Sprinting with an amputation: some race-based lower-limb step observations

Abstract

Study Design

The study comprises two elements:

1) A video based analysis of race based limb to limb symmetry

2) A video based analysis of race based step count.

Background/Objectives

T44 sprinting with an amputation is still in a state of relative infancy. Future scope for athletic training and prosthetic limb development may be assisted with a better understanding of information derived from T44 athletes when under race-based conditions. To this end, the behaviour of both step count and step frequency are investigated when under competitive conditions.

Methods

Video analysis of several major events from 1996-2012 are assessed for step count and step limb to limb symmetry characteristics,

Results

The video analysis highlights limb to limb imbalances greater than those indicated in previous literature. A low step count is determined to be desirable for success in the 100m event.

Conclusions

Future analysis of athletes with a lower-limb amputation would be worthwhile when placed under race based conditions as the limb to limb behaviour is more exaggerated than those seen in typical studies held within a laboratory setting. The within-event behaviour of step counts requires further investigation to establish where these take place or whether it is a cumulative step length issue.

Word Count of Abstract: *184*

Keywords

Sport with a disability, amputee, sprinting.

Clinical Relevance

This paper increases the understanding of race-based behaviour of amputee athletes and provides more information to contribute to any discussions on the performance of lower-limb prostheses.

Word Count of Clinical relevance: *26*

Background

The purpose of lower-limb prostheses is to help a user maintain a full and active lifestyle[1]. This assistive technology is also used under extreme loads and conditions in elite sports competition[2]. It has been suggested that to break any plateaus in sporting performance, greater improvements in the future will be driven by revolutions in sports technology rather than athletic performance[3]. As a result, a greater understanding of such technology is worthwhile so as to improve its design and function.

Competitive amputee sprinting is still in a state of relative infancy and has been previously evaluated[4-6]. This has more recently been driven by controversy surrounding the prosthetic limbs functional contribution[7,8]. However, the limitation of these studies is that it is not known how athletes with an amputation behave under actual competitive conditions. Such environments may alter an athlete's behaviour due to the level of emotional stress or the inability to cope[9]. It has been suggested that it is beneficial to ascertain if conditions simulated in the laboratory actually reflect those in real life[10] and this is of concern in sport with a disability[11]. This is known as the pursuit of *ecological validity*[10].

The pursuit leading to ecological validity is the need for context or event specific data[11]. In track athletics this can be achieved through the analysis of race-based footage of athletes[12]. The limitations of using race footage to form conclusions are its limited availability or subsequent quality. Even then, only an athlete's stride count and characteristics can be evaluated rather than the primary key performance indicators of sprinting such as ground reaction force[13]. This aside, lower-limb symmetry has been remarked as desirable in running gait[4] although this has been assumed in previous literature[14]. Biomechanical asymmetry has been shown to exist in amputee running[5,6] and has been indicated to be affected by the level of disability and the prosthesis employed[15]. In trans-tibial amputee sprinting, there have been observations that typical asymmetry exists in stance or swing phase ratio's and for step lengths[16]. It would be beneficial to provide further evidence of limb to limb behaviour observed from race-based conditions to see if such imbalances are noticeably distinctive to those reported in laboratory based studies.

Methods

To assess running with a lower-limb amputation under race-based conditions, race-based HDTV footage is used. Athletes step count and step limb to limb symmetry are evaluated.

Television based footage utilises the best field of vision and recall of an event that would be more difficult to undertake as an observer. The footage used for this study was derived from public domain sources including Paralympics TV (http://www.paralympic.org/Videos) via Youtube (www.youtube.com).

There are 3 competitive running distances that occur in the current Paralympic Games format. These events are the 100, 200 and 400m running distances. However, the issue with such events (and its subsequent footage) is that due to the *switch between* and *panning of* multiple video cameras, the same athletes do not always remain in shot or in clear view. This makes any assessment of their stride characteristics problematic. The only event which minimises such issues is the 100m sprint event. As a result, the male T44/43 100m event was investigated in this study.

The selected video footage was checked to ensure that its televised recording speed was the same as the actual events results. It was also evaluated for its visual quality to allow clarity of an athlete's ground impact. The footage was then imported into the Quintic Biomechanics 9.0 software (Quintic Consultancy

Ltd., Coventry, UK) which allowed frame by frame evaluation at the footages maximum specification of 0.04 second increments (25 frames per second).

The analysis in this study is split into two investigations. The first investigates *step count* and the second *step symmetry*. All athletes' names and performances are a matter of public record.

Step Count

When reviewing the footage to assess step count, the numbers of steps taken in the footage (by as many athletes that remain in shot for its duration) are recorded to achieve the 100m race distance. As the step count to achieve the 100m is never exact, the number of steps judged closest to the actual finish line is taken as the measured value.

The four events and its source evaluated for step count were:

- 1996 Paralympic Games T44/T43 100m Final (http://www.youtube.com/watch?v=WYxBWIY8iYc)
- 2008 Paralympic Games T44/43 100m Final (http://www.youtube.com/watch?v=UDDhZx54Jy4)

- 2011 IPC World Athletics Championships T44/43 100m Final. (http://www.youtube.com/watch?v=LTxypZ71-30)
- 2012 Paralympic Games T44/43 100m Final. (http://www.youtube.com/watch?v=mcdUsMULNzo)

Step Timing Symmetry

Whilst several videos were found to be available, only seven pieces of race-based video footage had the visual resolution it was felt to be examined in close enough detail to evaluate the footfall behaviour. Of these, four pieces of footage were of qualification heats of both the 2008 and 2012 Paralympic Games. In these, it was seen that several athletes intentionally slowed down before the finish line. This meant their stride would sometimes be seen to visibly slow down or shorten in stride length towards the end of an event. This made such data not representative of the events maximal effort and was therefore rejected from this study. In addition, the athlete’s reaction time to the starting pistol could not be confidently evaluated as this exact moment was not within the unit of measurement of the analysis software or the video footage.

The three suitable races evaluated for step frequency and symmetry were:

- 2008 Paralympic Games T44/43 100m Final (http://www.youtube.com/watch?v=UDDhZx54Jy4)
- 2011 IPC World Athletics Championships T44/43 100m Final. (http://www.youtube.com/watch?v=LTxypZ71-30)
- 2012 Paralympic Games T44/43 100m Final. (http://www.youtube.com/watch?v=mcdUsMULNzo)

When reviewing the footage, a definition of ground impact was required to define when a ground step-based impact had taken place. A ground impact was determined whereby the foot is seen to contact the ground just prior to the lower-limb beginning to bend at the knee and the prosthesis is seen beginning to compress.

The greatest possible error of the video footage evaluation is defined as half of the measurement unit. Therefore, potential errors in the step symmetry data are 0.02 seconds. The tolerance interval (or margin of error) is defined as +/- 0.02 over the established measurements. However, due to the conceded large imprecision of the video analysis process, the largest error possible is defined here as one measurement increment of +/- 0.04. Therefore, only a large and distinct change of greater than +/-0.04 from the previous data point is proposed to be significant in this study to then be defined as lower-limb asymmetry. It is conceded that such a large tolerance interval could be criticised since the method lacks the precision and accuracy seen in traditional laboratory based studies. However the value of this study is to investigate the step to step behaviour in a race-based environment and therefore contributes to the ecological validity of this area. To date, this has not been evaluated in this area.

The athletes were classified as having three types of lower-limb behaviour. These are designated as lower-limb to limb symmetry (LS), lower-limb to limb asymmetry (LA), and random event asymmetry (RA). LS is defined as a limb to limb timing within the measurement precision. LA is defined as a consistent limb to limb timing imbalance of greater than 0.04 seconds. RA is considered a single event limb to limb timing imbalance of larger than 0.04 seconds.

Results

Step Count

The recorded step count data is shown in figure 1.

It can be seen that in the race footage samples, the lowest step count is typically desirable to achieve the best possible finishing position. An event winner typically takes no more than 49 steps with other medal winners typically producing one step fewer. Interestingly, some slower runners in both 2011 and 2012 also exhibited a low step count yet performed poorly.

Step Symmetry

When reviewing the footage, three athletes in the 2008 event, six from 2011 and four from 2012 gave an appropriate level of visibility for their races and were therefore included in the results.

The three athletes' lower-limb to limb timing footfalls in 2008 are shown in figure 2.

Figure 2 illustrates the time taken from the foot's ground impact to the alternate foots impact upon the track. Both Pistorius and Singleton exhibited a lower-limb symmetry within the acceptable tolerance range of the study. However, Fourie demonstrated significant step to step RA in the first few strides of his race. It took him four steps to reduce to a more typical level of LS seen with the other athletes. Fourie's mid section of his race shows an extremely symmetrical period of limb to limb timing. Singleton demonstrated relatively consistent LS during his event. However, the last three steps of his event were slightly slower in duration.

The six runners from the 2011 World Championships are shown in figure 3.

In this event it can be seen that bi-lateral amputees Pistorius (2nd) and Leeper (5th) exhibit very high levels of lower-limb symmetry. Singleton has brief RA at the start and again with his finish. Oliveira's run was only visible for the first half of the event. This aside, he exhibited RA at his start and sporadically throughout the first half of the event. Pistorius had relative LS but his last stride saw a one-off RA. Peacock had extremely consistent initial LA until the latter part of the race whereby his gait reflected LS.

At the 2012 Paralympic Games, four athletes produced clear line of sight for evaluation. These are summarised in figure 4.

Peacock showed great improvement from the 2011 event to then later in 2012. However, his run still demonstrated significant RA. Unlike 2011, this took place towards the middle rather than the start of his race. Browne's run is perpetuated by RA throughout his event. Fourie exhibits RA after his start and towards the final stages of his run. Pistorius exhibits LS which is typical of both his 2008 and 2011 events.

The number of RA’s of athletes from the 2008, 2011 and 2012 events are summarised in table 1.

The finishing position does not correlate to the number of RA events. Peacock has improved his finishing position performance in the 100m between 2011 and 2012 yet still displays a large level of random RA between his two lower-limbs.

Discussion

Step Count

The step count data suggested that at elite level, a low step count of no more than 49 steps is desirable to perform well in the event. An assumption can be made that the step to step distance will vary throughout the event due to the rate of acceleration or speed at any given stage. However, the low step counts exhibited here suggest that step to step flight time is important. It is not clear in this study regarding the impact of the start technique and reaction time. It is conceded that this may affect the net step count if the first step out of the start blocks is performed poorly or is shorter in length than expected. The start will require further evaluation at a level beyond the resolution of the recorded TV footage. However, based upon the data in this study, it is proposed that stakeholders such as coaches could assess an athlete's step count to initially investigate the potential competitiveness of an athlete. A high step count could indicate an undesirable physical ability or that their prosthetics technology requires further adjustment.

Step Timing Symmetry

This study shows that in the limited number of case studies available, randomised asymmetry behaviour does take place in elite 100m competition.

It is conceded, knowing the limitations of the HD footage that the 25 frames per second is not a high enough resolution to detect the precise level of ground step to step asymmetry. However, the degree of consistent LA witnessed in this data is not dissimilar to those reported in published literature. This has seen lower-limb step timing asymmetry of 0.02 sec at 3.5m/s and 0.03 at 2.7m/s[17]. Despite the limitations of this method, the data has seen random asymmetry events of levels larger than those reported in this literature. This study reported some as great as 0.08 seconds. From this it could be concluded that athletes under race conditions can create occasional asymmetry that may not be reflected when running at either slower speeds, at a steady state or in non competitive environments. Differences in an athlete's prosthetic length are unlikely to be the root cause as previously proposed[18] when the asymmetrical step timing events are so randomised.

Limb to limb step timing asymmetry may not be a barrier to success in itself. Peacock went from finishing 6th to 1st from 2011 to 2012 yet still exhibited a similar level of RA in his races. However, what might be more important is *where* he exhibited the RA. In 2011 it was at the start whilst he was trying to accelerate. Yet in 2012 it took place when he was already closer to a steady state speed. It is proposed that the net loss in speed would be lower if the RA takes place later in the event. The impact of randomised step to step timing asymmetry within the 100m event (and its impact on running speed) is suggested for closer study in the future.

The actual cause of RA's is unknown. However, in some cases, a root cause can be identified by qualitatively assessing the race footage. For example, Singleton in 2008 and both Singleton and Pistorius in 2011 demonstrated RA in the last few steps of their events. The reason for this could be assumed to be physiological fatigue yet when looking at the video, both athletes were involved with a lunge for the line. However, when reviewing other athletes mid race step to step asymmetry, the root causes could not be clearly identified. It is proposed that the cases of RA need to be evaluated qualitatively alongside the quantitative data. Any RA's could be attributed to a poor start, a slow start, fatigue, falls, or torso lunging. . It could also be speculated that mid race RA's may not be the direct fault of the athlete themselves but as a result of their prosthetics technology. These events are recommended for further study in the future.

Consistent asymmetry in this study was not clearly obvious due to the previously conceded limitations of the measurement resolution. This is not to say it does not exist, but that it is not evident within the margin of error. However, large scale randomised asymmetry was still seen to occur in several cases. The cause of this could not easily be explained and the root causes require further investigation.

Conclusion

It was seen that within race-based video footage of athletes competing in the T44/43 100m event, a low step count of less than 50 steps may help athletes achieve better results. This will provide coaches with some insight regarding an athlete's potential for success in this event in the future.

The video evaluation methods were limited by the constraints of HD TV footage and did not provide suitable precision of ground step to step asymmetry of less than 0.04 seconds. However, some athletes' demonstrated large scale randomised step to step timing asymmetry that was greater than 0.04 seconds. The reasons for these events could not be explained and is worthy of further study.

Main text word count: 2537

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