Do prosthetic running blades make you faster?

Observing the effect of mass on speed

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Abstract

For years, there has been an ongoing debate about the ethical implications of amputee-runners and whether they should be allowed to compete in collegiate or post-collegiate athletic events alongside non-amputee athletes. Our proposed study will investigate whether or not prosthetic running blades give amputee-athletes an advantage over non-amputee-athletes. Specifically, we examined the effect of adding mass to prosthetic running blades on swing time, contact time, stride length, and ultimately speed. We hypothesize that adding mass will increase contact time, swing time, and stride length, and decrease speed. These results would suggest that running specific prostheses (RSP) give amputee athletes an advantage due to their smaller mass.

Introduction

Over the last 20 years, since the invention of the first sprint specific prosthetic running blade, the performance of bilateral amputee athletes has increased dramatically. In 2012, Oscar Pistorius become the first amputee track and field athlete to qualify to compete at the summer Olympic Games. Even more recently in January of 2018, Hunter Woodhall became the first amputee athlete to compete in division 1 NCAA track and field. The advent and improvement of these running specific prostheses(RSP) have opened up doors for amputee athletes to compete at the highest level of the sport and earn scholarships to division 1 universities. Some would say that this is just the beginning as prosthetic technology steadily improves and RSP become more and more accessible to amputees who wish to compete. However, in a sport in which the difference between winning and losing comes down to hundredths of a second, as opportunities increase, controversy ensues.

In 2007, just a year before the 2008 Beijing Summer Olympic Games, Oscar Pistorius was banned from competing by the International Association of Athletics Federations (IAAF) because they deemed that his RSP provided him with an advantage over able-bodied athletes. He then volunteered to undergo tests to prove otherwise[5] and was successfully reinstated though he did not make an Olympic team until 2012. The Weyand et al. studies ultimately concluded that Pistorius was “physiologically similar, but mechanically dissimilar” to someone running with intact legs. This result was sufficient to convince the IAAF that there was not enough evidence to ban Pistorius, but the public debate continues around whether or not those “mechanical dissimilarities” confer any type of advantage.

There are many factors that contribute to these mechanical differences between amputee and non-amputee athletes such as mass, length, stiffness, and material. However, in our study, we chose to focus on mass. Considering that a RSP weighs about half as much as a biological lower leg, the lightweight mass of a RSP is widely considered to be a source of an advantage. This study seeks to observe the impact of mass on swing time, contact time, stride length, and ultimately speed in bilateral transtibial amputee sprinters to determine whether or not the mass of the blade prosthetic confers an advantage to these amputee athletes.

Previous Studies

Due to the recent controversies regarding bilateral transtibial elite amputee runners, the body of research comparing non-amputee athletes to amputee athletes has grown considerably over the last 20 years. Amputee athletes and non-amputee athletes have been evaluated side by side with regards to many kinematic and dynamic gait-related parameters, and the mechanics of bilateral transtibial amputee running are well documented. However, there is still not enough information to determine a clear interpretation of the exact mechanism through which these mechanical properties confer an advantage or disadvantage to the amputee athlete and there remains much disagreement in this area.

Fortunately, the technology used to observe gait has also improved over the past 20 years. It is now standard practice across studies of gait at sprinting speeds to have participants run on treadmills equipped with force plates to measure ground reaction forces and slow-motion cameras to obtain information on metrics such as swing time and contact time (Weyand et al., 2009). Outside of the laboratory, some studies are even able to set up motion capture systems to record gait parameters in three dimensions in a more natural setting, allowing the runner to reach top speeds without the help of a treadmill (Bruggman, 2008). Such technology has allowed for very precise collection of data on gait parameters albeit on small sets of data.

One of the limitations of the previous research in this field is that large sample sizes are difficult to obtain because there simply aren't very many elite transtibial amputee sprinters. Standard sample sizes for these studies range from 1-5 amputee participants, which is not enough to rule out biological variation as a confounding variable despite matching amputee athletes with non-amputee athletes. Nonetheless, researchers have been able to perform and repeat experiments and come to some generally agreed upon conclusions.

It is known that amputee sprinters are able to reach the same top speeds as non-amputee sprinters (Weyand et al., 2009) (Bruggman, 2008). However, they are able to do so with slightly lower metabolic costs (Weyand et al., 2009) (Nolan, 2008), longer contact times (Weyand et al., 2009) (Hobara, 2014), and shorter swing times (Weyand et al., 2009), than non-amputee sprinters. With respect to ground reaction forces (GRFs), amputee athletes generate lower vertical GRFs (Bruggman, 2008) (Hobara, 2014), lower horizontal braking GRFs, and lower positive horizontal GRFs (Bruggman, 2008). Lastly, in regard to joint moments, amputee athletes developed higher "ankle" joint moments and lower knee flexion moments (Bruggman, 2008) (Nolan, 2008). These results have been found in several studies and are generally agreed upon within the subsection of the biomechanics community that studies amputee running. Although, there are still many there are still many questions with regards to whether or not these traits confer an advantage and to what extent.

In the case of contact time, some argue that longer contact times are a disadvantage because they cause the amputee runner to have a lower stride frequency despite faster swing times. Others would argue that these longer contact times act as an advantage because they give the athlete more time to generate stronger moments and GRFs (though not at the level of non-amputee runners). Researchers still need to gain a better idea of how energy is stored and released during contact and the relative influence of ground reaction forces and moments in contributing to an advantage or disadvantage.

Another area of study that is similarly well-researched, but also inconclusive is that of the effects of additional loads on gait parameters and metabolics in walking and running. In a 2010 study, Weyand and Bundle state that “the moment in athletic history when engineered limbs outperform biological limbs has already passed” (Weyand and Bundle, 2010). The researchers claim that RSP allow amputee athletes to achieve artificially high running speeds because they weigh less than half of what fully biological lower limbs weigh. In a 2010 published counterpoint, Kram et al. argue that due to exceedingly small sample sizes, Weyand and Bundle have insufficient evidence to make such claims (Kram et al., 2010). Kram et al. also suggest several potential studies that could add to the discourse, such as a thorough study of leg swing times for elite runners and a study of GRFs in unilateral amputees (Kram et al., 2010). Furthermore, Kram et al. hypothesize that adding mass to RSP of amputees will not increase swing times or decrease maximum running speeds (Kram et al., 2010), a hypothesis which goes untested.

Many studies have examined the effects of loads added to lower limbs while walking and running, though several draw conflicting conclusions. Several scholars conclude that increasing mass increases oxygen consumption and net metabolic rate (Divert et al., 2008) (Browning et al., 2007) and that the effect increases as the mass is place more distally on the body (Myers and

Steudel, 1985) (Browning et al., 2007). Some researchers found that adding mass to the feet of non-amputee runners produced a small, but significant increase in stride length, swing time, and flight time (Martin, P.E. 1985), while others found that adding mass to ankles of non-amputee runners did not significantly affect stride length or frequency (R. Cavanagh et al., 1989).

Several studies and review articles have examined the effect of adding loads to prosthetics in amputees while walking and have concluded that as mass is added (within the range tested), the kinematics and energy aspects of walking gait do not change (Rietman et al., 2002) (Selles et al., 1999). These studies, however, are limited by small sample sizes ranging from n = 1 to n = 10, and only examine the effect of added mass on walking gait parameters.

Previous studies have examined how amputee athletes compare to non-amputee athletes, how adding mass to the body of a non-amputee affects gait parameters and metabolics while walking and running, and how adding mass to the prosthetic of an amputee affects gait parameters and metabolics while walking. However, there has been little to no research conducted that investigates the effects of adding mass to the prosthetic of an amputee on gait parameters and metabolics while running or sprinting. Furthermore, most of the studies that involve the effects of mass measure gait parameters and metabolics while the participant is walking or running at constant, designated speeds. This precludes the researchers from determining the effect of added mass on maximum or average speed.

Proposed Research

Our proposed experiment aims to fill gaps left by previous research by examining how adding mass to the RSP of amputee athletes affects their speed and gait. Specifically, we will measure average speed, stride length, contact time, and swing time. We selected these parameters because we are interested in comparing the speeds of amputee and non-amputee athletes, and the two elements of speed are stride length and stride frequency. The gait cycle duration (inverse of stride frequency) can be divided into contact time (when the foot is on the ground) and swing time (when the foot is in the air). In addition to determining the effect of mass on speed, we will be able to determine which changes in specific gait parameters are responsible for a change, or lack thereof, in speed. We hypothesize that increasing the amount of added mass to the RSP of an amputee athlete will decrease his or her speed and increase his or her stride length, contact time, and swing time. This study will contribute to the larger conversation about whether RSP give amputee athletes an advantage over non-amputee athletes by determining whether or not the lightweight quality of RSP affects the speed of amputee athletes while sprinting.

Methods

Subjects. Ten healthy male or female elite bilateral transtibial amputee sprinters will serve as subjects in this study. We will recruit only sprinters that regularly use a Cheetah sprinting foot blade prosthetic (manufactured by Ossur). While this will narrow the selection pool, it will reduce the number of independent variables that would be introduced if we were to use different kinds of RSP. It would also eliminate the need for training each athlete to use the Cheetah, which would be necessary if we accepted subjects that were unused to running with a Cheetah. Each of the participants will be matched with an elite non-amputee sprinter based on gender, leg length, weight, age, and fitness level. Informed consent will be obtained from all subjects prior to their participation in the study.

Testing procedures. Each amputee subject will receive a custom-fitted Cheetah® Xtreme™ sprinting foot one month before the data collecting portion of the study, which will give them time to practice with and adjust to the new RSP. We will collect data on a publicly accessible track, where the subjects will sprint 100 meters. It is widely postulated that due to relatively slower accelerations, amputee athletes have an advantage over longer distances and a disadvantage over shorter distances. Since we do not want to favor either the amputee or non-amputee subjects, we chose 100 meters as a medium distance. The experimental apparatus will include several high speed slow motion capture cameras with a sample rate of 1000Hz. The cameras will be arranged along the length of the track, oriented to record each sprinter in the sagittal plane as he or she runs the length of the 100 meters. We will also have one camera on a moving track that will keep pace with and record each sprinter in the sagittal plane.

Three load conditions will be employed such that the effects of load magnitude can be examined. This will include (1) a baseline condition in which no additional load is carried; (2) 1.5kg added to the top of each RSP; and (3) 3kg added to the top of each RSP. Each amputee subject will participate in at least nine test sessions, made up of three trials of all three load conditions. Each non-amputee subject will participate in at least three test sessions, made up of three trials of only the first load condition. During each trial, we will use the previously described slow motion capture system and standard high-speed cinematography procedures to record each subject as he or she sprints 100 meters under the selected load condition. In post-editing, we will determine the average speed, stride length, contact time, and swing time achieved in each trial. Since the subjects will be sprinting at their respective maximum speeds, each subject will only perform one trial per day, which will give each subject a chance to recover between trials and reduce the influence of fatigue on our results.

This study is designed primarily to determine the effect of adding mass to RSP on speed, stride length, contact time, and swing time. The matched non-amputee subjects are included in the study to provide context for the results of the amputee subjects, since we are trying to contribute to the larger conversation about the comparison between amputee and non-amputee athletes.

Statistical Analysis. Data for the physiological variables will be analyzed statistically using analysis of variance (ANOVA), which will be able to compare all four means (RSP with no mass, RSP with 1.5kg, RSP with 3kg, and non-amputee) and determine statistical significance. If the differences between the groups are found to be statistically significant, then we will perform paired t-tests on the relevant pairings of groups.

Expected Results

The following is a set of sample results that we may expect to generate in our study. Figure 1 displays the expected means and standard deviations for the physiological variables in each of the four test conditions. As stated in our hypothesis and reflected in Figure 1, we expect that adding mass to the RSP of the amputee subjects will significantly decrease speed and significantly increase stride length, contact time, and swing time. Figure 1 also illustrates our expectation that the non-amputee subjects will achieve higher speeds, shorter stride lengths, shorter contact times, and longer swing times than those of amputee subjects under all load conditions.

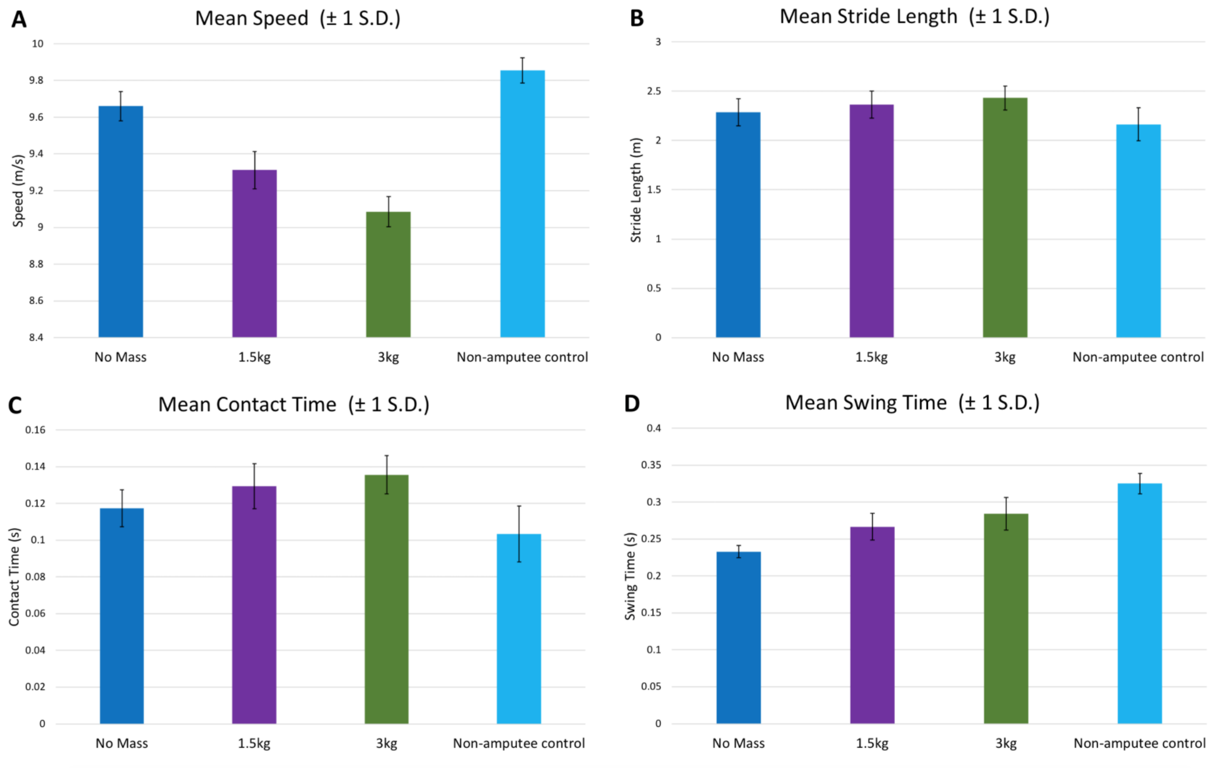

Fig. 1. Shown are speed (A), stride length (B), contact time (C), and swing time (D) during 100 meter track sprinting trials for our bilateral transtibial amputee (n = 10) and intact-limb (n = 10) sprint subjects under four different test conditions: (1, dark blue) amputee subject with no added mass; (2, purple) amputee subject with added 1.5kg; (3, green) amputee subject with added 3kg; and (4, light blue) non-amputee subject with no added mass. With more mass added, the amputee subjects are expected to achieve slower speeds, and longer stride lengths, contact times, and swing times. It is also expected that the non-amputee subjects achieve faster speeds, shorter stride lengths, shorter contact times, and longer swing times than amputee athletes under all load conditions. The error bars illustrate ± 1 SD.

Discussion

These results would imply that the smaller mass of RSP do give bilateral transtibial amputee athletes an advantage. However, the results would also indicate that the advantage is not significant enough to give the amputees a net advantage over non-amputees, which suggests that other disadvantageous factors outweigh the advantage gained from the smaller mass of RSP.

However, it is of note that there are several limitations to this study and those in the body of research in general. To begin with, small sample sizes are a significant issue in many amputee studies simply because it is difficult to find many elite bilateral transtibial amputee athletes. With

10 participants, this sample size is more than twice as large as most other studies of this sort. Nonetheless, it still remains too small to rule out individual variation as a possible confounding variable despite our best efforts to control for biological factors. Moreover, adding mass to the top of the prosthetic simulates the weight of the biological lower leg, but it is still far from similar to the distribution of weight along a biological lower limb. Our study could more accurately capture the effect of weight if it could be distributed down the lower leg more similar to the way mass is distributed in the lower leg and foot.

Moving forward, in addition to recruiting a larger sample size and distributing the load more accurately, it would also be informative to run similar tests on unilateral amputee elite sprinters to see if they experience similar results and if there are differences in performance between their intact leg and RSP. One could further expand this study by also collecting data on ground reaction forces, moments, and mechanical work, which would allow us to better understand the extent of their roles in the changes observed at different added masses.

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