PROSTHETIC LIMB VERSUS INTACT LIMB TAKE-OFF IN THE AMPUTEE LONG JUMP

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This study investigated whether selected kinematic parameters in the amputee long jump were influenced by the choice of take-off leg (prosthetic or intact). Seven male trans-femoral (TF) and seven male trans-tibial (TT) amputees competing in a World Championships final were video filmed at 100 Hz in the sagittal plane. Selected kinematic variables at touch-down onto the take-off board were computed to define postural characteristics influencing take-off. The TT athletes who took off from their prosthetic limb were able to control their downward velocity at touch-down, as demonstrated by able-bodied athletes, while the TT athletes who took-off from their intact limb could not. Thus, for TT athletes there appears to be some advantage in taking off from their prosthetic limb. The TF athletes were less able to control their downward velocity than the TT athletes. Only one athlete took-off from his prosthetic limb and used a different technique to the rest of the group. Despite possible advantages for this athlete, it is likely that a long jump take-off on the prosthetic limb would lead to higher forces acting through the stump and a greater risk of injury.

KEY WORDS: long jump, biomechanics, disabled, sport

INTRODUCTION: Disabled athletes now have similar opportunities to able-bodied athletes for participation at world level, but a scientific examination of their performances and the effect of their impairment on performance has only recently been the subject of investigation. This limited knowledge of technique and performance characteristics leads to limitations in coaching and ultimately performance. One previous investigation into the techniques used by amputee long jumpers (Nolan and Lees, 2000) has shown that the general model demonstrated by elite able-bodied jumpers (Hay, 1993; Lees et al., 1993, 1994) is adopted by TT athletes, but not by TF athletes in that they are more upright at touch-down (TD) and appear to utilize greater hip extension during take-off.
The long jump model considers performance to be determined by the vertical and horizontal velocities and height of the centre of mass (CM) at take-off, these in turn are determined by velocity and CM height at TD. The ability of amputee athletes to make the adjustments required in changing from a fast running posture to a lowered CM posture at TD, and the effect of using a prosthetic limb on this are unknown. As it is becoming more common for amputee athletes to take-off from their prosthetic limb, the effect of this on long jump performance is also unknown. For the majority of amputee athletes who take-off from their intact limb, the 2nd last stride involves stepping onto their prosthetic limb. As it has previously been shown that lower limb amputees have a longer step length and take a longer time stepping onto their prosthetic than their intact limb (Nolan et al., 2003; Simpson et al., 1998), there may be implications for adjusting stride length and knee angle, and as a result, lowering the CM to achieve an optimal position at TD. Thus, the aim of this study was to investigate the influence of choice of take-off leg (prosthetic or intact) on the adjustments made from the last stride to touch-down in the amputee long jump.

METHODS: Seven male TF athletes and seven male TT athletes were filmed during the finals of the long jump competition at the 2002 World Disabled Athletics Championships. One of the TF athletes and three of the TT athletes jumped off their prosthetic limb (Table 1). A digital video camera (JVC, model DVL9700), recording calibrated sagittal plane movements at 100 Hz, was placed so that the last approach stride to the take-off board were visible.

Table 1 Take-off limb and distance jumped.

Competitor	Level of Amputation	Take-off limb	Best jump (official distance) (m)
1	trans-femoral	prosthetic	5.28
2	trans-femoral	intact	5.08
3	trans-femoral	intact	4.80
4	trans-femoral	intact	4.76
5	trans-femoral	intact	4.67
6	trans-femoral	intact	4.41
7	trans-femoral	intact	3.79
1	trans-tibial	intact	6.79 (WR)
2	trans-tibial	prosthetic	6.42
3	trans-tibial	prosthetic	6.40
4	trans-tibial	intact	6.14
5	trans-tibial	intact	5.84
6	trans-tibial	prosthetic	5.79
7	trans-tibial	intact	5.75

The best jump (greatest official distance) for each competitor was selected for in-depth kinematic analysis. The video was de-interlaced using custom written Matlab software, digitised using eHuman digitising software (HMA Technology, Inc, Ontario, Canada), and analysed using a 9-segment biomechanical model defined by 18 points. The segmental data used (Dempster, 1955), for adult males, were modified for each long jumper to account for the prosthetic limb (Nolan and Lees, 2000). The data were smoothed using a Butterworth 4th order filter and a cut-off frequency of 7 Hz. Several variables were calculated at TD, the first frame in which the foot was clearly seen to be in contact with the ground/ take-off board. These included the height of the centre of mass (H_{CM}), horizontal and vertical velocity, hip angle (Hip_{ang}), knee angle ($Knee_{ang}$), and leg angle at touch-down (Leg_{ang}). The hip and knee angles were defined as the angle between shoulder, hip and knee, and hip, knee and ankle respectively. The leg angle was defined as the angle made by the line joining the CM and the ankle to the vertical. The frames of last stride take-off, the first frame in which the foot was seen to leave the ground, and TD were also used to identify stride length (SL), defined as the position of the toe when the foot was in contact with the ground just before last stride take-off to the position of the toe at TD.

As measurements of the athletes' heights were not available, individual estimated height was calculated as the sum of the length of individual intact segments (Hay and Nohara, 1990), and the H_{CM} was normalised to the individual's estimated height. Groups were established depending on whether the athletes jumped off their intact (TT_{intact} n=4, TF_{intact} n=6) or prosthetic (TT_{prosth} n=3, TF_{prosth}, n=1) limb. Due to the small group numbers, descriptive statistics are presented.

RESULTS AND DISCUSSION:

Centre of mass height: The TF_{prosth} athlete had a lower H_{CM} at TD (54.9%) than the TF_{intact} athletes (57.5%) whose last stride was performed on their prosthetic limb where knee flexion is restricted and is controlled solely by the prosthetic knee. Thus, the disadvantageous high H_{CM} at TD is likely to have resulted from being unable to flex the knee on the LS. In contrast, the TT_{prosth} athletes had a higher H_{CM} at TD (59.1%) than those who took off from their intact limb (56.9%). As all TT athletes are able to flex their knee during LS, this higher H_{CM} position at TD must be due to a lack of extension of their prosthetic leg at TD as noted in Table 2. Thus, there appears to be a noticeable difference in the way that both TF and TT athletes approach touch-down when jumping from their intact or prosthetic limb.

Approach velocity: Horizontal velocity at TD was lower for TF athletes (TF_{prosth} 6.30m.s^{-1}, TF_{intact}, 7.26m.s^{-1}) than for TT athletes (TT_{prosth} 8.72 m.s^{-1} and TT_{intact} 9.15 m.s^{-1}). The vertical velocities at TD also differed (Figure 1), with the TF_{prosth} athlete having a negative velocity

(-1.55 m.s^{-1}) about three times greater than the other TF_{intact} athletes (-0.43 m.s^{-1}). Thus, for the TF_{prosth} athlete, the advantage of being able to lower the CM at TD is offset by the high negative vertical velocity. In contrast, the TT_{prosth} athletes had only a slight negative velocity (-0.03 m.s^{-1}) compared to the TF_{intact} athletes (-0.53 m.s^{-1}). A large negative vertical velocity at TD is a disadvantage as this needs to be reversed before creating the upward velocity required to perform the jump. This suggests some advantage for taking off from the prosthetic limb for the T athletes and is likely to be due to the actions occurring on the preceding stride.

Joint angles: The TF athletes had a more flexed hip and knee at TD than the TT athletes (Table 2). The TF_{prosth} athlete had greater hip and knee extension at TD than the TF_{intact} athletes. This, combined with his lower H_{CM}, led to a greater leg angle at TD (Table 2). Thus, the TF_{prosth} athlete was able to adopt a posture similar to that used by able-bodied athletes. It is worth noting that this athlete won the competition. This is quite a remarkable performance as knee flexion on the prosthetic limb is entirely dependent on the knee mechanism and the loading/ unloading which 'locks' and 'unlocks' the knee. During stance on the prosthetic limb, very little knee flexion is possible as, just after the instance of TD, the knee needs to lock to support body weight. On unloading the prosthetic limb just prior to TO, the knee flexes, hindering any push-off that can be gained by a solid lever arm. Thus, for the TF_{prosth} athlete, taking off from the prosthetic limb has the disadvantage of no active knee extension during TO. With a more extended hip and a lack of active knee flexion/extension, this athlete does not use the compensatory mechanism of increased hip range of motion during take-off previously noted for TF athletes who take-off from their intact limb (Nolan and Lees, 2000). Thus, using of the prosthesis in a knee locked position may enhance the 'pivot' (Lees et al., 1994) and be the main mechanism used by this athlete to gain the required vertical velocity at TO. Whether the use of the prosthesis in this way is an advantage or disadvantage for other athletes is not known and further study is needed, but it is likely that the straighter, stiffer leg at TD will lead to high ground reaction forces with an implication for long-term injury.

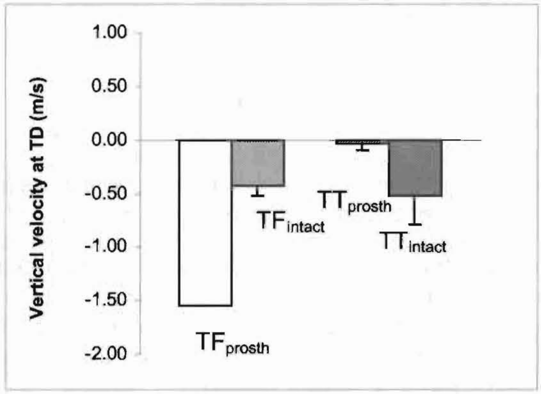

Figure 1 Vertical velocity at TD for TT and TF athletes grouped depending on take-off leg (prosthetic or intact).

All TT athletes exhibited similar hip and knee angles at TD regardless of which leg they took-off from, indicating that a TT prosthesis does not greatly affect long jump TD in the way that the prosthesis does for a TF athlete. The TT_{intact} athletes exhibited a greater (more horizontal) leg angle at TD than the TT_{prosth} athletes which reflects the differences in H_{CM} noted above and may be the result of problems stemming from taking off from their prosthetic limb on the previous stride. Thus, from joint angle data it does not appear that TT athletes have any obvious disadvantages in taking off from the prosthetic limb.

Stride length: All the TF athletes had a shorter strides than the TT athletes which is likely to be due to their slower approach speed as stride length tends to increase with running speed. The TF_{intact} athletes had a shorter LS (1.66 m) (stepping onto the intact limb) than the TF_{prosth} athlete (2.01 m, stepping onto the prosthetic limb) and reflects the longer step length and duration when stepping onto the prosthetic limb found for TF amputees when walking (Nolan et al., 2003). Thus, the TF_{prosth} athlete's long last stride enabled him to achieve a low CM position at TD, but also led to a high negative vertical velocity. Able-bodied athletes tend to extend their 2LS instead of LS (Hay and Nohara, 1990) in order to lower their CM while avoiding creating a large downward velocity at TD, an option not available to this athlete. The TT_{prosth} athletes had a slightly shorter LS (2.05 m) than the TT_{intact} athletes (2.11m). The TT_{prosth} athletes exhibited a higher H_{CM} at TD, and a low negative vertical velocity possibly as a result of their shorter LS. The lower velocity will give an advantage in terms of long jump technique, enabling the impulse generated during contact to be used for creating positive vertical velocity.

Table 2 Mean ± (SD) for hip, knee and leg angle at touch-down onto the take-off board. Presented are the results for athletes grouped depending on their take-off leg (intact or prosthetic). TF = trans-femoral amputees, TT = trans-tibial amputees.

	N	TD_{jump} Hip_{ang}	$Knee_{ang}$	Leg_{ang}
TF_{intact}	6	146 (13)	143 (10)	19
TF_{prosth}	1	**156**	**148**	**24**
TT_{intact}	4	157 (8)	156 (7)	25 (6)
TT_{prosth}	3	**159 (7)**	**154 (7)**	**18 (6)**

CONCLUSION:

There appears to be some advantages to TT athletes who take off from their prosthetic limb in long jump. As there was only one TF athlete who also did this, it is not possible to draw such conclusions for TF athletes. It is not yet known whether prosthetic limb take-off is likely to lead to long term injury and thus outweigh the short-term advantages for TT athletes.

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