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VERTICAL LOADING RATE USING RUNNING-SPECIFIC PROSTHESES IN TRANSTIBIAL AMPUTEES

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SUMMARY

Recent development of carbon fiber running-specific prostheses (RSPs) has allowed individuals with lower extremity amputation (ILEA) to regain the functional capability of running. However, their potential injury risks due to abnormal loading have not been thoroughly investigated. Loading rate of the vertical ground reaction force (vGRF) has been associated with running injuries in able-bodied runners but not for ILEA. The purpose of this study was to investigate loading rates of the vGRF in ILEA runners using RSPs at a range of running speeds. Eight ILEA with unilateral transtibial amputations and eight control subjects performed overground running at three speeds (2.5, 3.0, and 3.5 m/s). From vGRF, we measured vertical average loading rates, defined as the change in force divided by the time of the interval between 20 and 80% of the first impact peak. We found that loading rate both in ILEA and control limbs increases with an increase in running speed. Further, the loading rates in ILEA intact limbs were 45% and 30% greater than their prosthetic limbs and control limbs for this range of running speeds, respectively. These results suggest that 1) risk of running related injury may increase with running speed not only in able-bodied runners, but also in ILEA runners, and 2) the intact limb in ILEA may be exposed to a greater risk of running related injury than the prosthetic limb and control limbs.

INTRODUCTION

Recent development of carbon fiber running-specific prostheses (RSPs) has allowed individuals with lower extremity amputation (ILEA) to regain the functional capability of running [1]. In spite of this positive trait, the RSPs have not been thoroughly evaluated regarding potential injury risks due to the abnormal loading during running, specifically in unilateral amputees. For example, lower extremity injuries are more common in amputee athletes and typically occur during running activities [2]. Although these injuries are thought to mainly be attributed to the mechanical stress of the ground reaction forces during running [3], evidence regarding the abnormal loading in ILEA during running has not been reported.

It has been shown that abnormal lower extremity loading may be evaluated by vertical average loading rate (VALR)

calculated from vertical ground reaction force (vGRF). Greater loading rates are often implicated as the cause of overuse running injuries, such as tibial stress fractures in able-bodied runners [4, 5]. Although abnormal lower extremity loading during running with RSPs may put ILEA at increased risk for physical injuries and degenerative joint diseases, little is known about VALR in ILEA during running using RSPs. Therefore, the purpose of this study was to investigate VALR in ILEA runners using RSPs at a range of running speeds.

METHODS

Eight male subjects with unilateral transtibial amputations (ILEA) and eight healthy male able-bodied control subjects (ABS) volunteered to participate in the experiment. Each ILEA used his own RSP.

We instructed the participants to run overground on a 100-m long track at 2.5, 3.0 and 3.5 m/s. In order to monitor and concurrently provide subjects with feedback of the desired running speeds, we used six sets of laser sensors around the track. The average speeds over different sections of the track were instantaneously calculated when the subject passed through two consecutive sensors.

Ten six-degree-of-freedom piezoelectric force platforms (9260AA6, Kistler, Amherst, NY) embedded in the running track in series were used to collect vGRFs sampled at 1000 Hz. The vGRF data were filtered using a fourth order, zero lag low pass Butterworth filter with a cut-off set at 30 Hz. Five successful trials for the intact and prosthetic limbs at each of the three running speeds were taken and averaged for the further analysis.

Based on a previous study [4], VALR were calculated for the vGRF as the change in the force divided by the time of the interval between 20% and 80% of the first impact peak (Figure 1). When no distinct impact peak existed, the loading rate was measured at the same percentage of stance as determined for each condition in the trials with an impact transient [5].

A 2x2x3 three-factor repeated-measures ANOVA using Group (ILEA and ABS), Limb (prosthetic/intact in ILEA and left/right in ABS), and Speed (2.5 m/s, 3.0 m/s, 3.5 m/s)

was performed. Group was treated as a between-subject factor while Limb and Speed were treated as within-subject factors. Bonferroni post-hoc multiple comparison tests were performed if a significant main effect was observed. Statistical significance was set at $p < 0.05$.

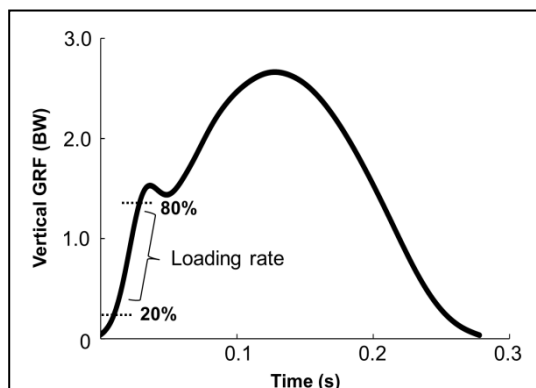


Figure 1: Vertical ground reaction force (vGRF) during the stance phase, recorded from the intact limb of a single ILEA at 2.5 m/s. Vertical average loading rate (VALR) was determined at early stance phase between 20% and 80% before the first GRF peak [4].

RESULTS AND DISCUSSION

No differences were observed between the left and right limbs in control subjects for VALR. Consequently, the data were averaged to generate a representative control limb for clearer presentation in the tables and figures. However, all statistical outcomes were based on the balanced statistical design that included both left/right limbs.

Statistical analyses revealed that there was significant main effect of running speed on VALR (Figure 2; $p < 0.01$). The VALR increased with running speed in all limbs. Several studies demonstrated that the vGRF loading rate increased with running speeds from 1.5 to 8.0 m/s in able-bodied runners [6, 7]. Therefore, the results of the present study suggest that loading rates increase with increasing running speed not only in able-bodied runners, but also in ILEA using RSPs.

Although VALR for the prosthetic limb and control subjects did not significantly differ at any running speeds, intact limbs in ILEA had significantly greater VALR than that in control subjects at 2.5 and 3.0 m/s (Figure 2). These results contrast with a previous finding which stated that the rates of loading (the linear gradient to the maximum vGRF) were significantly higher in able-bodied athletes than in a double amputee sprinter [8]. The differences in the results between the two investigations may be explained by the differences in running speeds (submaximal vs. maximal), computation of the loading rate (20% and 80% time interval of the first impact peak vs. the linear gradient to the maximum vGRF), level of amputation (unilateral vs. bilateral), and type of RSP, or any combination of these variables utilized in the experimental protocols.

Our data also showed that the intact limb in ILEA has greater loading rates as compared to both prosthetic limb and control subjects (Figure 2). Current results corroborate a

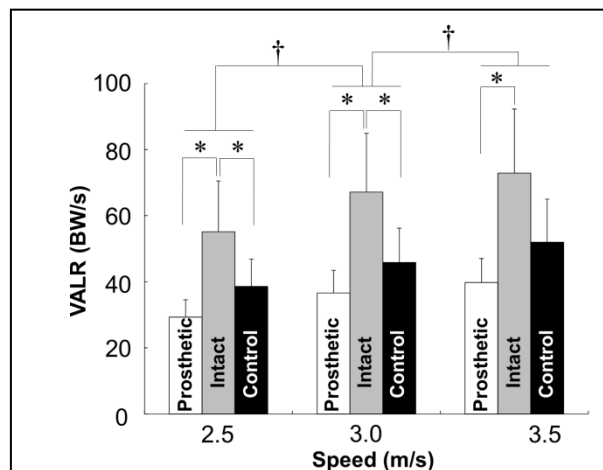


Figure 2: VALR for the prosthetic and intact limbs of ILEA as well as for the limbs of the control group at three running speeds, 2.5m/s, 3.0m/s, and 3.5ms. An asterisk (*) indicates statistically significant differences between limbs at $p < 0.05$. A dagger (†) indicates statistically significant differences between running speeds at $p < 0.05$.

recent finding which demonstrated that the loading rate in the intact limb was greater than that in the prosthetic limb during running in one transtibial amputee [9]. Further, our results suggest that the intact limb may be exposed to a greater risk of injury as loading rates have been indicated as a possible risk factor in developing running injuries [4].

A recent study demonstrated that a forefoot strike pattern in the intact limb in ILEA could decrease loading rates compared to a rearfoot strike [9]. Therefore, as reported in past findings [5], changes in footstrike patterns may be effective to reduce a risk for running related injury not only in ABS, but also in ILEA runners.

CONCLUSIONS

The results of the present study suggest that the vGRF loading rate in both ILEA and able-bodied control runners increases with increasing running speed. Loading rate in the intact limb is greater than both the prosthetic limb and the limbs of control subjects for a range of running speeds.

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