WeR5 - Human likeliness as a benchmarker for wearable robotics

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Abstract—**In recent years benchmarking has become an increasingly important topic for the wearable robotic community. One of the key abilities used during the benchmarking of wearable robots is motion ability. Successful motion ability is achieved once the wearable robot is capable of achieving human-like motion while integrating user controlled volitional movements. This requires an in-depth understanding of the mechanisms underlying commonly observed gait impairments. Only then, a wearable robot can allow the user to make the movements he or she desires while providing support where needed. In this conference contribution we present results of research into the mechanisms underlying gait impairments. We take individuals with a transtibial amputation as an example of unilaterally impaired individuals. These results illustrate how an increased understanding of the gait pattern can assist in the development and evaluation of wearable robots.**

I. INTRODUCTION

BENCHMARKING of wearable robotics has become an important research topic within the wearable robotics research community. Having a valid benchmarking methodology will allow a better comparison of different wearable robotics and also assist in determining the indication criteria for different types of wearable robotics. This information is indispensable for an optimal match between the intended use of the wearable robot and the technical capabilities of the device.

One of the starting points to be able to benchmark wearable robotics could be the key system abilities as they are described in the Multi-Annual Roadmap (MAR). The key system abilities for Healthcare are: configurability, adaptability, interaction ability, dependability, motion ability, manipulation ability, perception ability, decisional autonomy, cognitive abilities. This conference contribution will focus on motion ability, which is described as: (i) "the ability to follow human dynamics and perturbing physiological motion", and (ii) "capable to produce smooth human-like motion integrated with residual user controlled volitional movements". The latter is of particular importance for wearable robotics. In many trials where wearable robotics are investigated human-like motion is the norm. In other words, wearable robots are often programmed to stimulate or simulate human-like movements with the assumption that this would be most beneficial for the end-user. It is questionable whether this is true. As it is clear from the description from the MAR the wearable robot should incorporate the residual volitional movements. The robot should allow the user to make the movement he or she desires and only provide support where it is needed: the assist-as-needed principle.

One of the important prerequisites for the assist-as-needed principles is understanding the biomechanical user needs of the end-user. This, in turn, requires an understanding of the mechanisms underlying commonly observed gait alterations in individuals with unilaterally affected gait. In recent years, this has been increasingly studied. In this conference contribution we would like to highlight some results from these trials.

II. METHODS

In this conference contribution, we will primarily focus on individuals with a transtibial amputation as an example for individuals with unilaterally affected gait. In addition, we will mainly focus on straight-line walking, as this is the gait activity that has been most extensively studied.

III. RESULTS

A. Gait of individuals with a transtibial amputation

The gait pattern of individuals with a transtibial amputation has some striking differences when compared to individuals without an amputation: (i) increased oxygen cost of walking, and (ii) step length asymmetry.

Houdijk *et al.* [1] showed that the increased energy cost of walking of individuals with a transtibial amputation is associated with a decreased positive mechanical work of the prosthetic leg during the step-to-step transition (prosthetic leg trailing). During the same phase, the intact leg has increased negative mechanical work: it dissipates more energy when compared with the leg of an individual without an amputation. These mechanisms are less energy efficient, contributing to the increased energy cost of walking.

Another adaptation seen in individual with an transtibial amputation is increased mechanical work of the hip extensors of the intact leg during the loading response of the intact leg [2] (see Fig. 1). It is thought that this is a compensation for the reduced push-off of the prosthetic ankle and foot. The limited push-off reduces the forward velocity of the center of mass. The increased mechanical work of the intact hip

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extensors provides a forward impulse of the pelvis which increases the forward velocity of the body’s center of mass. Using the hip extensors for maintaining the walking velocity is less energy efficient than using the plantar flexors. This means that this adaptation also contributes to the increased energy cost of walking of individuals with a transtibial amputation.

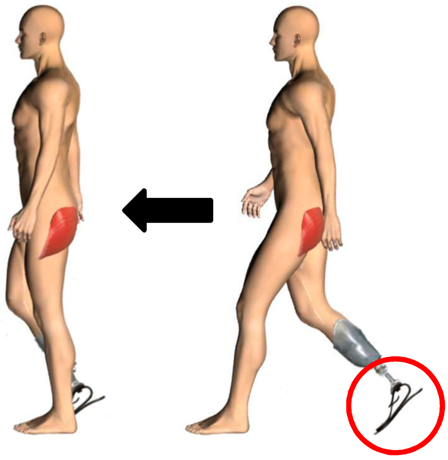

Fig. 1. Increased mechanical work of hip extensors.

The reduced push-off of the prosthetic ankle also leads to another adaptation in the gait pattern of individuals with a transtibial amputation: step length asymmetry. Individuals with a transtibial amputation have a reduced step length of the intact leg when compared to the step length of the prosthetic leg. Hak *et al.* [3] showed that the reduced prosthetic foot and ankle push-off leads to a drop in forward velocity of the body’s center of mass (CoM). This influences the position of the extrapolated center of mass (XcoM) which moves closer to the actual CoM position, see Fig. 2 for a graphical representation and explanation. This reduces the BMoS, increasing the risk of a backward fall. In this light, making a shorter step with the intact leg is functional in terms of gait stability, because it enlarges the BMoS

B. *Influence of prosthetic components*

The increased understanding of the mechanisms underlying gait impairments, as described in part A, can assist in the development and evaluation of prosthetic components. Wezenberg *et al.* [4] compared a rigid prosthetic foot to a prosthetic foot that is able to store and return energy. These latter category is able to provide prosthetic ankle and foot push-off to a limited extent. The authors found that the increased push-off of energy storage and return prosthetic foot indeed produced more positive mechanical work than the rigid prosthetic foot. It also led to a decreased negative work of the intact leg. These results provide an explanation as to why an energy storage and return prosthetic foot is associated with decreased oxygen cost of walking.

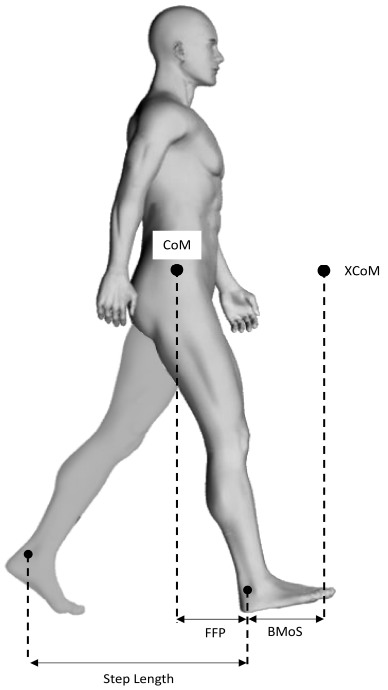

Fig. 2. Dynamic balance parameters.
CoM: Center of Mass, XcoM: Extrapolated Center of Mass, FFP: Foot Forward Placement, BMoS: Backward Margin of Stability. The XcoM is a position measure based on the CoM position and velocity. When the CoM velocity increases, the XcoM is positioned more anteriorly with respect to the CoM. If the velocity decreases the XcoM position moves more closely to the CoM position. The XcoM position can be related to the foot placement which is usually expressed as the backwards margin of stability (BMoS). A larger BMoS is thought to be related to a reduced risk of a backwards fall.

IV. CONCLUSION

This conference contribution shows how an in-depth understanding of the biomechanical mechanisms underlying gait impairments can assist in better understanding the effect of wearable robotics. As such, it shows that motion ability is an important key system ability for the benchmarking of wearable robots.

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