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# The Impact of Blade Technology on Paralympic Sprint Performance Between 1996 and 2016: Bilateral Amputees' Competitive Advantage

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It is known that high-performance sprinters with unilateral and bilateral prosthetic lower limbs run at different speeds using different spatiotemporal strategies. Historically, these athletes still competed together in the same races, but 2018 classification rule revisions saw the separation of these two groups. This study sought to compare Paralympic sprint performance between all-comer (i.e., transfemoral and transtibial) unilateral and bilateral amputee sprinters using a large athlete sample. A retrospective analysis of race speed among Paralympic sprinters between 1996 and 2016 was conducted. In total, 584 published race results from 161 sprinters revealed that unilateral and bilateral lower-extremity amputee sprinters had significantly different race speeds in all three race finals (100 m, $p$ value <.001; 200 m, <.001; 400 m, <.001). All-comer bilateral amputee runners ran faster than their unilateral counterparts; performance differences increased with race distance. These data support current classification criteria in amputee sprinting, which may create more equal competitive fields in the future.

***Keywords*:** classification, clinical/sport biomechanics

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The World Para Athletics (track and field) classification system serves two primary purposes: to determine who is eligible to compete in Para athletics competitions and to separate athletes into evidence-based sport classes to ensure equitable competition (Tweedy et al., 2016; Tweedy & Vanlandewijck, 2011; World-Para-Athletics, 2018b). As defined by the International Paralympic Committee (IPC) Athlete Classification Code, each sport class contains athletes with similar degrees of activity limitation based on their ability to perform a sport's key athletic disciplines: running and jumping, wheelchair racing, and/or throws (International Paralympic Committee, 2015; Tweedy & Vanlandewijck, 2011; World-Para-Athletics, 2018b). Runners with lower limb amputations who perform on the track or road are principally classified by the number of amputations and the relationship of amputation to the knee joint (World-Para-Athletics, 2018a). Before January 1, 2018, athletes in the "T42" sport class had a unilateral above-the-knee lower limb amputation or a condition that was functionally comparable. Athletes in the "T43" sport class had bilateral below-the-knee amputations (or combined arm/leg amputations) or a condition that was functionally comparable (World-Para-Athletics, 2018a), whereas athletes in the "T44" sport class had a unilateral below-the-knee amputation or could walk with moderately reduced function in one or both lower limbs (World-Para-Athletics, 2018a). As of January 1, 2018, revised classification rules saw sprinters with double- and single-leg amputation allocated into different sport classes ("T61–64"), in part due to observations that these two groups of athletes (i.e., those with unilateral lower limb amputation—T61, T62—vs. those with bilateral lower limb amputations—T63, T64) ran at different race speeds, using different spatiotemporal strategies (Hobara, 2014). Blade laterality was additionally implicated as a determinant of sprint performance (Taboga et al., 2016).

The introduction of energy-storing sprint prostheses in the early 1990s is one of the greatest inventions for Para athletics (Hobara, 2014; Nolan, 2008). Designed to mimic the spring-like properties of the human leg, running-specific prostheses (RSPs) have allowed athletes with prosthetic lower limbs to participate in athletics, significantly improve their performances, and protect their safety (Beck et al., 2016; Groothuis & Houdijk, 2019). Performance-related improvements in prosthetic technology, combined with the varying configurations amputee sprinters use, have fueled a debate over the extent to which energy-storing sprint prostheses impact (i.e., improve or impair) amputee sprint performance (Hassani et al., 2014, 2015; Weyand et al., 2009; Zettler, 2009). In the extant literature, there is minor disagreement over the exact impact sprint prostheses have on performance. Hassani proposed that runners with two prosthetic lower limbs may have a speed advantage over those with one or none in races longer than 400 m (Hassani et al., 2014). Hobara has shown that bilateral transfemoral amputee sprinters run at faster speeds with longer step lengths and lower step frequencies than unilateral transfemoral amputee sprinters (Hobara, 2014). Taboga found that in curve-running, unilateral transtibial amputee sprinters with their affected leg on the inside of the curve ran slower than counterparts with their affected leg on the outside of the curve (Taboga et al., 2016).

Based on the mechanical properties of carbon-fiber RSPs, there is growing consensus that bilateral lower limb amputee sprinters (i.e., competitors in the 100-, 200-, and 400-m dash races who compete in the traditional T43 classification) gain a performance advantage over their unilateral counterparts (i.e., sprinters who compete in the traditional T42 and T44 classifications; Brüggemann et al., 2008; Greenemeier, 2016; Hassani et al., 2014; Hobara, 2014; Hobara et al., 2015). Although most published studies rely on small, homogeneous athlete cohorts (i.e., bilateral vs. unilateral transfemoral amputee sprinters only or right- vs. left-sided transtibial amputee sprinters only), it is increasingly clear that sprint prostheses consistently impact performance outcomes. Despite this, T42-, T43-, and T44-classified athletes traditionally competed together in the same races, even at the Paralympic Games (Hobara et al., 2015; World-Para-Athletics, 2018a; Figure 1).

As Paralympic participation expands, it is important to clearly and definitively understand the impact of prosthetic technology on sprint performance and the implications for classification. This study sought to compare Paralympic sprint performance between all-comer (i.e., transfemoral and transtibial) unilateral and bilateral amputee sprinters using a large and heterogeneous athlete sample classified after the advent of RSPs but before the revised classification system of 2018. The primary aim was to confirm whether bilateral lower-extremity amputee runners had a competitive advantage over their unilateral counterparts over time. The second goal was to understand if race distance impacted performance differences, which tests the potential cumulative advantage of RSP energy-storing technology over longer distances. Finally, has the proportion of bilateral amputee runners in Paralympic sprint races changed over time? This would stress the importance of understanding the impact of RSP technology on performance to ensure fairness in Paralympic sprint races (McNamee & Parnell, 2018).


**Figure 1** — An elite bilateral lower-extremity amputee sprinter (Oliveira) winning against unilateral lower-extremity amputee sprinters in the same race. Adam Davy/PA Images via Getty Images.

## Materials and Methods

This study was deemed exempt from the need for ethical approval by the Yale School of Medicine Institutional Review Board.

Race results from the 1996 to 2016 Paralympic Games' sprint races (100, 200, and 400 m) for lower limb amputee athletes were extracted from the official IPC website. There were 584 races (trials and finals) on record. Race distances of 100, 200, and 400 m and athletes who had ambulation-related disabilities classified as T42, T43, or T44 were included. Sport classification for each athlete was retrieved from the Paralympic Games results record, embedded within the IPC website. Three hundred and eighty-four athletes with an ambulation-related disability were identified, of which 180 had lower limb deficiency. Nineteen athletes were completely excluded from the analysis because they had cerebral palsy, impaired muscle power, reduced lower-extremity range of motion, or another nonamputation condition. Following this exclusion, demographic data including name, sex, and country of representation as well as race type(s) were recorded. The lower limb amputation status of each athlete was verified through analysis of their sport classification listed on the official IPC website. We reclassified athletes in a minority of cases when an athlete's official recorded classification was inconsistent with the amputation status shown in the athlete's biography and/or online photographic data. Through inspection of all publicly available data, the authors first confirmed that the number of prosthetic lower limbs had not changed between 1996 and 2016 and then categorized athletes by amputation/prosthetic status evident through multiple personal biographies and/or online photographic data.

The main response variable was race speed (in meters per second), calculated from race time (in seconds) and race distance (in meters), to compare the performance of athletes in different sport classes. The normality and homogeneity of variances (i.e., whether different groups had the same level of variation) assumptions were tested using the Shapiro–Wilk test and Barnett's test, respectively. If both assumptions were satisfied, then a $2 \times 6 \times 3 \times 2$ factorial analysis of variance with Type III sums of squares was adopted to test the main effect of having unilateral versus bilateral prostheses as well as the interaction effect of other variables, including race year, race type, and sex. Only significant results are included in the "Discussion" section. If the assumptions were not satisfied, then the nonparametric alternative Kruskal–Wallis rank-sum test was adopted to conduct group comparison.

## Results

The final analysis included 584 race results (trials and finals) from 161 sprinters with prosthetic lower limbs (28 with bilateral prosthetic lower limbs and 133 with unilateral prosthetic lower limbs). Sprinters with unilateral leg prostheses completed 461 sprint races (trials and finals) during the Paralympic Games between 1996 and 2016, whereas those with bilateral leg prostheses completed 123 races—nearly a 4:1 ratio (Table 1). The mean speed of bilateral lower limb prosthetic sprinters was faster than that of their unilateral counterparts in all Paralympic sprint races between 1996 and 2016 (Table 2; Figure 2). Cumulative data from all six Paralympic Games showed significant differences in mean race speed between

**Table 1 Number of Participants With Prosthetic Lower Limbs in Paralympic Games Short Sprint Races Between 1996 and 2016**

| | 2016 (Rio) | | | 2012 (London) | | | 2008 (Beijing) | | | 2004 (Athens) | | | 2000 (Sydney) | | | 1996 (Atlanta) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 100 m | 200 m | 400 m | 100 m | 200 m | 400 m | 100 m | 200 m | 400 m | 100 m | 200 m | 400 m | 100 m | 200 m | 400 m | 100 m | 200 m | 400 m |
| U | 39 | 13 | 7 | 41 | 27 | 7 | 32 | 14 | 4 | 18 | 15 | 10 | 20 | 20 | 13 | 18 | 8 | 0 |
| B | 15 | 17 | 7 | 9 | 7 | 4 | 2 | 3 | 1 | 2 | 1 | 0 | 2 | 1 | 0 | 1 | 1 | 0 |

*Note.* U = unilateral amputee sprinters; B = bilateral amputee sprinters.

**Table 2 Mean Race Speeds for All Unilateral and Bilateral Lower-Limb-Prosthetic Short Sprinters at the Paralympic Games Between 1996 and 2016**

| | 2016 (Rio) | 2012 (London) | 2008 (Beijing) | 2004 (Athens) | 2000 (Sydney) | 1996 (Atlanta) |
|---|---|---|---|---|---|---|
| Mean speed, bilateral (m/s) | 7.71 | 7.68 | 8.16 | 7.94 | 7.68 | 8.33 |
| Number of athletes | 22 | 10 | 3 | 2 | 2 | 1 |
| Mean speed, unilateral (m/s) | 7.41 | 7.33 | 7.24 | 7.24 | 7.26 | 6.35 |
| Number of athletes | 51 | 48 | 35 | 24 | 28 | 18 |

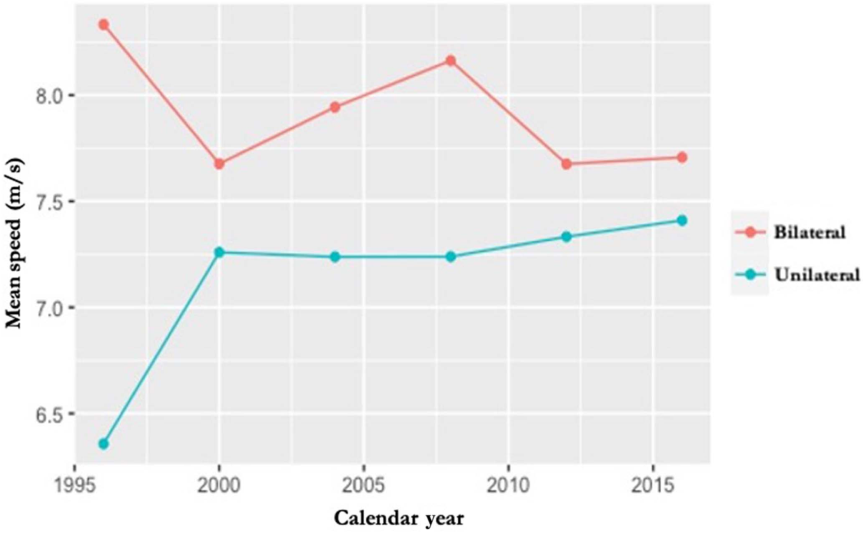


**Figure 2** — Mean speed of Paralympic sprinters with bilateral and unilateral prosthetic lower limbs over time.

bilateral and unilateral amputee runners in all three races (100 m, $p < .001$; 200 m, $p < .001$; 400 m, $p < .001$), and speed differences increased as race distance increased (Table 3; Figure 3).

The proportion of bilateral lower limb amputee runners participating in Paralympic sprint races increased over time (Figure 4). During the 1996 Atlanta Games, the number of unilateral lower limb amputee runners ($n = 18$) was 18 times that of bilateral lower limb amputee runners ($n = 1$), but during the 2016 Rio Games, the numbers were more similar ($n = 51$, $n = 22$, respectively; Table 2). Overall, the ratio of bilateral to unilateral prosthetic lower limb competitors narrowed over time.

**Table 3 Mean Race Speeds of Unilateral and Bilateral Lower-Limb-Prosthetic Sprinters During All Paralympic Games Trials and Finals Between 1996 and 2016 (Using Official International Paralympic Committee Athlete Classifications)**

| Race distance (m) | Number of athletes, unilateral | Number of athletes, bilateral | Mean race speed, unilateral (m/s) | Mean race speed, bilateral (m/s) | Difference (m/s) | *t* test (*p* value) | Shapiro–Wilk normality (*p* value) | Homogeneity of variances (*p* value) |
|---|---|---|---|---|---|---|---|---|
| 100 | 112 | 23 | 7.16 | 7.56 | 0.40 | <.001 | <.001 | .007 |
| 200 | 72 | 24 | 7.38 | 8.09 | 0.71 | <.001 | <.001 | <.001 |
| 400 | 34 | 10 | 6.98 | 7.80 | 0.82 | <.001 | .0264 | .007 |

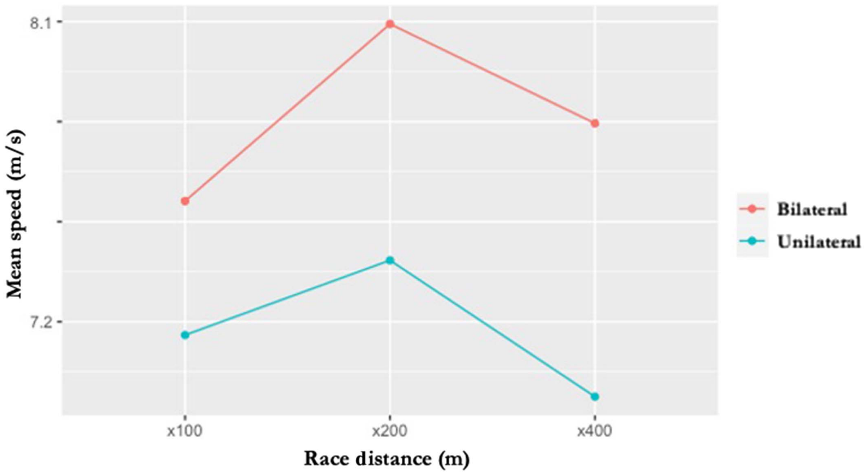


**Figure 3** — Mean speed of all sprinters with bilateral and unilateral prosthetic lower limbs in all 100-m-, 200-m-, and 400-m-dash races at the Paralympic Games between 1996 and 2016.

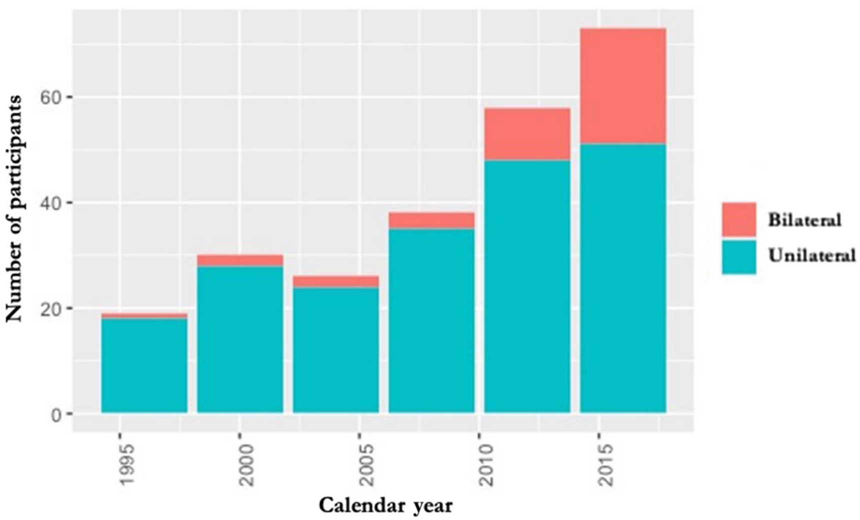


**Figure 4** — Proportion of Paralympic sprinters who used bilateral and unilateral prosthetic lower limbs at the Paralympic Games between 1996 and 2016.

Misclassification or discrepancies between official IPC classification records and athletes' profiles, biographies, and/or online photographic evidence was identified in approximately 8% of the cohort (*n* = 13). Six lower-extremity amputee athletes officially participated as T46-classed competitors (T46 was defined as

"Upper limb/s affected by limb deficiency, impaired muscle power or impaired range of movement"), and seven bilateral lower-extremity amputee athletes officially participated as T42-classified athletes (T42 was defined as "Single above-knee amputees and athletes with other impairments that are comparable to a single above-knee amputation").

## Discussion

Participation opportunities and performance outcomes for elite runners who use prosthetic lower limbs have increased, in part due to advances in RSP technology. There has been considerable debate and study as to how modern energy-storing prostheses impact performance ever since prostheses were introduced to Para sports (Greenemeier, 2016; Hassani et al., 2014; Weyand et al., 2009), but unfortunately, most studies have been limited to small, homogeneous Para athlete groups. In 2018, World Para Athletics introduced the T61–64 Sport Classes, more fairly dividing competitors who run or jump with one versus two prosthetic lower limbs. This study attempted to provide additional evidence from the official race records of a large, heterogeneous cohort of Paralympic sprinters to quantitatively assess performance differences between single- and double-leg prosthetic wearers—thus, either supporting or challenging current Para Athletics classification trends.

Despite being the smaller group numerically, bilateral lower-extremity amputee sprinters outperformed their unilateral opponents in terms of race speed regardless of the race distance (100, 200, or 400 m). The proportion of bilateral amputee sprinters increased over time, making the imperative to understand the impact of RSP technology on performance through studies like these all the more important for fairness in Paralympic sprint races. This highlights the potential effect of any subtle difference between two athlete groups—although there may not be a large observable disparity in the shortest sprint events, a small performance-enhancing effect may confer a large advantage in longer sprint races. It is also possible that this finding represents improved endurance and decreased fatigue of the prosthetic relative to the anatomical leg, that is, a cumulative advantage of RSP energy-storing technology over longer distances. We are unable to definitively conclude whether this advantage exists, but regardless of the race distance, bilateral amputee sprinters had faster mean speeds than their unilateral counterparts across each distinct race length. Further research is needed here. Finally, the dramatic difference in mean speed between bilateral and unilateral amputee sprinters in the early years of this analysis (1996, 2000, 2002, and 2004) may be due to sampling error as there were very few (i.e., less than five) participants on the bilateral side during those years. Despite this, speeds remained higher in bilateral amputee athletes. Study results support current T61–64 groupings wherein sprinters who use unilateral prosthetic lower limbs are classed separately from those who use bilateral blades.

This study had several strengths. By double-checking athlete class, the internal validity of findings was enhanced (i.e., recognition of classification error and/or incorrect allocations during official events). Also, the time range of the dataset was the longest of its kind, providing the largest sample size so far. In addition, multiple statistical tests were investigated to comprehensively evaluate the data.

This study also had some limitations. Mean race speed differences may be attributed to any number and combination of factors, intrinsic and extrinsic to athletes (i.e., talent, training volume and program, nutrition, rest, length of stump, quality and maintenance of prostheses, etc.)—use of one versus two prosthetic lower limbs may not completely explain findings. Further, because publicly available data were used, complete race results during all qualifying rounds during the selected Paralympic Games were unavailable. Given the retrospective study design, it was not possible to perfectly pair athletes with specific types of prostheses (i.e., brand, material, length, etc.). Head-to-head comparisons like this between athletes who differ only by the *number* of prosthetic lower limbs, not type, were impossible. Asymmetric data points wherein there were unequal numbers of athletes in each category were, therefore, used, and these numbers changed over time. Further, athletes in earlier years invariably used older model prostheses than athletes competing more recently. It would be ideal to analyze data from athletes who wore RSPs with identical or at least highly similar structural properties and performance profiles. There may have been sampling error inherent to the mix of athletes who competed in different Paralympic Games and at different distances. Finally, in 13 cases where the race class assigned to athletes was inconsistent with athletes' identified sport classification following a thorough search and summation of both official IPC data and all publicly available data, we corrected the athletes' classification. Further analyses might consider testing the impact of misclassification on measured performance differences. An important future direction is prospective data collection in athletes who are intentionally matched based on the aforementioned intrinsic and extrinsic characteristics.

The results of this study support the separation of sprinters who wear unilateral versus bilateral prosthetic lower limbs into different classes. In response to ongoing efforts to achieve parity, the T61–64 classification structure may help improve equity in Para sprinting competitions. As worldwide participation in Para athletics is expanding, boosting demand for top performances from amputee sprinters, the importance of establishing equitable competitive conditions where race outcomes are determined by athletes' ability, not by external factors, is critical.

In summary, contemporary energy-storing running prostheses appear to grant competitive advantages to athletes with bilateral prosthetic lower limbs over unilateral peers in all races. Separating these two types of athletes during training (i.e., coaches) and competition (i.e., IPC, competition officials) may create fairer playing fields. Additional research is needed to discern how to best serve athletes who wear unilateral versus bilateral RSPs during practice as well as how to fairly incorporate sprinters who do not require prostheses but sprint on two anatomical lower limbs. As studies like these are executed at a large scale, the evidence base will continue to help ensure that all eligible Para sprinters participate on fair grounds at all levels of competition.

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