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## Monitoring sprinting gait temporal kinematics of an athlete aiming for the 2012 London Paralympics

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### Abstract

Elite running typically requires performance analysis. This equally applies to able-body and amputee athletes who use prosthetic limbs. Amputee runners with artificial limbs deal with unique situations such as balance and control of the prosthetic. A new lower limb has been developed and performance requires ongoing monitoring. Inertial sensor technology, accelerometers and gyroscopes, were used to measure the limb's development, in particular stride, step, and stance duration. While research has been reported on these variables for able-body athletes, no research has investigated these kinematics from Paralympic athletes using inertial technology. The participant's existing and new prosthetic performance were compared. Performance monitoring of the limb during athlete use is required in order objectively assess the new limb's capabilities.

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### 1. Introduction

Human gait is forward progression, which is achieved using the limbs. It can describe many functional movement patterns including swimming and cycling. However, it is generally used for classification of ambulation, of which different limb movement patterns define the type of gait used. Depending on the type of pattern, gait can vary greatly in velocity from walking to sprinting. Walking can be defined by having a phase of double leg support and involves no flight time whilst running or sprinting only has

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phases of single leg support and includes flight time [1]. Research on human gait has ranged from understanding fundamental patterns of movement to assessing pathological changes and optimising performance of elite athletes.

Previously, assessment of human gait has typically been conducted in laboratories using fixed motion analysis systems [2, 3]. The artificial nature and environmental constraints of this setting and equipment can limit the scope of data collected and may cause alterations in gait [2]. It appears that advances in microtechnology in the form of non-invasive inertial sensors may increase the accessibility and affordability for researchers and practitioners to assess human movement in a range of settings [4-6]. Previous inertial sensor gait studies have found accuracy decreases as gait velocity increases [7, 8]. However, a more recent study reported that inertial sensors can accurately measure running gait temporal kinematics [9]. Moreover, lower limb joint kinematic measures using inertial technology has been reported [10].

People with an amputation of the lower limb and above the knee (transfemoral) have been shown to have gait patterns that reflect in slower walking, while requiring an increase in energy output [11, 12]. While below knee (transtibial) amputee data is closer in kinetic and kinematic patterns to able body gait [13]. Asymmetrical gait patterns were evident in the studies of transfemoral amputees [11, 12] and less pronounced in transtibial amputees [13, 14]. With an able body athlete sprinting, greater force is applied in the plane of travel i.e. sagittal plane direction and less vertically [1]. As a sprinter accelerates the athlete tilts their trunk anteriorly, thus a forward shift of the centre of mass, resulting in the forward direction of ground reaction force. However, Grabowski et al [15] measured vertical ground reaction force and showed that even if the shift towards a forward direction occurs, there remains a vertical ground reaction force component in running gait. This kinetic output results in kinematic outcomes, which has been shown to be measurable using inertial technology [16]. Therefore one would assume that measurable asymmetry in amputee running would be possible with the same instrumentation. Specifically, measurement of vertical acceleration kinematics to assess amputee asymmetry while running may assist athlete performance.

Kinematic measures describe a movement and while kinetic assessment is important, the former measures may benefit Paralympic athletes in a manner that assists their strive to attain a running pattern as close to symmetrical as possible. As with many aspects of human society, continual technological development is aimed at improving transtibial amputee's athletic performance. A new design has recently been offered to an athlete. Leading into the 2012 London Paralympic games, continual assessment will be required. This will be to compare the new prosthetic against the amputee's existing prosthetic limb in relation to the athlete's running performance. Therefore based on existing research, the proposed investigations will: a) monitor the angular velocity of the knee of a newly designed transfemoral prosthetic limb and compare against the prosthetic previously used by the athlete, as well as comparison of both prosthetics against the athlete's anatomical limb and b) what are the inertial sensor technology kinematic measure outcomes. The aim of the present study and the basis of this report was to determine the effectiveness of inertial technology to detect an athlete's temporal kinematics of stride, stance, and step during running.

## **2. Methods**

A female transtibial athlete who, at the time of the research was nationally ranked 2nd and one of the candidates for the 2012 London Paralympic Games freely consented to the study. The athlete was a left limb amputee. The research investigated the characteristics of a 100 m below knee amputee sprinter's running gait. To the point of this research, the athlete's newly designed prosthetic limb had yet to be monitored for athletic performance.

This research monitored the athlete's performance output with her previous prosthetic limb and compared the output from data gathered from the new prosthesis. Both comparisons were assessed against the athlete's anatomical limb. The data gathered included vertical accelerations at S1 of the sacrum, as well as stride timing from anteroposterior accelerations at the same landmark. A sport specific designed inertial sensor [17] that was used was calibrated using software from a custom designed toolbox [18]. Its positioning was orientated to capture data in the three orthogonal planes.

A fully synthetic athletics track was used for data capture. The athlete ran four 100 m runs using the new design prosthetic, followed by four 100 m runs with her existing prosthetic. This was aimed at deciding whether it could be used as a benchmark for ongoing monitoring leading into the national selection for the Paralympic Games.

Statistical analysis was carried out using a paired T-test to compare stride, stance, and step durations of the new prosthetic limb to the athlete's anatomical limb. The same analysis was applied to the old limb. Data outcomes were considered significant when  $p < 0.05$ .

### 3. Results

#### 3.1. Timing Statistics

The average old prosthetic leg stride time was the same as the anatomical limb ( $p > 0.05$ ) (Table 1). A significant difference ( $P < 0.000$ ) was found between the prosthetic and anatomical limbs. There was a significant difference ( $P < 0.000$ ) between the step of prosthetic to anatomical compared to anatomical to prosthetic. No significant difference ( $p > 0.05$ ) was shown in the timing between the new prosthetic limb and the athlete's anatomical limb for stride (Table 2). Similar values and also a significant difference ( $p < 0.000$ ) was found between the stance timings. Once again for step timing, a significant difference ( $p = 0.01$ ) between the data was shown to be present.

Table 1. Average  $\pm$ SD time in seconds of stride, stance, and step comparisons for the athlete's old prosthetic limb against the athlete's anatomical limb

Limb	Stride	Stance	Step
Old Prosthetic	0.56 $\pm$ 0.08	0.09 $\pm$ 0.01	0.30 $\pm$ 0.05
Anatomical	0.56 $\pm$ 0.09	0.12 $\pm$ 0.02	0.26 $\pm$ 0.03

Table 2. Average  $\pm$ SD time in seconds of stride, stance, and step comparisons for the new prosthetic limb against the athlete's anatomical limb

Limb	Stride	Stance	Step
New Prosthetic	0.52 $\pm$ 0.05	0.10 $\pm$ 0.01	0.28 $\pm$ 0.04
Anatomical	0.53 $\pm$ 0.06	0.12 $\pm$ 0.01	0.26 $\pm$ 0.02

### 3.2. Timing percentages

The athlete spent 18% of her stride time in stance on both the new and old prosthetics. Stance on her anatomical limb was 21% and 22% when using her old and new prosthetics respectively.

The time in stance for the old prosthetic to anatomical step (31.5%), while the time in stance for the anatomical to old prosthetic step was almost half the time (46.4%). The values for the step variables showed that the time in stance on the new prosthetic (34.4%) was shorter than the time for the anatomical limb stance (46.7%).

### 3.3. Visual observations

Visual observation of the magnitude of vertical acceleration between the anatomical stride and prosthetic stride indicates little difference for both the old (Figure 1) and new (Figure 2) prosthetics. Anteroposterior acceleration signatures for both the new and old prosthetic limbs display large negative peaks following initial contact. Compared to the anatomical leg there is also a large secondary positive peak following initial contact.

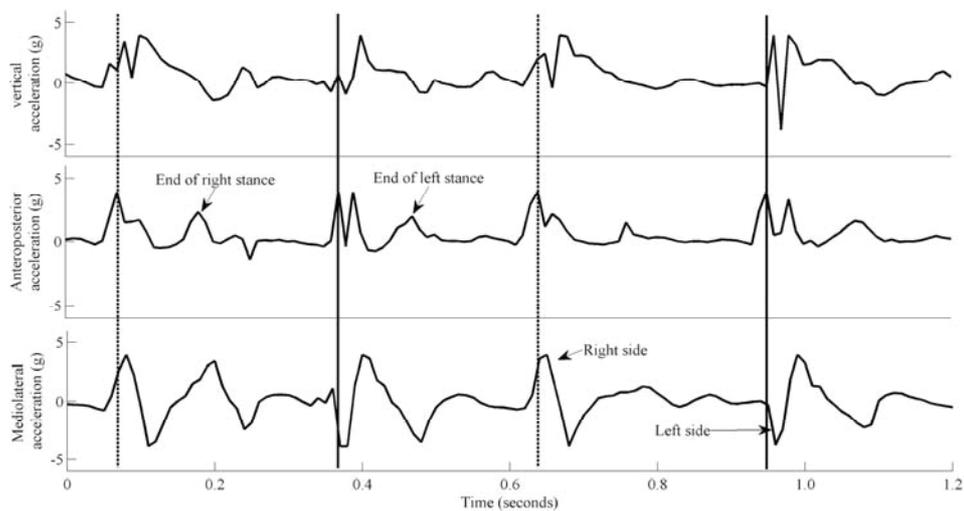


Fig. 1. Acceleration patterns of a transtibial amputee using her old prosthetic limb. The solid vertical line signifies initial contact of the prosthetic limb and the dashed line the anatomical limb. Negative acceleration in the mediolateral data occurring just after initial contact indicates right limb ground contact. A positive peak indicates left limb initial contact

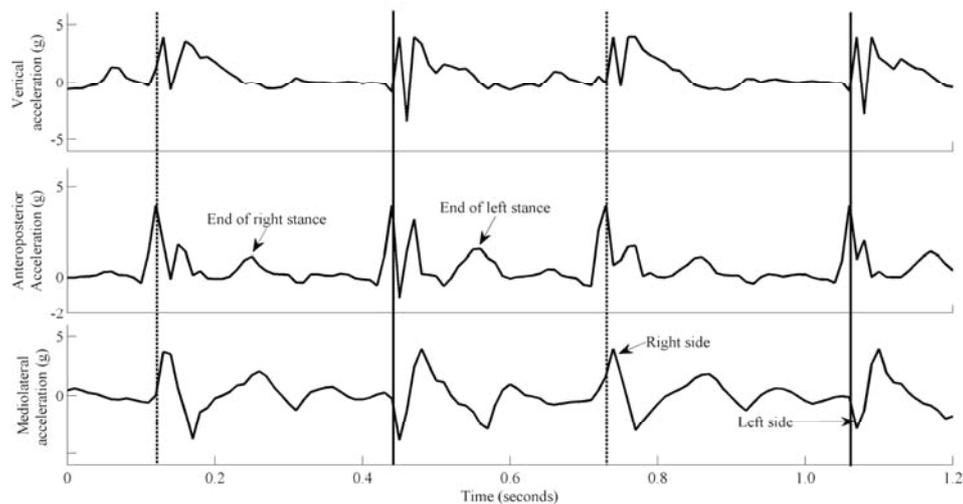


Fig. 2. Acceleration patterns of a transtibial amputee using her old prosthetic limb. The highlighted events are identical to those in Figure 1

#### 4. Discussion

The aim of this study was to determine whether inertial sensor technology could detect temporal measures in stride, stance, and step durations of a single limb transtibial amputee. This was with the purpose to see if the technology can be used for ongoing monitoring of the athlete's new and old prosthetic limbs leading into the 2012 London Paralympic Games. The research has shown that temporal kinematic measures from the S1 sacral landmark are possible in this circumstance.

Visual observation of acceleration signatures indicate clear patterns within each channel. Initial contact was can be seen in the anteroposterior acceleration for both prosthetic and anatomical kinematics. When this occurred just prior to a positive acceleration peak in the mediolateral channel, right limb data was being observed. Occurrence of a negative acceleration peak in the mediolateral data just after initial contact indicated left limb data points. This is agrees with previous published research where mediolateral data was used to identify left or right kinematics and initial contact (heel strike) in the anteroposterior data [16]. Vertical acceleration data shows events occurring at the same timepoint of initial contact. This does not reflect previously reported research. Researchers have indicated sinoidal type vertical acceleration patterns of the centre of mass (S1 mounted sensor) during running [9]. Further investigations are required to determine whether these differences are unique to the athlete that was tested, to amputee sprinters, or to sprinters in general.

Similar stride timing was shown between the athlete's anatomical limb and her prosthetic limbs. In both cases, no significant difference was found. This result supports previous research that reported little asymmetry between amputee's limbs at running and sprint velocities [13]. While outside the scope of this research, the possible reason for this may be that a below knee amputee still has the large muscle groups of the femur intact. Therefore shock absorbing, energy storage, and release of these muscles would work similarly to the anatomical limb.

## 5. Conclusion

Due to the reported outcomes here, which are in line with previous research that show similarities between anatomical and transtibial amputee prosthetic outcomes, the technology will be a viable method for monitoring the athlete's performance leading up to the London Paralympics. The research here also generally reflects outcomes of able body athlete temporal kinematics.

## References

- [1] T.F. Novacheck. The biomechanics of running. *Gait Posture* (1998): 7.1: 77-95.
- [2] R. Barrett, M.V. Noordegraaf, and S. Morrison. Gender differences in the variability of lower extremity kinematics during treadmill locomotion. *J Mot Behav* (2008): 40.1: 62-70.
- [3] T. Bushnell and I. Hunter. Differences in technique between sprinters and distance runners at equal and maximal speeds. *Sport Biomech* (2007): 6.3: 261-68.
- [4] J.W. Harding and D.A. James. Performance assessment innovations for elite snowboarding. *Proc Eng* (2010): 2.2: 2919-24.
- [5] D.A. James, The application of inertial sensors in elite sports monitoring, in *The Engineering of Sport*, E.F. Moritz and S. Haake, Editors. 2006, Springer: New York. p. 155-60.
- [6] Y. Ohgi, H. Ichikawa, M. Homma, and C. Miyaji. Stroke phase discrimination in breaststroke swimming using a tri-axial acceleration sensor device. *Sports Eng* (2003): 6.2: 113-23.
- [7] H. Lau and K. Tong. The reliability of using accelerometer and gyroscope for gait event identification on persons with dropped foot. *Gait Posture* (2008): 27.2: 248-57.
- [8] R.E. Mayagoitia, A.V. Nene, and P.H. Veltink. Accelerometer and rate gyroscope measurement of kinematics: an inexpensive alternative to optical motion analysis systems. *J Biomech* (2002): 35.4: 537-42.
- [9] J.B. Lee, R.B. Mellifont, and B.J. Burkett. The use of a single inertial sensor to identify stride, step, and stance durations of running gait. *J Sci Med Sport* (2010): 13.2: 270-73.
- [10] A. Findlow, J.Y. Goulermas, C. Nester, D. Howard, and L.P.J. Kenney. Predicting lower limb joint kinematics using wearable motion sensors. *Gait Posture* (2008): 28.1: 120-26.
- [11] S. Jaegers, J. Hans Arendzen, and H. de Jongh. Prosthetic gait of unilateral transfemoral amputees: A kinematic study. *Arch Phys Med Rehabil* (1995): 76.8: 736-43.
- [12] P. Macfarlane, D. Nielsen, and D. Shurr. Mechanical Gait Analysis of Transfemoral Amputees: SACH Foot Versus the Flex-Foot. *J Prosthet Orthot* (1997): 9.4: 144-51.
- [13] E. Isakov, H. Burger, J. Krajnik, M. Gregoric, and C. Marincek. Influence of speed on gait parameters and on symmetry in transtibial amputees. *Prosthet Orthot Int* (1996): 20.3: 153-58.
- [14] J. Buckley. Sprint kinematics of athletes with lower-limb amputations. *Arch Phys Med Rehabil* (1999): 80.5: 501-08.
- [15] A. Grabowski, C. McGowan, W. McDermott, M. Beale, R. Kram, and H. Herr. Running-specific prostheses limit ground-force during sprinting. *Biol Lett* (2010): 6: 201-04.
- [16] J.B. Lee, K. Sutter, C. Askew, and B. Burkett. Identifying symmetry in running gait, using a single inertial sensor. *J Sci Med Sport* (2010): 13.5: 559-63.
- [17] N. Davey, M. Anderson, and D.A. James. Validation trial of an accelerometer-based sensor platform for swimming. *Sport Tech* (2008): 1.4-5: 202-07.
- [18] D.A. James, A. Wixted. ADAT: A Matlab toolbox for handling time series athlete performance data. *Procedia Eng* (2011): 13: 451-56.