GROUND REACTION FORCES DURING LONG JUMP TAKE-OFF FOR TRANSTIBIAL AMPUTEES

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The purpose of this study was to investigate ground reaction forces during long jump take-off for lower limb amputees. Elite transtibial amputee (n=3) and able-bodied (n=6) athletes performed six running long jumps in an indoor athletics stadium with a force plate sunk into the runway. For each athletes' longest jump, vertical (Fz) and horizontal (Fy) peak forces and impulses were calculated. The amputees had a shorter braking impulse duration, followed by a longer propulsive impulse duration with greater peak horizontal propulsive force and impulse than the able-bodied athletes. Vertical loading force and rate of force development at take-off was smaller for the amputees. It may be that amputees attempt to conserve as much horizontal velocity as possible by braking briefly, providing a longer duration in which to apply propulsive forces.

KEY WORDS: ground reaction force, long jump, amputee.

INTRODUCTION:

Many studies have investigated able-bodied long jump technique resulting in descriptive kinematics of the last few approach strides and take-off phase (Hay et al., 1986; Hay and Nohara, 1990; Lees et al., 1994), ground reaction force analysis at take-off (Ballreich, 1973; Luhtanen and Komi 1979; Bruggeman et al., 1982) as well as information gained from mathematical models (Alexander, 1990; Witters et al., 1992; Seyfarth et al., 2000) and computer simulation (Chow and Hay, 2005). As a result, this knowledge has been incorporated into training, coaching and technique analysis of elite able-bodied athletes to further advance the sport.

For athletes participating at elite level at the Paralympic Games and Disabled World Championships, similar knowledge is not available. Only a few studies have investigated the long jump techniques used by lower limb amputees (Nolan and Lees, 2000; 2007; Nolan et al., 2006; Patritti et al., 2005; Simpson et al., 2001) and these have been concerned with describing the techniques using kinematic analysis. Lower limb amputees cannot perform long jump in the same way as able-bodied athletes due to constraints with the prosthetic limb and loss of musculature. Many amputee athletes today are attempting to use the same technique as able-bodied athletes due to lack of information, but trying to replicate an able-bodied technique may be of disadvantage to an amputee athlete (Nolan et al., 2006).

While descriptive kinematics are now available for amputee long jump technique, the underlying causes of the movements, as measured by kinetics, have not so far been investigated and thus a deeper understanding of the event is lacking. The aim of this study is therefore to investigate ground reaction forces at take-off in the long jump for lower limb amputees.

METHOD:

The participants consisted of three unilateral transtibial amputee athletes, (2 male, 1 female, mean ± SD age 25±6 years, height 1.83±0.1 m and weight 70.0±9.4 kg) and six able-bodied athletes (all male, 20±3 years, height 1.85±0.1 m and body mass 74.3±6.4 kg). All participating athletes trained specifically for and competed in the long jump event and all amputee athletes took off from their intact limb. A specially constructed runway 20m x 2m x 0.06m was placed on the long jump approach in an indoor athletics stadium. The runway contained a force plate (Type 9261A, Kistler, Winterthur, Switzerland) which replaced the usual take-off board. A 10mm thick surface suitable for running on in spiked shoes covered both the runway and force plate surface. The outer perimeters of the force plate were marked with white tape so the plate area was easily visible to the long jumpers. The landing pit was filled with extra sand to ensure landing was at the same height as take-off. Ethical approval was given by the Karolinska Institutet ethics committee and written informed consent was obtained from all participants.

Each athlete warmed up then performed 6 jumps as they would under normal training conditions. The only instructions given were to jump as far as possible. All athletes started their run up from the 20m mark. The actual distance jumped for each trial was measured from the front of the force plate. A 50Hz video camera (Sony, model DCR-TRV33E) filmed foot contact on the force plate in the sagittal plane. The distance between the front of the foot and the front of the force plate was later measured using eHuman digitising software (HMA Technology, Inc, Ontario, Canada). This distance was added to the actual distance jumped to obtain 'effective' distance jumped.

The force plate was sampled at 2000Hz using a ProReflex analogue board and QTM software (Qualisys, Gothenberg, Sweden). From the 6 jumps, all athletes performed at least 3 jumps where their foot was fully in contact with the force plate from touch-down to take-off. From these, the best jump (greatest distance) for each athlete was selected for an in-depth analysis of the ground reaction force using Visual3D software (C-motion Inc, MD, USA).

The force data were filtered using a low pass Butterworth filter and a cut-off frequency of 300Hz based on frequency analysis of the force plate signal in its above-mentioned set-up. Several parameters were then calculated for the vertical (Fz) and horizontal (Fy) ground reaction force, normalised to individual body mass (kg) for all subjects. Impact peak force (Fz1), loading peak force (Fz2), total impulse (integral from touch-down to take-off), loading impulse (integral from Fz minima to take-off), rate of force loading (the slope of the line from Fz minima to Fz2) (Figure 1a), and peak braking force (Fy1), peak propulsive force (Fy2), braking impulse (integral from touch-down to the point at which Fy changes from negative to positive) and propulsive impulse (integral from he point at which Fy changes from negative to positive to take-off) (Figure 1b) were calculated. Temporal parameters, expressed as a percentage of the foot contact duration (touch-down to take-off) of: time to peaks Fz1, Fz2, Fy1, Fy2, braking duration (touch-down to the point at which Fy changes from negative to positive) and propulsion duration (the point at which Fy changes from negative to positive to take-off) were also calculated. Due to low subject numbers, descriptive statistics were used. Means, standard deviations and 95% confidence intervals were calculated for the able-bodied group. Individual data are presented for each amputee athlete.

RESULTS AND DISCUSSION:

The able-bodied athletes (AB) jumped a mean ± SD distance of 5.78± 0.41m, while the transtibial amputee athletes (TT) jumped a distance of 4.66 ± 0.4m (4.16m, 5.00m, 4.83m).

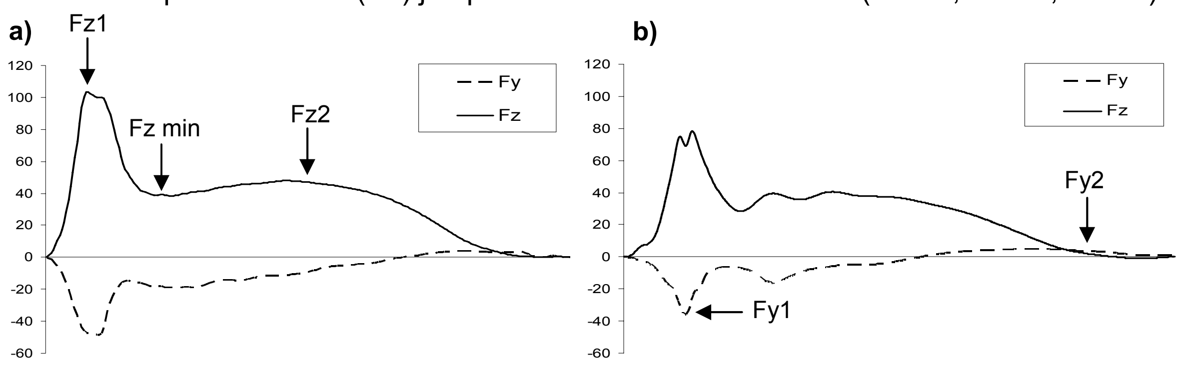

Figure 1 – Example ground reaction forces for a) an able-bodied athlete, b) an amputee athlete. Presented are the forces normalised in the x axis from touch-down to take-off.

The AB athletes' vertical and horizontal ground reaction force and impulse magnitudes, before normalising to body weight, were within the order of magnitude of that previously reported for AB male long jumpers (Luhtanen and Komi, 1979). The AB athletes in this study displayed the same characteristic Fz and Fy ground reaction force curve shapes (Figure 1a) to those previously seen in the above-mentioned literature. The TT athletes exhibited similar shaped curves (Figure 1b), but with some observed magnitude and temporal differences.

Table 1 – Ground reaction force and temporal parameters at take-off. Shown are the means ± (SD) for the able-bodied and individual transtibial amputee athlete results (TT1, TT2 and TT3). All forces are normalised to body weight. * indicates those values for the transtibial amputee athletes that fall outside the 95% confidence interval values for the able-bodied group.

	AB athletes	TT1	TT2	TT3
Fz1 (N/kg)	97.23 (6.32)	78.39*	88.06*	133.21*
Fz2 (N/kg)	48.04(2.84)	40.49*	41.38*	42.93*
Total impulse (N.s/kg)	4.91(0.39)	3.52*	5.18	4.21*
Loading impulse (N.s/kg)	3.47(0.36)	2.44*	3.94*	2.87*
Rate of force development (N/kg.s)	951.89 (610.52)	529.09	370.21	486.86
Fy1 (N/kg)	-57.19 (8.39)	-36.01*	-30.27*	-74.01*
Fy2 (N/kg)	3.99 (0.89)	5.09*	4.36	8.13*
Fy braking impulse (N.s/kg)	-1.48 (0.22)	-0.68*	-1.56	-1.82*
Fy propulsive impulse (N.s/kg)	0.09 (0.02)	0.20*	0.14*	0.36*
Foot contact duration (s)	0.137 (0.02)	0.125	0.175	0.125
Time to Fz1 (% foot contact)	8.7 (1.7)	9.6	8.6	8.8
Time to Fz2 (% foot contact)	38.9 (8.4)	40.0	44.6	41.6
Time to Fy1 (% foot contact)	11.4 (2.4)	11.2	21.7*	9.6
Time to Fy2 (% foot contact)	90.5 (2.3)	81.6*	84.6*	83.2*
Braking duration (% foot contact)	76.6 (2.4)	60.0*	71.4*	60.0*
Propulsion duration (% foot contact)	23.4 (2.4)	40.0*	28.6*	40.0*

During the take-off phase (the period in which the foot is in contact with the take-off board), long jumpers convert horizontal to vertical velocity by 'pivoting' over the take-off leg (Lees et al., 1994) effectively producing vertical velocity at take-off while retaining sufficient horizontal velocity. Ballreich (1973) suggested that for AB athletes, the reduction in horizontal velocity depends not on the magnitude of mean braking force but on the duration of horizontal braking impulse. In the current study, all TT athletes exhibited a shorter braking duration and a lower braking force (Fy1) magnitude than the AB athletes i.e. all had values outside the 95% confidence interval boundary (Table 1). TT athletes have previously been reported to lose less horizontal velocity than AB athletes during the take-off phase (Nolan and Lees, 2000). This occurs mostly during the 'compression phase' (from touch-down to the point of maximum knee flexion). Thus a shorter braking duration may explain why TT athletes lose less horizontal velocity than AB athletes in the initial part of the take-off phase. A negative correlation between braking impulse duration and flight distance has been found for AB athletes (Bruggeman et al., 1982) showing a short braking period is an advantage. However, braking duration for TT athletes is even shorter, possibly in an attempt to conserve as much horizontal speed as possible as they have a slower horizontal velocity at touch-down than AB athletes (Nolan and Lees, 2000; 2007).

During the propulsive part of the take-off phase, all TT athletes displayed a greater propulsive impulse magnitude and duration compared to AB athletes and also as a consequence of the shorter braking duration, reached (a greater) peak propulsive force (Fy2) sooner (Table 1). Thus a greater horizontal force was applied over a longer time for TT athletes compared to AB athletes. For the vertical force, peak (Fz2) force magnitude has been shown to positively correlate with flight distance for AB athletes (Bruggeman et al., 1982). Thus the greater the force magnitude, the longer the flight distance. All TT athletes had a smaller peak Fz2 force magnitude compared to the AB athletes. Thus, while exhibiting a greater horizontal propulsive impulse and force magnitude than AB athletes, TT athletes do not exhibit the same trends in the vertical direction, which may have been due to the shorter braking duration (and less horizontal velocity lost) during the braking part of the take-off phase. One can produce a large vertical impulse even from a low peak or average force by increasing the duration the vertical force is applied over. This is what the TT athletes are doing either in compensation for a low peak Fz2 force, or as a result of a shorter braking and thus prolonged propulsive duration. For example, athlete TT2, who jumped the furthest of all three TT athletes, did not have the highest peak Fz2 force magnitude, but did display a longer time to peak Fz2 force magnitude and longer foot contact time than the other two TT athletes. Consequently, athlete TT2 had a greater loading impulse magnitude than both the other two TT athletes and the AB athletes. A consequence of applying the vertical loading force over a longer duration is that the rate at which the force is developed is small. It is interesting to note that, while not significantly falling outside the confidence interval boundary, the rate of force development for the TT athletes was much less than that of the AB athletes.

CONCLUSION:

TT athletes exhibit similar ground reaction force patterns at take-off to AB athletes but with some observed magnitude and temporal differences. The observed shorter braking duration and longer and greater propulsive horizontal force and impulse are either a compensation for the prosthetic limb or the result of attempting to perform an able-bodied long jump technique. Either way, coaches should proceed with caution when trying to teach a TT athlete to replicate an AB long jump technique.

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Acknowledgement

The authors would like to thank CIF and GIH (Stockholm) for financial support and Oscar Gidewall for help with data collection.