The biomechanical effects of increased load carriage on the lower extremities and their prosthetic implications

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INTRODUCTION

Load carriage is commonly encountered in both daily activities and vocational responsibilities. There have been several studies in both military and civilian research documenting the effects of load carriage during gait. Load carriage has been found to impact such parameters as horizontal and vertical ground reaction forces, resultant joint moments, the kinetics of the body's response to these external moments and the observed kinematics. While the biomechanical demands upon the lower extremities can alter significantly with increasing load carriage, most prosthetic foot and ankle mechanisms are only designed for use within a given, fairly narrow weight range. The ability of prosthetic feet to address the altered demands associated with load carriage is better understood when considering the body's typical responses to these conditions

METHOD

A literature search was undertaken to determine the effects of load carriage on the biomechanical characteristics of gait including resultant ground reaction forces, joint moments, kinetics and kinematics. Literature addressing prosthetic implications was also discovered.

RESULTS

Load/Force interactions: Evaluations of load carriage have been performed ranging from +20-+66% body weight. Load carriage causes increases in both the vertical and horizontal ground reaction forces. Vertical forces are directly proportional to the sum of body weight and additional load. Horizontal forces, including the braking forces experienced at heel strike and the propulsive forces at toe off are also linearly related to absolute loads, though at a reduced ratio (Harman, 2000; Birrell, 2007; McGowan 2008).

Joint Torque Moments: Ankle joint moments also increase in load carriage conditions. Dorsiflexion torques are minimally affected. By contrast, external plantarflexion torques increase by 20%, 27% and 38 % with load carriages of +26%, +43% and +61% of body weight (Harman, 2000; Polcyn 2002; McGowan 2008)

Observed Kinematics: Despite the tremendous increases in ground reaction forces and external joint moments induced by additional load carriage conditions of as much as 66%, ankle kinematics consistently remain relatively unchanged and knee kinematics change only minimally (Harman 2000; Polcyn 2002; Attwells 2006).

Internal Kinetics: Constant kinematics at the ankle and knee throughout a wide range of load carriage conditions is attributable to the counter moments generated by the muscles of the ankle and knee. EMG activities at the gastrocnemius increase by 11% and 34% respectively with load carriages of +26% and +43% of body weight. Increases in soleus activity are further pronounced, reaching approximately 50% in load carriages of +50% of body weight. By contrast, tibialis anterior EMG activities increase by only 4% and 6% respectively in the same +26% and +43% of body weight load carriage conditions. (Harmen, 2000; McGowan, 2008).

Prosthetic Implications: Limited observation in transtibial applications verify that augmented load carriage increases external joint moments. Optimal energetics requires increased stiffness or resistance in the prosthetic foot and ankle mechanism when load carriage exceeds 20% (Hitt 2010).

DISCUSSION

To accurately mimic the body's response to load carriage requires that a prosthetic foot be capable of augmenting it's resistance to dorsiflexion with increasing load. This augmented resistance should ideally be capable of replicating the resistance generated by increases of roughly 35% and 50% respectively of gastrocnemius and soleus activity.

CONCLUSION

Existing literature provides an understanding of how the lower extremities adapt to increases in load carriage of up to two-thirds body weight. It further defines the attributes required to replicate this response in prosthetic applications, namely variable internal resistance to a range of external joint moments.

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