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Inter-joint synergies prevent tripping during walking

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Control of swing foot trajectory is an important motor function during walking, as failure to clear the walking surface results in a trip and potentially a fall. The potential for a trip is greatest during mid-swing, at which time a minimum toe clearance (MTC) of ~ 15 mm occurs. Achievement of adequate MTC during walking requires the coordination of a 21-degree-offreedom (DOF) kinematic chain comprised of both lower limbs and the pelvis. The DOFs within this kinematic chain exhibit stride-to-stride variability, which results in stride-to-stride variability of MTC. Despite a low MTC central tendency and a high sensitivity of MTC to fluctuations in many of the lower limb kinematic DOFs, the incidence of trips during daily living is low. It is possible that stride-to-stride fluctuations of individual DOFs within the kinematic chain are involved in a compensatory synergy that acts to minimise MTC variability. The aims of this study were to: i) determine whether compensatory kinematics synergies that act to reduce MTC variability exist during level walking, ii) describe the contributions of individual stance and swing leg DOFs to these synergies, and, iii) compare the structure and strength of these synergies between healthy young and older men. A surrogate data forward kinematic modelling approach termed randomised sensitivity analysis was used to identify, describe and quantify the compensatory synergies. 3D kinematic gait data for 100 swing phases were acquired from 10 young and nine older men during preferred speed treadmill walking and processed using the randomised sensitivity analysis approach. Compensatory synergies that acted to minimise MTC variability were identified for all participants and acted to reduce MTC variability to 20% of that which would occur had the synergies not been present. Derangement of this synergy would have resulted in the occurrence of a trip once every 6 steps. The overall effect of these synergies on minimising MTC variability was not different between the age groups however the older men had fewer DOFs involved in the synergies than the young. Despite substantial inter-individual variation in the structure of these synergies, some trends regarding the contributions of DOFs to the overall synergy were identified with greater contributions from: the stance limb compared with the swing limb; the ankle joint compared with the knee and hip joints; and from the sagittal plane DOFs compared with the frontal and transverse plane DOFs. The results from this study indicate that compensatory synergies play an integral role in minimising MTC variability in both young and older men.