Effect of A Foot Pad on the Push-Off and Joint Trajectories for the Powered Transfemoral Prosthesis: A Pilot Study

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RESEARCH HIGHLIGHT

- Investigating the effects of the foot pad on the gait kinetics & kinematics of the powered prosthesis
- Examining joint trajectory profiles and the push-off force at the toe while the foot pad condition was varied

INTRODUCTION

Gait abnormality

- Transfemoral amputees commonly have gait abnormalities that can cause to long-term problems.
  e.g. fatigue, arthritis and scoliosis [1].

Finite human walking phases

- Human walking consists of several events: heel-strike, foot-drop, heel-off, push-off, and toe-off [2].
- Between heel-off and push-off, positive work is required to insert energy into the moving body and to transition from the stance phase to the swing phase [3].
- To provide positive work to the user, a toe joint is essentia l for the foot; the toe joint lets the foot to bend naturally as the gait cycle progresses and provides appropriate pus h-off torque to the body [4].

POWERED PROSTHETIC SYSTEM

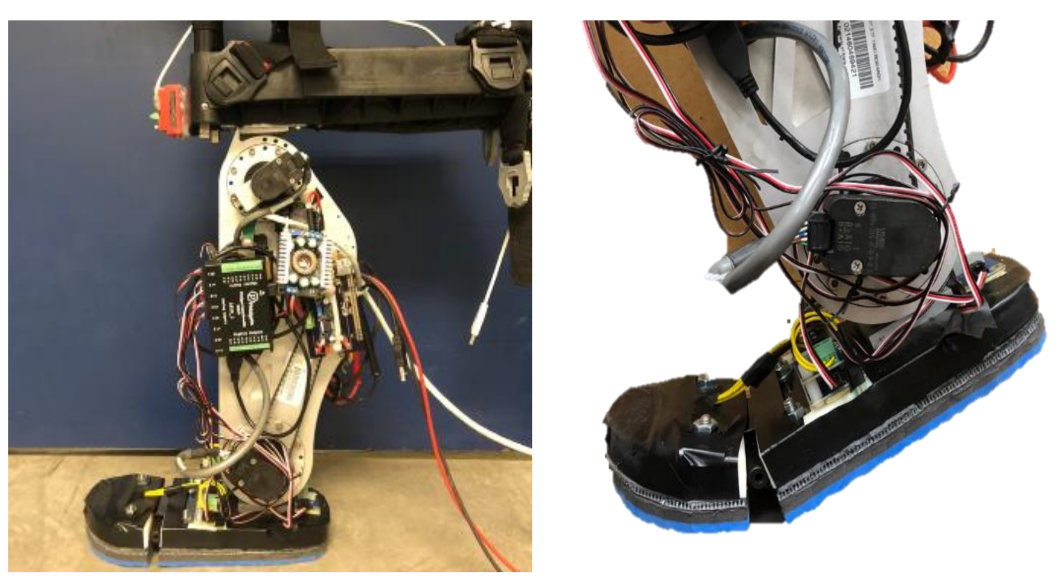

Fig. 1 The powered transfemoral prosthesis AMPRO II (left), and its human-inherent designed foot considering a toe joint with spring steel for providing required PO force (right).

Powered Transfemoral Prosthesis

- AMPRO II, the 2nd generation of custom-built A&M powered transfemoral prosthesis, has two actuations at ankle and knee.
- AMPRO II detects a contact with the ground based on 5 FlexiForce sensors located on its foot.

IMU Setting

- An IMU placed on the prosthesis detects the thigh angle, which is used as the phase variable to synchronize with the user's walking progression.

Human-inherent designed foot

- Prosthetic foot consists of the toe joint and foot base.
- Two parts are connected by the hinge and flat shaped spring steel.
- The toe length is determined based on the human factor considering where the forefoot strike occurs [5].

CONTROL FRAMEWORK

Stance phase: Trajectory tracking

- Cubic Bezier polynomials generates the desired walking trajectories for the swing phase.
- The generic cubic Bezier polynomials are described as below where t ∈ [0,1]:

$$Z(t) = (1-t)^3 P_0 + 3t(1-t)^2 P_1 + 3t^2(1-t) P_2 + t^3 P_3$$

- In Fig. 2, by controlling P_1 & P_2, any different inclined walking curves can be generated.

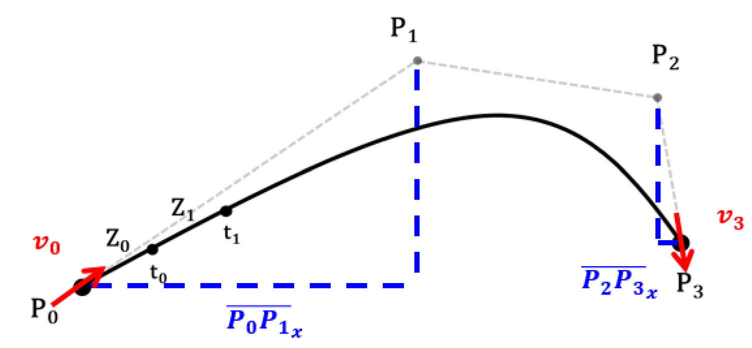

Fig. 2 The relationship between (P_1,P_2) and (P_0,P_3)

- P_0 is updated in every single gait cycle and P_3 is fixed point since all trajectories are merging at this point. $\overline{P_0P_1}_x$, $\overline{P_2P_3}_x$ are free variables to determine the control points P_1, P_2.

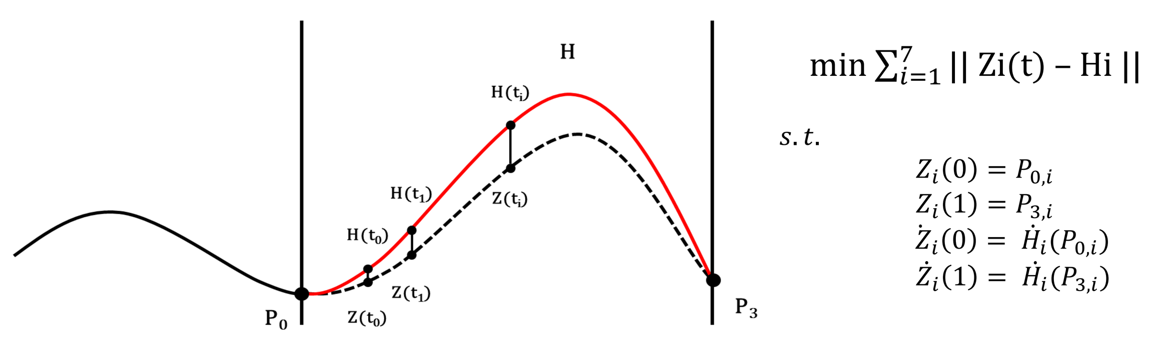

Fig. 3 H_i indicates a human walking trajectory of the i-th slope condition, where i = {1,2,3,4,5,6,7} ≡ {-15°,-10°,-5°,0°,5°,10°,15°} inclination. P_0, P_3 refer to the joint angle at 60%, 85% of a gait cycle, respectively.

- The optimization problem is solved to minimize the sum of error between the Bezier curves and corresponding human trajectories (Fig. 3).

Swing phase: Impedance control

- During the stance phase, impedance control is used to adopt to different terrain conditions.
- The torque at each joints can be described in series of passive impedance parameters which are the function of the phase variable.

$$\tau = k(\theta - \theta^e) + b\dot{\theta}$$

- The optimal stiffness, damping, and equilibrium were chosen from the previous studies [6-8].

EXPERIMENTAL SETUP

Experiment subject

- A healthy male (29 years, height 175cm, weight 75kg)
- Using a L-shape adapter to simulate an amputee gait

Experiment environment

- On a level-ground treadmill with 2 different conditions (without foot pad vs. with foot pad)
- User comfort speed (1.71 km/h)

Experiment data recording

- For each trial, 20 gait cycles were recorded.
- The kinematic data (i.e., knee and ankle joint angles) were captured via 2 encoders on the prosthesis.
- The kinetic data (i.e., force at the toe) was measured from 2 force sensors underneath a foot.

RESULTS

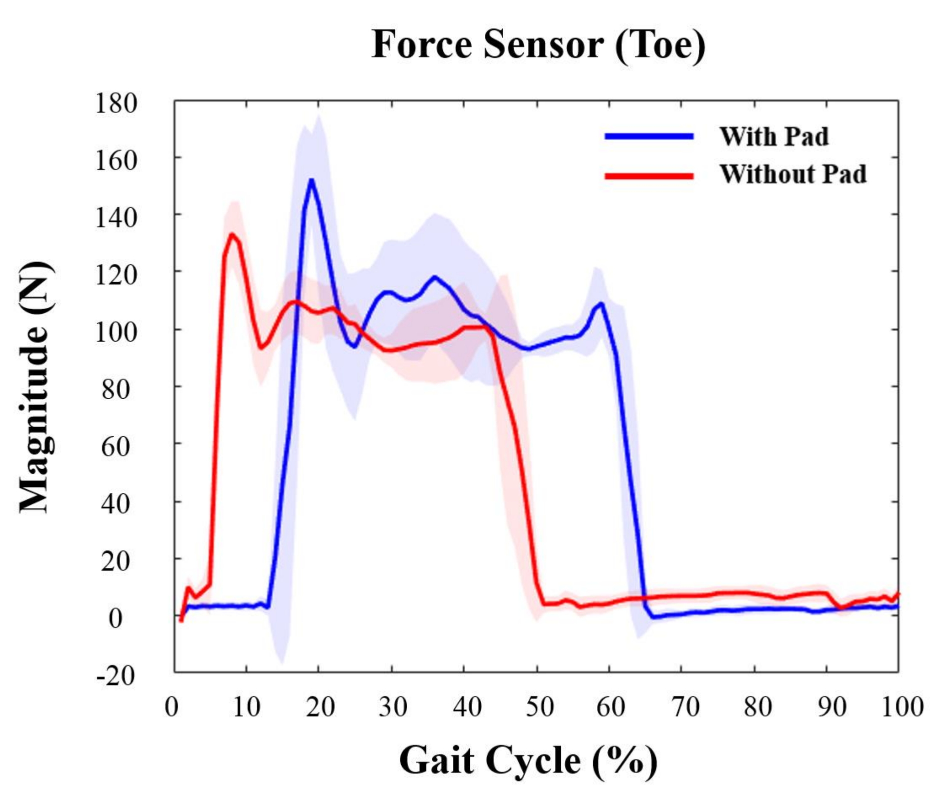

Fig. 4 The toe force profiles during the gait cycle with two different foot pad conditions (with foot pad vs. without foot pad). The bold lines and shaded regions are indicated the mean value and the range within one standard deviation.

- It is shown that the foot pad made the 1st peak occurred at the delayed timing (20% of the gait cycle) whereas for the foot without a pad, the 1st peak occurred around 10%.
  (In the normal human gait, it happens between 10 - 20% [5])
- Onset of the 2nd peak was delayed from 43% to 60% for a rigid foot with a pad compared with a foot without a pad.
- The delayed onset of the 1st peak is possibly due to the delayed force transfer to the force sensors due to the soft material of the pad.
- By varying the softness of the pad, the onset of the 1st and the 2nd peaks seems to be modulated.

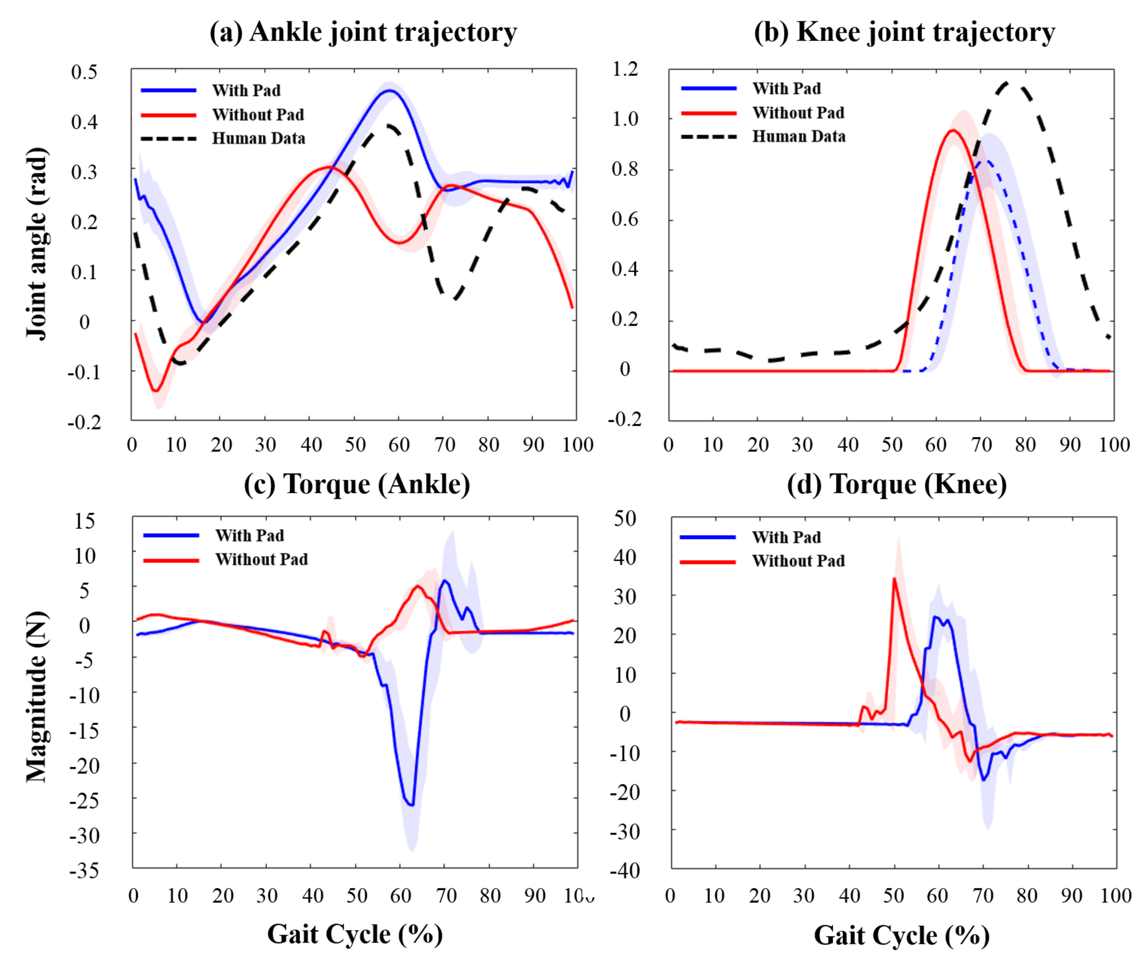

Fig. 5 Ankle joint trajectory (a), knee joint trajectory (b), ankle torq ue (c), and knee torque (d) from 2 different cases: rigid foot with a pad vs. rigid foot without the pad. Dashed black line indicates the j oint trajectory of the normal healthy gait.

- Interestingly, in Fig. 5, the push-off may have occurred late compared with the rigid foot without a pad.
- When a foot pad existed, the push-off happened around 60% whereas it happened around 43% without a pad. (Fig. 5a)
- In Fig. 5c, ankle torque profile also support its delay.
- When a foot pad was used, the ankle and knee joint trajecto -ries more resembled the normal human walking.
  Pearson correlation: 0.89 vs. 0.56 (ankle), 0.81 vs. 0.38 (knee)

CONCLUSIONS

It was observed that …

- The foot pad existence with appropriate softness enhanced both the onset timing of the push-off and the joint trajectory profiles for both ankle and knee.

FUTURE WORKS

- Conduct systematic experiments with a higher number of subjects, more conditions of the softness of the pad, motion capture system, and force plates.
- Anticipate that optimal softness of the foot pad will provide optimal push-off with more normative joint trajectories for the powered transfemoral prosthesis

References

[1] Gailey, et al., *J.Rehabil. Res. Dev.*, 2008.
[2] Neuman, *Kinesiology of the Musculoskeletal System: Foundations for Rehabilitation*, 2010.
[3] Usherwood, et al. *Journal of The Royal Society Interface,* 2012.
[4] Honert, et al., *American Society of Biomechanics 2017*, 2017.
[5] Winter, *The Biomechanics and Motor Control of Human Gait*, 1987.
[6] H. Lee, et al., *Transactional Engineering in Health and Medicine*, 2016.
[7] E. J. Rouse, et al., *Neural Systems and Rehabilitation Engineering*, 2014.
[8] F. Sup, et al., *Neural Systems and Rehabilitation Engineering*, 2011.