Can alternatives to the forceplate be used for accurate detection of key gait events?

Findlow AH, Kenney L, Howard D

Centre for Rehabilitation and Human Performance Research, University of Salford, Salford M6 6PU, UK

Email: a.h.findlow@salford.ac.uk

Abstract

The key gait events in drop foot stimulation are believed to be heel strike and heel off. When evaluating new sensors to replace the current foots witch, an accurate (gold standard) method for the identification of these events is important. Heel off is difficult to accurately determine from force plate data without careful foot placement and hence other methods are sought. Previously reported methods that use kinematics to define these events have proven laborious and a fixed threshold approach to footswitch data is inadequate, due to variability in loading patterns in the pre-swing and swing phase of a typical gait cycle. In recognition of the problems with foots witch signals, the Salisbury group implemented an algorithm in their stimulator that has proven clinically effective. This study evaluated the accuracy of this algorithm and developed an approach to the determination of the key gait events based on kinematic data alone. The results show that in normal, steady, shod walking, both the new kinematic algorithm and the Salisbury-developed footswitch circuit are satisfactory and more practical alternatives to the force plate for evaluating alternative sensors for drop foot stimulation.

1 Introduction

Although gait timing events are fundamental to many experimental studies and the functioning of certain assistive devices (e.g. FES systems for foot drop), the search continues for a practical and universally accepted "gold standard" [1]. Although heel contact and toe off are events that can be accurately identified from floor-located force plate data, practical limitations severely limit the number of measurements that can be taken with this approach. More importantly, heel off cannot easily be identified from these data. The reasons for this are two fold; heel off is associated with a gradual offloading from the heel and gradual change in kinematics, with no obviously detectable associated event. Further, unless the foot placement is such that only the heel is in contact, loads acting through the forefoot mask the offloading associated with heel off. One alternative is to use a heel-located force sensitive resistor (FSR or footswitch), which overcomes the practical limitations associated with fixed location force plates, but the accuracy and repeatability of using a simple threshold approach to these data is open to question. In recognition of the problems with footswitch signals, the Salisbury group implemented an algorithm in their stimulator that has proven clinically effective [2]. However, a systematic study of this algorithm has not been previously reported. Methods for the identification of the two gait events using kinematic data only have received less attention and a practical, rapid and robust algorithm based on this approach has yet to be reported.

Our study is part of a larger project developing an inertial-sensor controlled drop foot stimulator. Although several previous studies have demonstrated the use of various artificial and natural (neural) sensors as replacements for the footswitch, the approaches taken to their evaluation in terms of timing accuracy are open to question. For example, papers by Willemsen [3] and Hansen [4] both use unspecified algorithms to identify footswitch defined timing events from footswitch data, against which new sensors were tested.

Although the footswitch is the sensor of choice in the clinical FES applications, it has yet to be demonstrated that it is suitable for use as a gold standard against which to evaluate a novel gait phase detection system. The study reported here addressed this question.

A further element to the study concerned the development of a rapid and accurate algorithm that allows key gait events to be identified from kinematic data. This study builds on a previous kinematic study of gait event timing in barefoot walking [5].

2 Methods

To determine how accurately heel contact and heel off could be determined using kinematic or footswitch data, the corresponding estimated times of each event were compared to the "gold standard" gait event timings, derived from force plate data. As will be described below, a non-standard approach to identifying gait timing events from force plate data was used.

Ten subjects, 6 males and 4 females, with no discernable gait abnormalities were recruited for the study (Table 1).

	Age (years)	Weight (Kg)	Height (m)
Mean	43.9	80.2	1.72
Min	29.6	65.0	1.63
Max	61.6	98.0	1.80
Stdev	10.6	9.3	0.05

Table 1: *subject descriptive statistics*

For each subject, data for the left leg was used throughout the study. All subjects wore the same type of shoe, (Zen shoes, Ecco, Godalming, UK) and thin socks. Subjects wore rigid marker sets (Figure 1) and insoles with four footswitches connected to a routing box and an Odstock Drop Foot Stimulator, ODFS, (Figure 2). The ODFS incorporates a comparator circuit that provides a logical signal (0 or 5V) from the footswitch derived voltage data. Both the unprocessed voltage signal from the footswitch and the logical output from the comparator circuit were synchronously logged. The kinematic marker sets (arrangement of reflective markers defining the local axis systems) were developed from earlier work on the foot and ankle at Salford [5, 6]. The 3D co-ordinates of the marker sets were recorded using an eight-camera motion analysis system (Qualisys Medical AB. ProReflex. 2003) at a sampling frequency of 100 Hz. The vertical ground reaction force, was measured by the force plate (Kistler Instruments Ltd) at 100 Hz.

Data were collected whilst the 10 subjects walked at self-selected speed under two constrained walking conditions, (1) walking with only the heel contacting the force plate, and (2) walking with the whole foot contacting the force plate. For the reference condition (gold standard), heel strike was said to occur when the force plate first registered a vertical force above 10N during walking condition (2). Heel off was said to occur at the instant the heel lifted from the force plate during walking condition (1), which was defined to be the first data sample with a vertical force less than 10N.

With the kinematic data, the minimum value of the vertical velocity of the origin of the heel's local axis system identified heel strike. A threshold on the resultant velocity of the same local system was used to define heel off.

The comparator (footswitch) signal (0 or 5V) was used to identify heel strike and heel off.

An external trigger started simultaneous capture of the kinematic, footswitch/comparator and kinetic data, which was collected over 4sec. Subjects were requested to perform twenty walks under each condition. For each condition, six satisfactory trials (no missing data) were digitised and used for analysis.

Figure 1: *Kinematic marker arrangement*

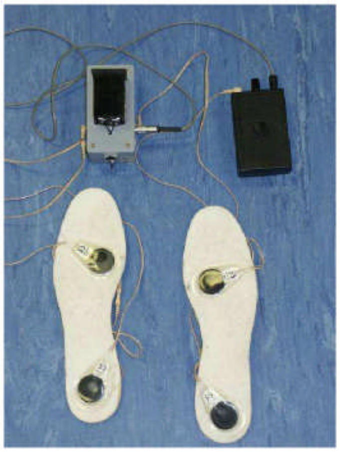

Figure 2: *Footswitches, ODFS and routing box to link signals to data capture equipment*

3 Results

Figure 3 shows an example of the kinematic (position P and velocity V), footswitch (FS) comparator (C) and forceplate (FP) data over a period of the gait cycle including heel strike and heel off.

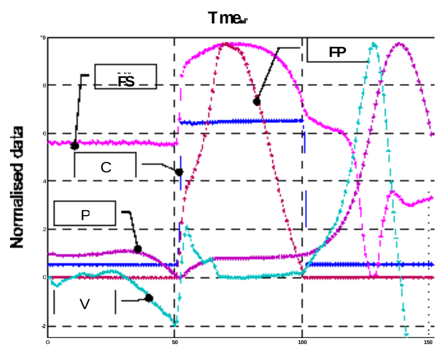

Figure 3: *Example of kinematic, footswitch, comparator and forceplate data*

Table 2 shows mean, sd and rms errors for heel contact and heel off from both the comparator (footswitch) and kinematic data.

	Heel Contact		Heel off	
	K	C	K	C
Mean error	0.0 15	-0.007	-0.028	0.002
SD error	0.017	0.019	0.035	0.030
RMS error	0.023	0.020	0.044	0.030

Table 2: *Error (secs) calculated from kinematic data (K) and footswitch comparator (C)*

4 Discussion and Conclusions

The results presented in this paper indicate that in normal steady shod walking both kinematic data and heel located comparator (footswitch) data can be used to accurately estimate the timing of key gait events. As expected, heel off timing was slightly less accurate than heel contact. The timings from the footswitch were better than those derived from kinematic data. However, in both cases, errors were not considered to be significant enough to rule either approach out as an alternative to the force plate. The small difference between the two approaches may have been a result of the time lag between offloading and detectable motion at the heel, as suggested by the mean error of -0.028s for heel off.

As can be seen from figure 3, the unprocessed footswitch data shows that a simple fixed threshold would be unlikely to give an adequate definition of key gait events. The forces acting on a footswitch are complex and in most instances do not remain zero during the swing phase due to factors that may include pre-loading from lacing of the shoe and inertial effects. Further, the impedance properties of FSRs are both variable from batch to batch and may change with time.

The study was conducted with normal subjects who all wore shoes of the same type. While this was acceptable in our study, the ultimate goal of which is to provide a practical gold standard against which to measure the accuracy of a new inertial-sensor based gait phase detector, it is not known whether and to what extent this factor may have increased the apparent accuracy of the footswitch and/or kinematics methods. Therefore, caution should be adopted in extrapolating these results to other conditions (e.g. abnormal gait, different footwear etc).

References

[1] A. H. Hansen, D. S. Childress, and M. R. Meier, "A simple method for determination of gait events," *J Biomech*, vol. 35, pp. 135-138, 2002.

[2] P. N. Taylor, J. H. Burridge, A. L. Dunkerley, D. E. Wood, J. A. Norton, C. Singleton, and I. D. Swain, "Clinical use of the Odstock dropped foot stimulator: its effect on the speed and effort of walking," *Arch Phys Med Rehabil*, vol. 80, pp. 1577-1583, 1999.

[3] A. T. Willemsen, F. Bloemhof, and H. B. Boom, "Automatic stance-swing phase detection from accelerometer data for peroneal nerve stimulation," *IEEE Trans Biomed Eng*, vol. 37, pp. 1201-1208, 1990.

[4] M. Hansen, M. K. Haugland, and T. Sinkjaer, "Evaluating robustness of gait event detection based on machine learning and natural sensors," *IEEE Trans Neural Syst Rehabil Eng*, vol. 12, pp. 81-8., 2004.

[5] A. H. Findlow, C. J. Nester, and P. Bowker, "Repeatability of kinematic data for five segment foot/ankle model, and validation of its use in the definition of key gait events," presented at International Society of Biomechanics XIXth Congress, Dunedin, New Zealand, 2003.

[6] C. J. Nester, A. F. Findlow, P. Bowker, and P. D. Bowden, "Transverse plane motion at the ankle joint," *Foot Ankle Int*, vol. 24, pp. 164-8., 2003.

Acknowledgements

This work was funded through the EU Framework V project TUBA (IST-2001-32750). The authors would also like to acknowledge Paul Taylor who provided the modified ODFS.