LATEST RESEARCHES ON RUNNING-SPECIFIC PROSTHESES: TOWARD SOCIAL IMPLEMENTATIONS OF BIOMECHANICS

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Recent developments in running-specific prostheses (RSPs) have allowed individuals with lower extremity amputation (ILEAs) to regain the functional capability of running and jumping. However, the biomechanical characteristics of ILEAs using RSPs remain largely unknown. Understanding the biomechanical adaptations that occur during running and jumping with RSPs will assist clinicians and coaches in making objective decisions regarding the most appropriate prostheses, as well as in the fitting and alignment of these devices, for performance improvements in ILEAs. This presentation introduces our project regarding biomechanics of amputee athletes wearing RSPs, and its applications to athletes, prosthetists, manufacturers, and clinicians for the promotion of activity among amputees.

KEYWORDS: Prosthetic sprinting, Paralympic, Sport technology, deep data, big data.

INTRODUCTION: Limb loss—particularly lower extremity amputation—often leads to a reduction in physical activity levels, which can in turn lead to weight gain, depression, anxiety, increased risk of cardiovascular and other chronic diseases, and an overall reduction in quality of life. Current challenges in providing appropriate rehabilitation to assist ILEAs in adapting to new physical conditions and demanding physical activities largely lie in the lack of knowledge regarding the biomechanical and physiological characteristics of this patient population in active contexts. Our limited understanding of biomechanical consequences resulting from lower extremity amputation is mainly due to the lack of research on this topic, which limits orthopaedic surgeons, physical therapists, and prosthetists in their ability to prescribe individualised prostheses and rehabilitation plans for this population.

Although running-specific carbon-fibre prostheses (RSP) are prevalent in individuals with lower extremity amputation, the biomechanical adaptations associated with such devices remain largely unknown due to the lack of biomechanical studies in ILEAs and the dearth of information on RSPs. For example, our bibliographic survey identified only 94 publications when “amputees” and “running” were used as keywords (Figure 1). Thus, athletes support as well as fabrication, selection and proper use of RSPs have been conducted in a largely subjective manner. Therefore, the goal of this project is to provide biomechanical evidence for athletes, prosthetists, manufacturers, and clinicians for the promotion of activity among ILEAs.

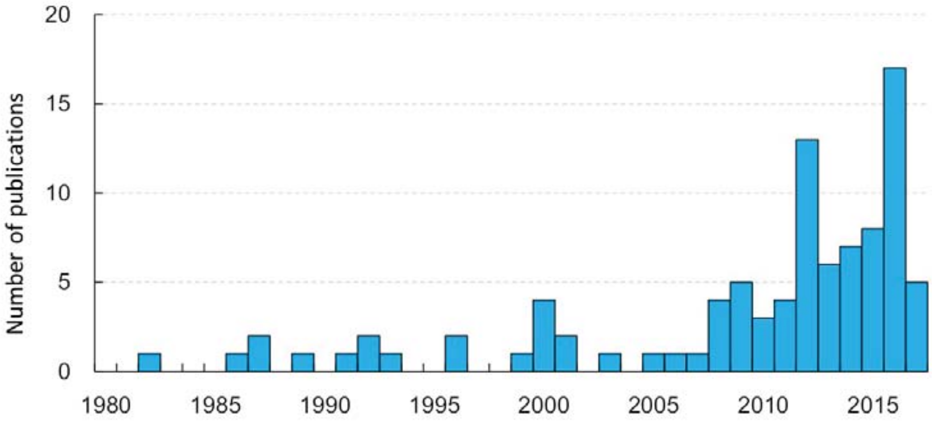

Figure 1: Publication trends in prosthetic running and jumping. So far, 94 papers were published over 35 years. However, 75% of papers were published in recent 10 years.

APPROACHES: Our research is focused on understanding how ILEAs and amputee athletes control locomotion, and on the application of this knowledge to athletic training and gait rehabilitation in these populations. To quantify the biomechanical characteristics of ILEA running and jumping, we use two different approaches. Three-dimensional motion capture is currently the gold standard for analysing movement adaptations in the field of biomechanics. This technique involves placing reflective markers on specific body landmarks to capture segmented motion. When combined with force platform data, inverse dynamics techniques can be used to calculate the forces and moments at each major lower extremity joint during running and jumping (the first approach; deep data analysis). In addition, using the 3-D motion capture data, we have developed a digital human model for ILEAs with RSP. This simulation model demonstrated that spring-like leg behaviour during running in ILEAs varies according to the mechanical characteristics of different RSPs.

Despite the fact that 3-D motion capture is thought to be advantageous to determine biomechanical characteristics of ILEAs, the technique is associated with several inherent constraints (e.g. subject recruitment, constraints for experimental set-up, and environmental dissimilarities to athletic fields). To solve these problems, we recently developed a database for spatiotemporal parameters of amputee sprinters using publicly-available Internet broadcasts (second approach; big data analysis). The average speed, average step length, and step frequency for each ILEA sprinter in 100- and 200-m sprints were calculated using the number of steps in conjunction with the official race time. In addition, we collected personal information for each ILEA (e.g. competition information, name, sex, amputation level, amputation side(s), ethnicity, nationality, competition level, body height, RSP and prosthetic knee joint utilised, qualification standards, etc.). Although dependent variables and personal information are limited in this technique, the large population analyses make it possible for us to compare fundamental spatiotemporal parameters of ILEAs among these characteristics.

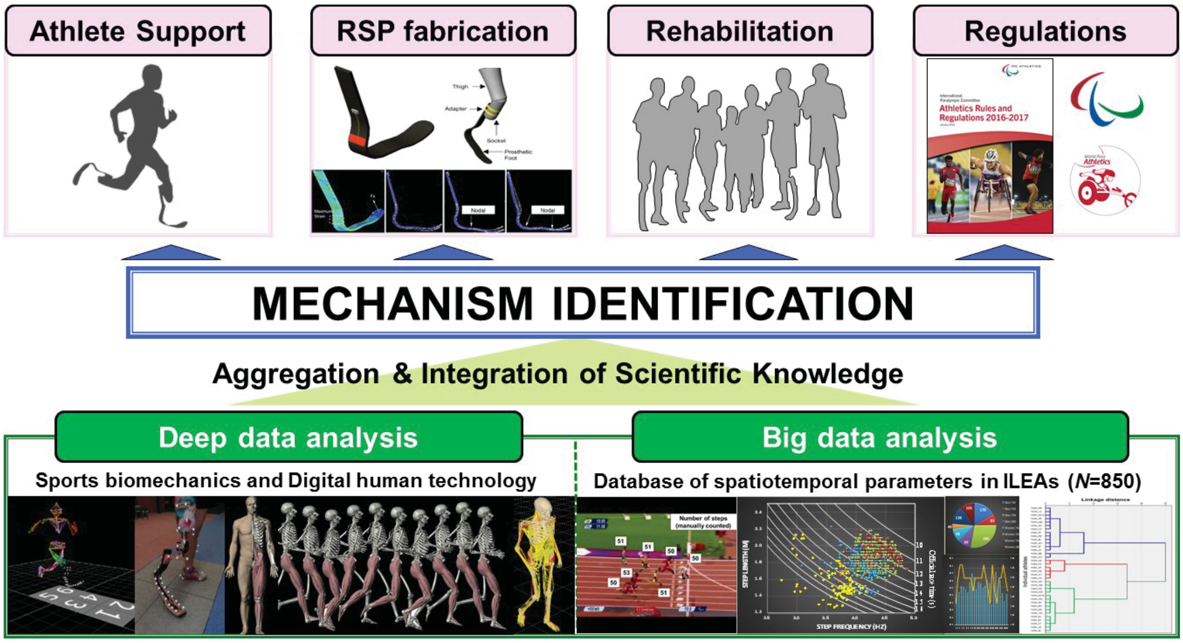

Figure 2: A schematic representation of our project. The goal of this project is to provide biomechanical evidence for athletes, manufacturers, prosthetists, and orthotists for the promotion of activity among ILEAs. To achieve this goal, our team aims to identify the biomechanical characteristics of ILEAs wearing RSPs during running and jumping, by means of three-dimensional motion capture and digital human technology (deep data analysis), and database of spatiotemporal parameters in ILEA (big data analysis).

RESULTS: For the first approach, current studies by our team seek to understand how ILEAs with RSP achieve faster sprint velocity and longer jump distance, within the mechanical constraints and capabilities of the musculoskeletal system. From 2012, we conducted experiments to assess whole-body dynamics, joint kinetics, and kinematics of ILEAs wearing RSP during sprinting and jumping. Briefly, we revealed that propulsive impulses of ground reaction forces generated by the prosthetic limb rather than the intact limb may be the key parameter for achieving greater sprint velocity in sprinters with unilateral transfemoral amputations (Makimoto et al., 2016). These force production capabilities are mainly associated with joint extension in the prosthetic hip joint during the stance phase (Namiki et al., 2017). We extended these biomechanical analyses to a long jumper with unilateral transtibial amputation wearing RSP to determine whether or not he possesses a competitive advantage over able-bodied counterparts in the long jump event.

For second approaches, we acquired 850 spatiotemporal data from 147 ILEAs in 35 countries (as of 3 April 2017). To date, we have revealed that spatiotemporal parameters in amputee sprinters vary according to amputation levels, sex, ethnicity, competition level, and RSP type, but NOT according to body height or amputation side (Hobara et al., 2015ab, 2016abcde).

APPLICATIONS: As shown in Figure 2, the results of our studies have been applied to several translational outcomes. First, several athletes have used our biomechanical data to enhance their athletic performance. Indeed, we have already collected data from nine para-athletes, providing them with feedback regarding their running/jump style. Fortunately, four of these nine athletes won several medals at the 2016 Paralympic games in Rio. Second, we utilise our data to fabricate new RSPs for sale in collaboration with several industrial partners. The aim of such partnerships is to familiarize manufacturers and consumers with low-cost, evidence-based prosthetic components. Third, our data aid prosthetic users in resuming running via effective rehabilitation conducted by physiotherapists and prosthetists. To date, relatively little research has focused on untrained ILEAs who wish to begin running. As a result of our research and concise feedback, some of these individuals have re-learned how to run using RSPs via effective rehabilitation and elimination of inefficient training techniques. These achievements were due in part to cooperative partnerships between medical doctors, researchers, clinicians, and prosthetic end-users. Finally, our biomechanical data are used to update regulations in para-athletics. In October 2015, using our data, the International Paralympic Committee (IPC) launched an official statement regarding the maximum allowable standing height for bilateral transtibial/femoral amputees, which changed beginning January 1st, 2017 (Amendment to IPC Athletics Classification Rules and Regulations Appendix 1, 3.1.4.3.1 and 3.2.4.3.1). In 2016, we further undertook a study to justify whether transtibial amputees with RSPs possess any competitive advantage over able-bodied counterparts in the long jump event. By organising an international collaboration with Germany and the US, we investigated the long jump mechanics of RSP users, revealing that the biomechanical determinants of a long jumper with RSPs differ substantially from those of able-bodied athletes.

FUTURE DIERCTIONS: Quantifying the biomechanical characteristics during running and jumping in ILEAs is a critical step that will lead to objective, targeted improvements in rehabilitation and prosthetic designs. The results of this project will yield valuable information on the biomechanical adaptations of ILEAs running and jumping with RSPs. Understanding how ILEA adapt joint kinetic control while dynamic activities and joint loading asymmetry between limbs will lead to improved guidelines for rehabilitation and prosthetic design. These results will also provide a basis for future investigations that can lead to reductions in degenerative joint disease (see Baum et al., 2016 and Hobara et al., 2014), increased activity levels of ILEA, and increased athletic performance.

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