A motion capture protocol for the in-vivo assessment of running and long jumping biomechanics in transfemoral and transtibial running elite para-athletes

R. Di Marco [a], S.G. Breban [b], G. Zullo [b], G.L. Migliore [c], F. Gariboldi [b], M. Scapinello [b], G. Marcolin [d], A.G. Cutti [c], N. Petrone [b]

[a] Department of Engineering for Innovation Medicine, University of Verona, Italy; [b] Department of Industrial Engineering, University of Padova, Italy; [c] Centro Protesi, INAIL, Vigorso, Italy; [d] Department of Biomedical Sciences, University of Padova, Italy

Introduction

Paralympic athletes compete at high levels thanks to technologies that allow individuals with amputations to engage in sports. Current studies focusing on enhancing athletic performance, device safety, comfort and production process lack standardized procedures, hindering result generalizability [1]. The OLYMPIA project aims to address this gap, improving prosthetic device quality and effectiveness, and enhancing measurement transferability from in-vivo to bench testing. We propose a novel method to evaluate running and long-jumping biomechanics using marker-based motion capture, useful to inform video analysis, bench tests, FEM and musculoskeletal models.

Methods

The protocol includes definition of segments, local coordinate (LCS) and joint coordinate systems (JCS), marker locations and labels. Definitions are similar to those given in [2] for sound segments, while each component of the prosthetic limb is associated with a segment, a marker cluster and LCSs: socket to accommodate the residual limb; socket clamp (socket and subsequent distal part interface); prosthetic knee for transfemoral (TF) amputees (with proximal and distal LCSs); foot clamp; and Running Prosthetic Foot (RPF), with its most proximal and most distal extremities. Socket clamp corresponds to foot clamp for transtibial (TT) amputees. At least three markers were placed on each segment and redundancy was sought using clusters. If the prosthesis configuration prevented from positioning markers directly on the segments, a marker-equipped wand was used to locate and reconstruct them [3]. Prosthetic joints were: (i) socket-pelvis as hip in TF; (ii) distal-proximal prosthetic knee in TF; (ii) socket-thigh as knee in TT; and (iii) distal RPF-clamp as virtual ankle in TF and TT (with virtual null angle when unloaded). The protocol was tested on a female athlete (58 kg; 1.65 m; T63 100 m medallist in 2020 Paralympic Games) wearing a 1E91 Standard Runner Cat 4.0 RPF and 3S80 monoaxial prosthetic knee joint (Ottobock, Germany) on her left residual limb. Across trials, an expert prosthetist adjusted the socket tilt relative to the great trochanter-knee joint centre line (sagittal plane) from 5° (A0) to 15° (A3) [4].

Results

Joint kinematics for sound and prosthetic lower limbs (Fig. 1) demonstrate that LCS and JCS definitions effectively track joint motion during running. They also highlighted the effects of the two prosthesis configurations on joint kinematics.

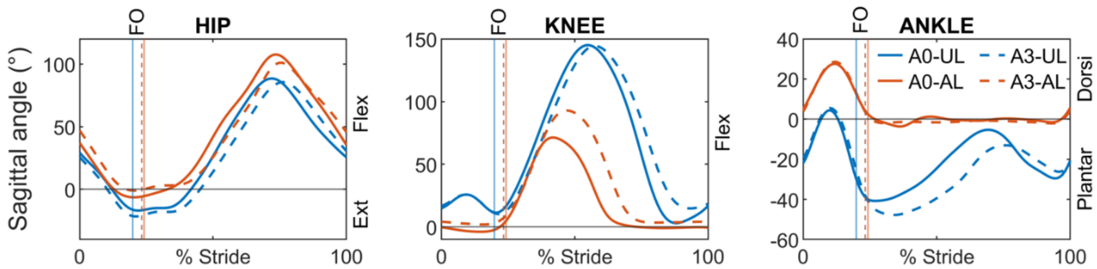

Figure 7. Sagittal kinematics of anatomical (on the unaffected limb – UL; in blue) and prosthetic (on the affected limb – AL; in orange) hip, knee and ankle angles normalized over the percentage of the stride, computed for a transfemoral amputee wearing a prosthetic limb in two different configurations (socket sagittal tilt: 5° - A0; and 15° - A3) on two running trials. Vertical lines represent foot-off (FO) events.

Discussion

The presented protocol allows collecting and analysing running biomechanics data in para-athletes with lower limb amputations, setting a new standard for future studies and applications.

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