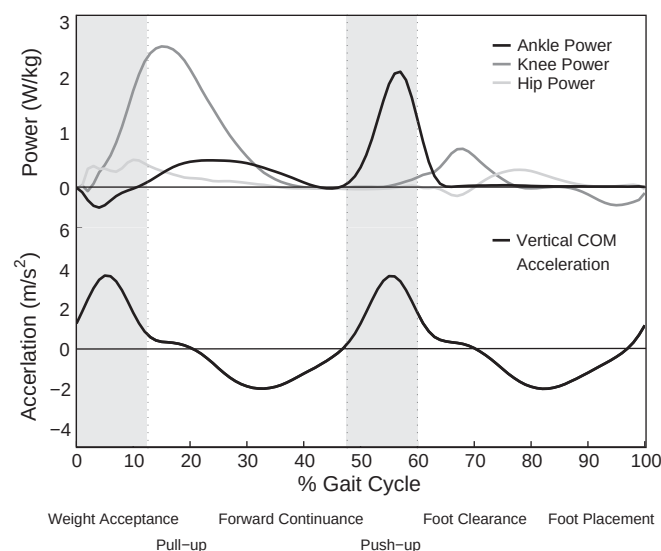


Fig. 2. Mean joint powers and vertical center of mass acceleration for all subjects. Text at the bottom of the figure illustrates stair ascent gait cycle phases including the proposed push-up phase during late stance. The vertical grey bands represent the double limb support phase of the gait cycle. The contribution of peak knee and hip powers during early stance were assessed in relation to the first peak in vertical center of mass acceleration, while the peak ankle power at the end of stance was assessed relative to the second peak in vertical center of mass acceleration.

### 3. Results

Fig. 2 displays the mean lower extremity joint powers and COM<sub>A</sub> during stair ascent for all subjects. The center of mass accelerates vertically twice during the SA gait cycle with peaks at  $6 \pm 1\%$  and  $56 \pm 1\%$  of the SA gait cycle. During early stance, the leg acts as the lead limb and generates positive power at the knee ( $15 \pm 2\%$  cycle) and hip ( $8 \pm 4\%$  cycle), which contributes to the first peak COM<sub>A</sub>. During late stance, the leg acts as the trail limb and generates power at the ankle ( $57 \pm 1\%$  cycle), which contributes to the second peak COM<sub>A</sub>.

The timing of peak ankle joint power and peak COM<sub>A</sub> (Fig. 3A) during late stance are significantly correlated ( $R^2 = 0.93$ ,  $p < 0.01$ ). The timing of peak knee joint power and peak COM<sub>A</sub> (Fig. 3B) during early stance demonstrated a  $R^2$  value lower than observed for ankle joint power ( $R^2 = 0.41$ ,  $p < 0.01$ ). The relationship between hip joint power timing and peak COM<sub>A</sub> (Fig. 3C) timing during early stance was not significantly correlated ( $R^2 = 0.08$ ,  $p = 0.21$ ).

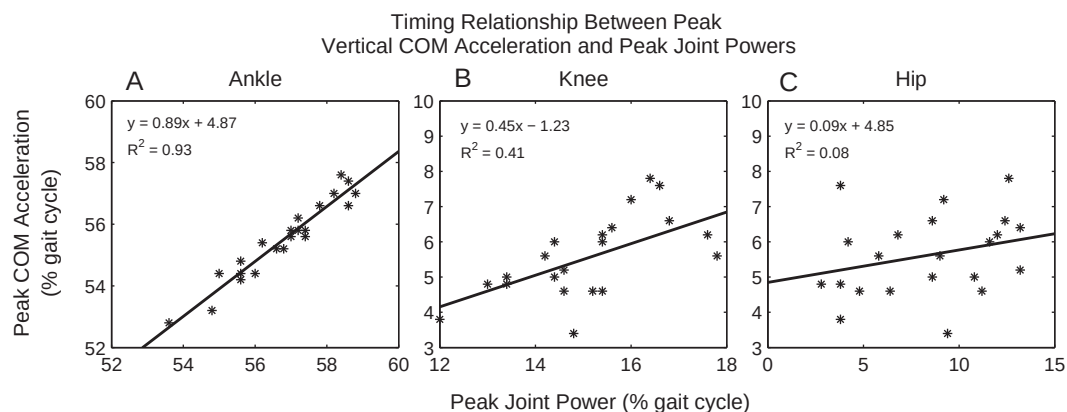


Fig. 3. The relationship between the timing of peak ankle joint power and vertical center of mass acceleration (A), the relationship between the timing of peak knee joint power and vertical center of mass acceleration (B), and the relationship between the timing of peak hip joint power and vertical center of mass acceleration (C).

The magnitude of peak ankle joint power and peak COM<sub>A</sub> were significantly associated with an  $R^2$  value of 0.3 ( $p < 0.01$ ). The peak knee and hip joint power magnitude were not associated with peak vertical COM<sub>A</sub> magnitude ( $R^2 < 0.13$ ,  $p < 0.16$ ).

#### 4. Discussion

The current investigation was conducted to better understand the role of lower extremity joint powers in successful stair ascent. The results of this study suggest the ankle plantarflexors contribute substantially to vertical acceleration of the body during stair ascent. Peak ankle power is similar in timing and relative magnitude to peak COM<sub>A</sub>. Although peak ankle and knee joint power are both temporally associated with COM<sub>A</sub>, peak ankle joint power and peak COM<sub>A</sub> events occur within 1% of SA gait cycle whereas peak knee power occurs 9% of SA gait cycle after peak COM<sub>A</sub>. During the first half of stance there is significant positive power generated at the knee, but the peak occurs after peak COM<sub>A</sub>, and a majority of knee joint power occurs while vertical COM<sub>A</sub> is near zero. It is possible ankle joint power is used to accelerate the COM<sub>A</sub> vertically, while subsequent power production at the knee maintains vertical motion of the body during the remainder of the pull-up or vertical thrust phase of the stair ascent cycle.

The results of the current study suggest the stair ascent cycle definition first proposed by McFadyen et al. [5], which includes the actions of weight acceptance, pull-up, forward continuance, foot clearance, and foot placement should be revised. We suggest a “push-up” phase be included after forward continuance, during the period of double limb support, to recognize the role of the plantarflexors. An important role of the ankle plantarflexors in successful stair ambulation is consistent with recent musculoskeletal computer simulations suggesting ankle push-off is a key contributor to upward acceleration of the body during normal level ground walking [7,10].

#### 5. Conclusion

Although limitations of inferring the effects of joint powers on distant segments are well documented [10], the findings of the

current study suggest the importance of ankle plantarflexors in successful stair ascent and warrant further investigation. An improved understanding of the mechanics of stair ascent has potential implications for the development and testing of powered prosthetic and orthotic devices designed to facilitate the normalization of stair performance through the restoration of ankle power.

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#### Conflict of interest statement

The authors have no conflicts of interest to report.

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