Comparative Analysi Accelerated Treadmi Amputee Paralymp

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Abstract- Running Prosthetic Feet (RPF) enable athletes with lower limb amputation to compete in track races. Both Ground Reaction Forces (GRFs) and kinematics analyses allow evaluating running performance but they are seldom measured together. This work aims to compare kinematic and kinetic biomechanical parameters of an elite amputee Paralympic sprinter in a pilot feasibility study. Tests were performed on a commercial treadmill placed on four force platforms. Two conditions were tested: Steady State Running (SSR) and Resisted Accelerated Running (RAR). SSR results show that unaffected limb (UL) vertical GRF was 70% higher than affected limb (AL). Differences in trunk, hip, knee, and ankle angles were observed both between AL and UL sides (e.g., knee extension during stance), and between SSR and RAR tests (e.g., trunk inclination). Results obtained could be helpful to trainers to improve overall sprinting performance.

***Keywords*— running prosthetic feet, ground reaction forces, kinematics, treadmill.**

I. Introduction

Since the introduction of Running Prosthetic Feet (RPF) the interest in studying sprinting biomechanics of Paralympic athletes has grown. Indeed, RPFs enabled many athletes with leg amputations to compete with nonamputees in track races [1] On this matter, some authors speculated about a possible advantage in performance when using RPF vs biological legs. However, a debate is still open about this possibility [2], and further studies regarding amputees sprinting biomechanics and adaptations are ongoing. This knowledge will allow specific rehabilitation and training strategies, as well as developments in prosthetic devices to be objectively evaluated. Kinematic alterations between sound and prosthetic limbs result from using RPF. Findings suggest that in case of transtibial amputation prosthetic could have similar behaviour of the intact one [3]. Conversely, in case of transfemoral amputations affected limb is considerably different compared to the sound limb or able-body subjects [3].

About Ground Reaction Forces (GRFs) authors reported a significant difference in average vertical GRF production between intact and prosthetic limbs among elite sprinters with lower limb amputations [4], [5]. In the above studies, affected side has lower GRFs than the intact one.

Differences in force production and joint kinematics between prosthetic and intact limbs in sprinters with unilateral transtibial amputations are due to the lack of the ankle joint [6].

The current research aims to better understand sprinting biomechanics and improve racing performance. As well known, during sprinting athlete accelerate their body forward to develop velocity in the shortest possible time. Speed is dependent upon a number of factors which include technique and force production capability, in particular lower limb musculature. Moreover, sport scientists have observed that one the most effective way to improve the overall performance is through resisted sprinting training which is usually done on track [7]. Pairing instrumented treadmill and motion capture system allows to measure GRFs and kinematics. However, treadmill was usually used to perform SSR only, while little was done to implement RAR tests.

The aim of this work is to perform a feasibility study on an elite amputee Paralympic sprinter, comparing GRFs and kinematics during SSR and RAR tests performed on treadmill.

II. Methods

A. Participants

A female, gold medallist, elite Paralympic sprinter with unilateral transfemoral amputation was recruited for this study. The athlete (mass: 55 kg, height: 1.60 m) used Ottobock 1E91 standard RPF Cat. 3.5, mono-axial Ottobock 3S80 knee, and a specific alignment of the socket and the foot [8]. In this case the angle between socket axis and the axis passing through grand trochanter and knee joint centre was 15°.

During all tests the subject wore a safety harness.

B. Experimental Procedure

Tests were performed in a laboratory using a commercial treadmill (SkillRun Technogym) placed on four force platforms (BTS P6000- acquisition rate 1000 Hz). Kinematics was measured using a BTS motion capture system composed of eight infrared cameras (DX-6000, acquisition rate 250 Hz). This setup, as evaluated in [9] could give reliable results as concern SSR GRFs measurements compared with literature.

In this session two type of conditions were studied: Steady State Running (SSR) and Resisted Accelerated Running (RAR).

SSR was performed on the treadmill and consisted in reaching a self-selected constant speed and maintaining it for 7 seconds, time necessary to acquire at least six consecutive steps of each limb. The speed reached during this session was 5 m/s.

As regards RAR, athlete reached a steady speed of 3.11 m/s starting from zero. During RAR the treadmill motor was switched off to simulate passive inertial and air resistance. A load cell (FS 1000 N, acquisition rate 1000 Hz) was fixed to athlete’s back through a preloaded elastic band with elastic constant K=120 N/m to measure the instantaneous resistance applied to the harness at the sacrum bone. In Figure 1 a schematic representation of both configurations is shown.

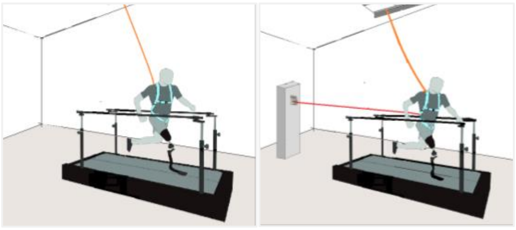

Fig. 1: Schematic representation of SSR (left) and RAR (right).

GRFs analysis

GRFs were collected at 1000 Hz and filtered to remove noise in input. After a spectral analysis of the GRF signal, a zero-phase low-pass Butterworth filter (15 Hz cut-off frequency, second order) was applied to data. Foot-contact and toe-off were detected using a threshold of 100 N on the filtered vertical GRF. For both SSR and RAR tests, GRFs obtained are in ground coordinate system: X- anterior posterior axis pointing forward; Y- vertical axis pointing upward; Z- medial lateral axis pointing rightward.

In the SSR test average curves of GRF_X and GRF_Y of the last 6 consecutives steps for each limb were collected.

In the RAR test, we focused on the acceleration phase and only the first 10 consecutive steps for each limb were considered, starting from the first ground contact of the prosthetic side at the beginning of the running phase. Therefore, to analyse acceleration phase we have considered for each limb 3 steps: one at the start, one during the acceleration, and one at the end. Indeed, from the 10th step onwards, the acceleration became considerably lower and a steady state running was achieved.

C. Kinematics analysis

During tests passive markers ’s anatomical landmarks. The full marker set was composed of 56 markers: 23 applied on the upper part of the body, 4 on the pelvis and 33 on the lower part of the body.

The goal of the kinematics analysis was the calculation of Cardan Angles of hip, knee and ankle joints. The sequence used was ‘ZXY’ for hip and knee, while ‘ZYX’ for foot, considering X- anterior posterior axis pointing forward, Y- longitudinal axis pointing upward, Z- medial lateral axis pointing rightward. For the sound limb hip, knee and ankle Cardan angles were calculated after defining each relative coordinate system. Conversely, for the prosthetic limb, hip and knee joint angles only were calculated. Hip angles were obtained considering the rotation between pelvis and socket, while knee angles were calculated from rotation between socket and foot.

In the SSR test average curve of joint angles of the last 6 consecutive steps for each limb were calculated. In the RAR test, joint angles of the first 10 steps were presented for both limbs.

Finally, to better understand sprinting technique and athlete position during tests, trunk angle was calculated. This angle was obtained considering inclination in the sagittal plane of the segment joining 7th cervical vertebra to midpoint of posterior superior iliac spines with respect to global vertical axis.

III. Results

A. GRFs results

In Figure 3, GRFs average curves of affected (AL) and unaffected (UL) limbs are shown as percentage of stance for SSR test. GRF_Y peak values are of 4.43 N/BW and of 2.60 N/BW for UL and AL, respectively. As concern $GRFs_X$ UL has mainly a braking effect, while AL is mostly propulsive.

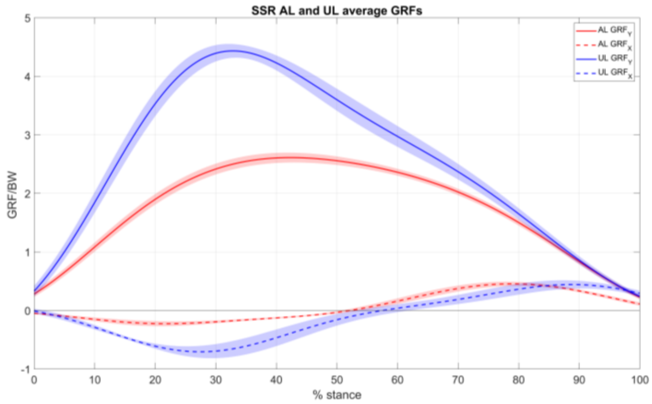

Fig. 3: Average GRFs curves for AL and UL during SSR test

In Figure 4, GRFs from RAR test are shown for three steps of the acceleration phase: 1st, 5th and 9th for AL and 2nd, 6th and 10th for UL. GRF_Y peak values are greater for UL, rather than AL. It could be observed that UL GRF_Y peak values increase from 2nd to 10th step. As regards GRF_X, during the acceleration phase: the braking phase is almost zero for both limbs, and the athlete was pulling an average of 0.185 N/BW on the rope.

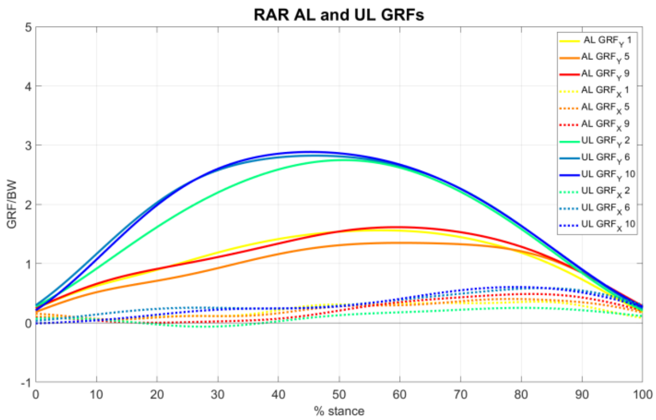

Fig. 4: GRFs curves of three steps for AL and UL limbs during RAR

Table 1 reports spatial-temporal parameters during the acceleration phase for all the steps analysed. The athlete started to run at 1.00 m/s and at the 10th step she reached a speed equal to 80 % of her maximum velocity. As concerns stance time, it could be observed that for both limbs it decreased at increasing speed. AL stance times were higher than those of a consecutive UL step (51 %, 40% and 27 %, respectively).

TABLE I: SPATIAL-TEMPORAL PARAMETERS DURING ACCELERATION PHASE

Step	*Side*	*Speed [m/s]*	*Stance time [s]*
1	AL	1.00	0.236
2	UL	1.15	0.156
5	AL	1.69	0.216
6	UL	1.82	0.152
9	AL	2.19	0.188
10	UL	2.29	0.148

B. *Kinematics results*

In Figure 5, joint angles of both limbs are presented as percentage of stride. For what concern hip angles, it could be observed that AL has a greater flexion angle during stance, rather than UL. At foot off AL hip angle is slightly extended, but considering the initial contact angle, the range of motion varies during stance. Regarding knee angles, differently than UL, the prosthetic knee keeps in extension during the whole stance phase. Indeed, if otherwise, the sprinter would have fallen. Conversely, biological knee is in flexion along the entire stride. Trend shows two flexion peaks: one during stance and one during swing. For the ankle joint only the unaffected limb is presented. During the initial contact with the ground the foot is in plantarflexion and then changes
into dorsiflexion until foot off, where it is again in dorsiflexion.

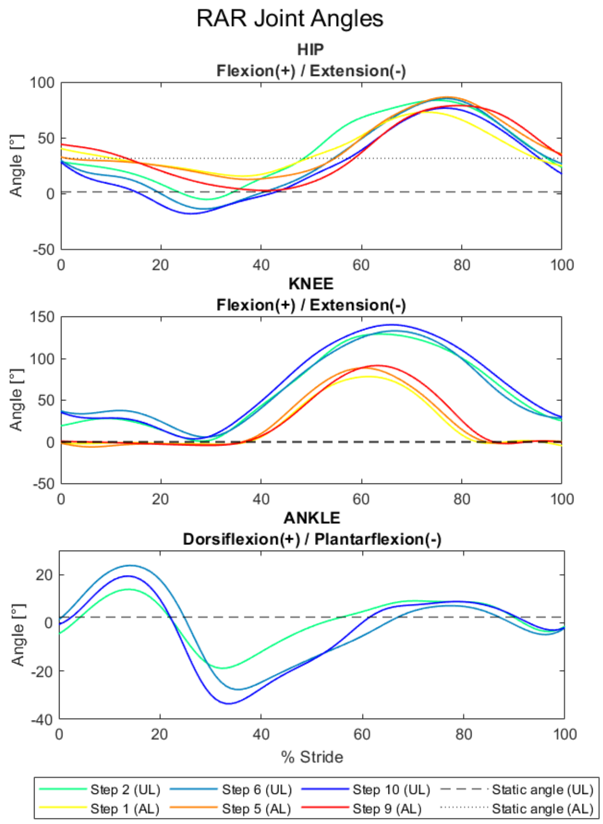

Fig. 5: Joint angles of AL and UL during SSR

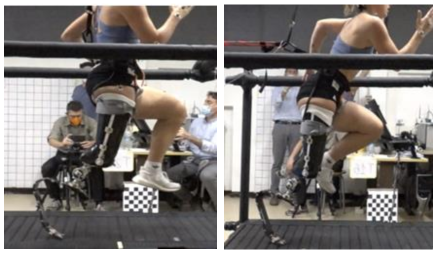

Fig. 7: Trunk inclination during SSR (left) and RAR (right)

Figure 6 presents joint angles of RAR test. As for GRF analysis, we have focused on some steps of the acceleration phase. Regarding hip angles, it could be seen that moving from the first step to the last one, for each limb the range of motion increases. Angles become more and more flexed during the acceleration phase. With reference to knee angles, it is possible to observe that the mechanical knee shows little variability between steps. Its range of motion is different from that of the unaffected one. During swing phase mean values of knee flexion are about 130° and 83° for UL and AL, respectively. Ankle angles presented are referred only to the UL. Ankle range of motion varies from step 2nd to 10th: it increases both in swing and stance phases.

Finally, trunk angle is calculated for both configurations: SSR and RAR. For SSR trunk angle is about 10.92°±2.8°, while for RAR is about 36.5°±2.63°. During RAR trunk is more inclined as shown in Figure 7. Indeed, it is well known that to reach higher speeds athlete propels the body forward.

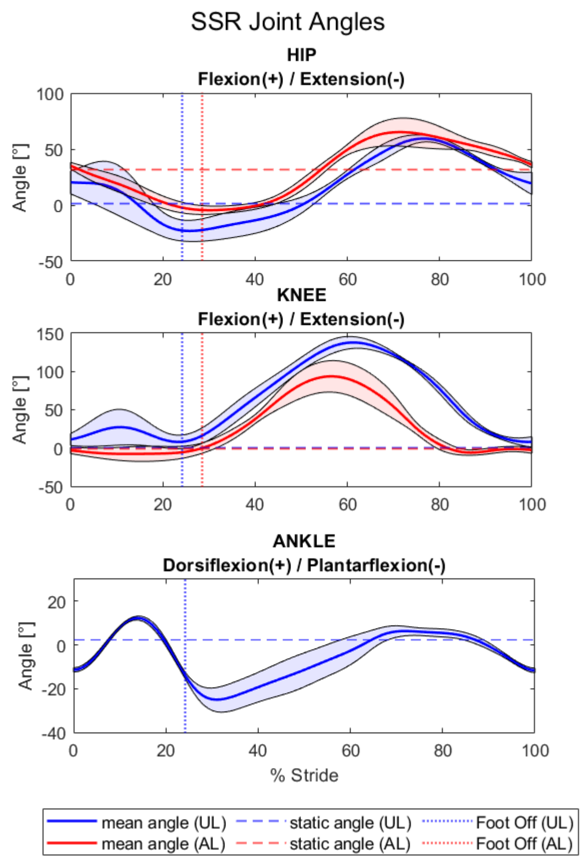

Fig. 6: Joint angles of AL and UL during RAR

IV. Discussion

Biomechanical analysis of GRFs and kinematics is necessary to better understand running technique and help trainers to improve athletes' performance. Concerning differences in GRFs between RAR and SSR, it could be observed that for both limbs vertical GRFs are higher for UL, consistently to previous findings[10], [11]. About horizontal GRF, in RAR no braking phase was present. As expected, during the acceleration phase the athlete needs propulsion to increase the running speed. In RAR test, stance time decreases as speed increases, accordingly with literature [6].

As regards kinematics, the main difference between AL and UL is knee angle. For both tests, during stance, prosthetic knee is always extended, unlike a biological knee where a small flexion occurs [3]. When comparing RAR and SSR tests, main difference regarding knee joint, is that the angle at foot contact is higher in the former case. This different behavior that we measured, agrees with literature which states that knee flexion at foot strike is greater during acceleration rather than maximum velocity sprinting [7]. We would like to verify with further tests if the two conditions are ideally represented by RAR and SSR performed on our instrumented treadmill.

In both tests performed, AL hip is almost entirely in flexion. Indeed, during sprinting as body's center of mass lowers, hip, knee and ankle flexion increases [3]. As observed during RAR trial, hip angles at foot strike keeps constant as speed changes [7].

About differences in kinematics found between SSR and RAR tests, a noticeable change was found in trunk inclination. Coaching observations suggest that during the initial stages of acceleration the body should be at an angle of 45°, compared to 36.5° that were measured in the present work. Then, as sprinter's velocity increases the body become more upr [7]. Another difference regarded ankle joint, it could be observed that during SSR and RAR ankle angle has different values at foot strike. In SSR foot is more plantarflexed than in RAR. This may be related to trunk position; the more the trunk is inclined the more the foot is dorsiflexed. Results obtained during treadmill session will be compared with those obtained in track [12].

V. Conclusions

The aim of the present work was to compare GRFs and kinematics during SSR and RAR tests of an elite amputee Paralympic sprinter. Results confirmed that in both tests AL and UL have different behaviour. At the same time, analysis evidenced differences between the two configurations studied: SSR and RAR. However, the presented work is a case study and further tests are needed to perform an inferential statistical analysis and draw general conclusions on the observed data.

Acknowledgement

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