TIME VS. SPACE: COMPARING GAIT CYCLE NORMALIZATION METHODS AND THEIR EFFECT ON FOOT PLACEMENT CONTROL

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Introduction

Mediolateral (ML) foot placement (FP) is actively controlled to stabilize human walking. Studies agree that deviations in ML FP can be explained from the center of mass (CoM) state throughout the gait cycle [1,2]. The deviations are also explained increasingly better as the FP event is getting nearer. To do this analysis, the gait cycles must be normalized, but normalization methods differ between studies. In [1], strides are normalized based on the fore-aft distance between the CoM and the stance foot in every frame in percentage of the trial's mean stride length. At phase 0, the CoM is directly above the stance foot in the sagittal plane and this moment is defined as midstance (MS). As the normalization is based on distance rather than time, we refer to this method as spatial normalization (SN). Other studies use temporal normalization (TN) [2], where the period of interest is resampled to a number of points with uniform temporal distance, instead of the uniform spatial distance used in SN. This difference means that different information is used in these approaches. In this study, we investigate the effect of this difference by comparing SN and TN and their ability to explain ML FP from the CoM state. We expect that differences will be small in normal walking but larger if the gait is clearly asymmetric, as can be the case in persons with neurological diseases or other impairments.

Methods

We used raw data of normal [3] and asymmetric [4] treadmill walking. An approximation of the CoM was available in both datasets. We filtered the data and detected gait events. We extracted individual gait cycles (from MS to MS) and normalized every cycle using SN and TN. Only unperturbed strides starting at right MS were considered. The CoM was expressed relative to the stance foot position at left MS. We thus calculated the position of the next FP as the relative ML position of the right foot at the next right MS, which marked the end of the cycle. For every person and speed, we demeaned the data and created multiple linear regression models based on the CoM state. We created a single model for each time point for TN and each distance point for SN according to [1,2]. The dependent and independent variables of each model were the position of the next ML FP and the three-dimensional position and velocity of the CoM. The coefficient of determination (R2 score) of every model indicates how well deviations in ML foot placement can be explained by the CoM state at phase i.

Results

As expected, we did not observe large differences between TN and SN in normal walking, except for a drop of the R2 score in SN for phases $i < -0.5$. At left MS, both models can explain more than 80% of the next ML FP variance. For asymmetric walking, we also did not find considerable differences between TN and SN. However, an increase of the R2 value can be seen at the beginning for SN (Figure 1). Further, the R2 values after the left heel strike are generally lower than in normal walking (R2 is 0.67 and 0.66 at left MS for TN and SN).

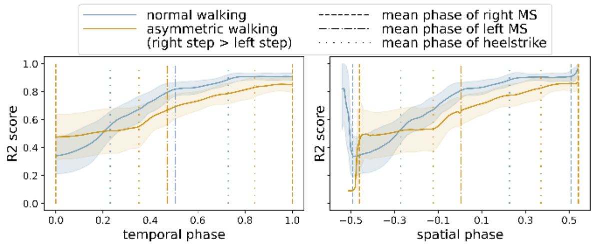

Figure 1: Mean R2 values for TN (left) and SN (right). Shaded areas are the standard deviation. Vertical lines are the mean phase of the specific event over all strides.

Discussion

Our results show that TN and SN can be used interchangeably for the development of phase dependent controllers, even for asymmetric walking. In SN, special care should be taken at the start of the stride though. In asymmetric gait, the R2 value at this phase ($i <= -0.51$) stems from only one subject who had low R2 values for the complete first third of the stride. No other subject had strides starting at a spatial phase $i < 0.48$ though, so the low R2 score could not be compensated. The drop in SN for normal walking can also be traced back to this. The high variance in R2 score between subjects requires further investigation though. Future work should also compare both methods for faster motions like the swing foot movement or motions with changes of direction.

References

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