

TIME NORMALIZING GAIT DATA BASED ON GAIT EVENTS

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INTRODUCTION

Time normalization of kinematic, kinetic and/or EMG gait data to % gait cycle is a common practice of assessing average behavior over several gait cycles or comparing gait patterns from different populations. This process assumes that gait cycles are periodic and assigns consecutive ipsilateral heel-strikes to 0 and 100% gait cycle. This approach however generally ignores timing variability in movement patterns both between and within gait cycles, e.g., variations in peak value times or toe-off times. Thus movement data averaged over multiple gait cycles may express reduced peak magnitudes and increased standard deviations due to inter- and intra-cycle variability in timing [1,2].

Although gait researchers often acknowledge these alignment problems, relatively few studies have attempted to address them. If used, separation between stance and swing phases by aligning data to toe-off is the most common approach. A few have tried aligning gait data at multiple instances throughout the gait cycle, such as peak values [1], arbitrary states [2], or across the entire gait cycle [3]. These works did not consider alignment based on clinically-relevant gait events that identify subphases of the gait cycle. Alignment by gait events could also allow comparison across joints and gait parameters, which may not be possible with the other techniques. Further, these works were interested in reducing temporal differences in order to better explore intensity differences in gait parameter magnitudes. They did not consider that added information about the system may be obtained by examining the temporal shifts necessary to make these alignments.

We recently explored multiple methods for time normalizing gait data and have found piecewise linear length normalization (PLLN) to be a preferable technique for removing timing variability between discrete points of interest throughout the gait cycle [4]. PLLN is essentially curve registration that compresses or expands the time axis of a cycle to-be-aligned with a target data set. Alignments are

done using linear interpolation between specified points of interest along the gait cycle.

In this paper, we time normalized gait data using PLLN to specific gait events (based on subphases of the gait cycle). We also illustrate the potential utility of examining temporal shift signatures, i.e., temporal differences which highlight the direction and magnitude of temporal shifts necessary for alignment.

METHODS

Walking data from [5] were used in this study. In these experiments, ten healthy males, ages 19-23, walked for three minutes on a treadmill under two conditions: (1) normal, non-braced, and (2) braced right knee. The addition of a knee brace simulated an injury or other irregular gait pattern by preventing knee flexion. Sagittal-plane joint angles were calculated from motion capture data (Vicon, Oxford, UK). For each subject, one gait cycle of the right leg per condition was used. Right ankle angle data for eight subjects are reported here.

We defined only the subphases of stance phase due to the relative ease and repeatability in determining these events. Five subphases were identified from six gait events [6]: (i) loading response: ipsilateral heel strike (IHS¹) to contralateral limb toe-off (CTO¹), (ii) mid-stance: CTO¹ to limb alignment (LA, i.e., bilateral hip and knee alignment), (iii) terminal-stance: LA to contralateral heel strike (CHS¹), (iv) pre-swing: CHS¹ to ipsilateral toe-off (ITO¹), and (v) swing: ITO¹ to IHS².

A consensus data set was created from the unbraced ankle angle data by determining the average timing, in % gait cycle, for each gait event. Each of the individual unbraced cycles was then aligned to these average timings using PLLN. The average of these aligned unbraced data sets became the consensus curve (Fig. 1).

PLLN was then applied to ankle angle data from each knee-braced gait cycle relative to the consensus timings. The aligned knee-braced curves

were averaged. Individual temporal and intensity differences for the aligned cycle relative to the consensus cycle were also recorded from each braced and unbraced cycle. Finally average temporal and intensity differences were determined.

RESULTS AND DISCUSSION

Average timings for the gait events based on unbraced data were: 12 ± 1.4 (SD) %GC for CTO¹, 25 ± 2.0 %GC for LA, 51 ± 0.9 %GC for CHS¹ and 64 ± 0.9 %GC for ITO¹ (Fig. 1). Bracing resulted in noticeable time variation from normal unbraced motion in the ankle angle (solid vs. dotted curves in Fig. 1). By using curve registration through PLLN of the braced data to the gait event timings in the consensus data, alignment of motion patterns was improved (red dashed vs. dotted curves in Fig. 1). This alignment allowed for examination of intensity differences in ankle angle magnitudes throughout the gait cycle (Fig. 2), rather than at individual specific points as is commonly reported.

PLLN allowed for the calculation of the temporal shifts associated with all points in a gait cycle. By examining the temporal differences, it can be easily observed that events in the braced data generally occurred before, or lead, comparable events in the consensus data (Fig. 2). The greatest timing variation occurred at toe-off, ITO¹ (9.4 ± 5.1 %GC); however by examining the temporal differences throughout the gait cycle, we also observe that timing variations occur at other gait events but with reduced variability (e.g., CHS¹ at 4.4 ± 2.0 %GC).

It is interesting to note that by selecting gait events as the points of interest for alignment, the peak magnitudes of the average aligned data did not increase (Fig. 1), as was observed in [1] which aligned to peak values. Therefore, the choice in alignment points will be affected by the motivation of the research question.

CONCLUSIONS

By specifically selecting clinically-significant gait events, it may be possible to provide improved interpretation of gait behaviors, especially behaviors that deviate from normative patterns. By capturing and examining the temporal differences that were necessary to expand or contract the given cycle relative to the consensus pattern, we also are provided with greater insight into more subtle timing differences within the gait cycle. These

subtle timing differences may further provide added information about impaired control mechanisms of gait.

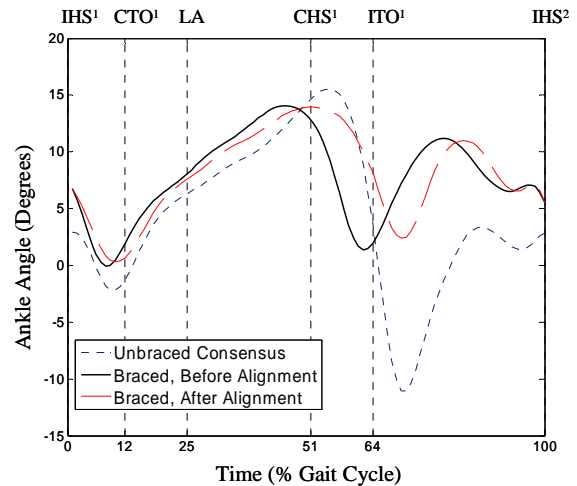


Figure. 1: Average ankle angle trajectories for right leg with knee brace before and after alignment with the consensus by PLLN. Average timings for key gait events based on unbraced motions are noted with vertical lines.

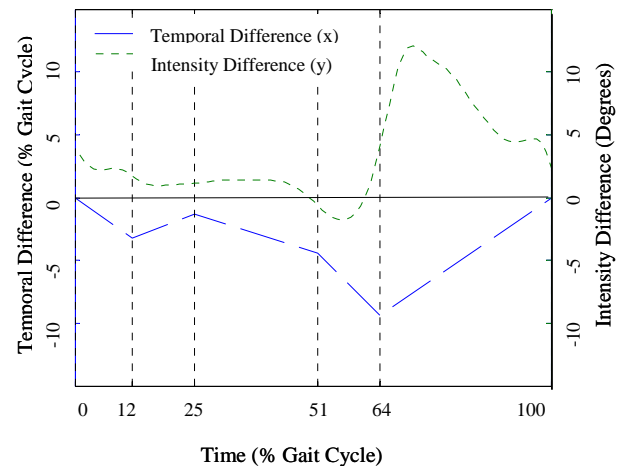


Figure 2: Average temporal and intensity differences

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