INTRODUCTION

During the swing phase of walking, the minimum vertical height of the swing toe ($Y_{SWMIN}$) is $\sim 10$ mm (Winter, 1992). For any given individual, $Y_{SWMIN}$ is a function of the angles of each of the segments within the multi-link chain comprising of both the stance and swing legs and the pelvis. Small deviations, well within the range of that typically seen, in just one of a number of these segmental angles, are sufficient to cause the toe to contact the ground (Winter, 1992), the cause of a trip. However, despite the sensitivity of $Y_{SWMIN}$ to these small angular changes, the incidence of trips in the general population is relatively small, which suggests that one or more compensatory relationships between the segmental angles within the kinematic chain may act to minimise $Y_{SWMIN}$ variability.

The purpose of the study was to determine whether $Y_{SWMIN}$ variability is minimised by a compensatory synergy(s) within the lower limb-pelvic kinematic chain using a surrogate data sensitivity analysis (SDSA) (Mills et al., 2002). An additional aim was to provide a quantitative description of any compensatory synergies that were identified.

METHODS

Ground reaction forces (GRF) and sagittal plane marker excursions were acquired while a young male performed 20 s of treadmill walking at 1.5 m.s$^{-1}$. Foot contact events, identified from GRF data, enabled 18 individual strides to be extracted from the time series data and temporally normalized to stride duration. A 2-dimensional 9-link model (Fig. 1) was used to represent both legs and the pelvis in the sagittal plane. The vertical position of the swing toe ($Y_{SW}$) was represented as a function of: the vertical position of the stance toe ($Y_{ST}$), the external foot angle ($\theta$), the relative joint angles ($\alpha_{1:9}$), and the lengths ($l_{1:9}$) of the segments within the chain (Eq. 1).

$$Y_{SW} = Y_{ST} + \sin(\theta_i)l_i + \sum_{i=2}^{9} \sin(\theta_{i-1} - \alpha_i)l_i$$  

(Eq. 1)

Eq. 1 was simplified by setting $Y_{ST}$ to zero, and condensing the terms into $\beta$ (Eq. 2).

$$Y_{SW} = \sum_{i=1}^{9} \beta_i$$  

(Eq. 2)

$Y_{SWMIN}$ was identified from each of the 18 temporally normalised strides and the absolute deviations from the mean of the individual strides’ $Y_{SWMIN}$ were calculated. SDSA was applied to assess whether any compensatory inter-term, intra-trial relationships acting to minimise $Y_{SWMIN}$ variability were present, and if so, which $\beta$ were involved. In brief, the process involved performing an intra-term, inter-stride permutation of individual terms ($\beta_1$: $\beta_9$), to generate surrogate $\beta$, and systematically entering the surrogate terms into Eq. 2 to identify which, if any of the terms are involved in an intra-trial relationship that acts to minimise the variability of $Y_{SW}$.

RESULTS AND DISCUSSION

Entering all of the surrogate terms into Eq. 2 together resulted in a six-fold increase in the absolute deviation of $Y_{SWMIN}$ from the measured value ($13\pm7$ vs. $2\pm1$ mm, p<0.001). The stance foot ($\beta_1$), swing thigh ($\beta_7$), swing shank ($\beta_8$) and swing foot ($\beta_9$) terms were identified as playing a significant role (p<0.01) in the compensatory relationship that was responsible for 78% of the difference in $Y_{SWMIN}$ between the real and surrogate datasets.

SUMMARY

The existence of a compensatory relationship(s) between segmental angles at $Y_{SWMIN}$ was assessed using SDSA. For the individual examined, fluctuations of the individual segmental angles at $Y_{SWMIN}$ were not indicative of noise but acted in a synergistic manner that acted to minimize $Y_{SWMIN}$ variability.

REFERENCES


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