RECOVERY LIMB POSITIONING AND TRIP RECOVERY SUCCESS

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INTRODUCTION

About 30% of people aged over 65 fall at least once a year, with tripping as the main cause [1]. Most studies investigating biomechanical aspects of trip recovery have focused on response time [2], lower limb strength [3] and muscle activation [4]. The aim of this study was to investigate the force required by the recovery limb to recover successfully in more challenging trip situations. To be able to better control the trip conditions a simulation modelling approach was used.

METHODS

An inverted pendulum model of trip recovery (Fig. 1) was developed to investigate how walking velocity and recovery limb placement influenced the force required by the recovery limb for a successful elevating strategy recovery. The model was developed in Simmechanics (Mathworks Natick, MA) and comprised a rigid segment with a mass (m_{body}=61 kg). A rotational spring, with stiffness K_{rot}, at the base of the rigid segment simulated the reduction of the body's forward angular momentum by the initial stance limb. A massless linear spring, with stiffness K_{lin}, attached to the rigid segment by a fixed hinge joint (hip) at an angle α, simulated the reduction of the body's forward angular momentum by the recovery limb during the first recovery step. The initial body inclination (θ_0) was set to 8°. Perturbations were initiated with initial walking velocities (v_{walk}) between 0.5 and 3.0 m/s, and α between 0° and 95°. To simulate perturbations of different magnitudes v_{walk} was varied. A larger initial walking velocity results in a larger initial angular momentum, which corresponds to a larger perturbation. To simulate different recovery limb placements α was varied.

K_{lin} and K_{rot} were estimated from previously collected experimental trials [5] (15 kN/m and 1850 Nm/rad, respectively). Recovery was successful when the angular momentum was reversed ($\dot{\theta}<0^\circ$/s) and a fall occurred when $\theta>90^\circ$.

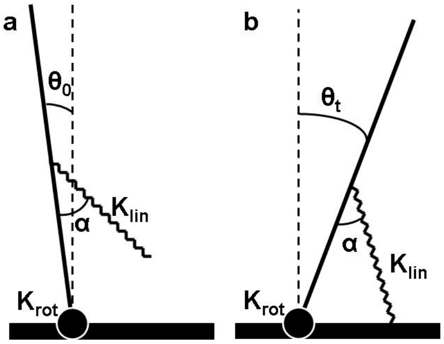

Figure 1: Structure of the inverted pendulum trip recovery model, a) at the instant of the trip stimulus and b) at ground contact of the recovery limb.

Outcome measures indicated whether successful recovery was possible, as well as the maximum force in the linear spring during the contact phase (F_{max}).

An analysis was performed to investigate the sensitivity of the maximum force required for successful recovery (F_{max}) to variations in α and v_{walk}. F_{max} for mid-range values of α and v_{walk} (35° and 0.75 m/s) was compared to F_{max} values one standard deviation (SD) away from this (9° and 0.2 m/s). To increase the moment arm to reverse the body angular momentum and therefore reduce the required recovery effort, α was increased by one SD from the mid-range value. As a slower initial walking velocity would result in a smaller body angular momentum after the trip perturbation and reduce the required recovery effort, v_{walk} was decreased by one SD from the mid-range value.

RESULTS AND DISCUSSION

Simulation results are shown in a surface plot (Fig. 2) with α on the horizontal axis, v_{walk} on the vertical axis and F_{max} (the maximum force in the recovery limb) on the surface. The surface is white where simulations resulted in a fall. This occurred for the smaller α values (corresponding to a smaller recovery step). F_{max} was 0 N when successful recovery was achieved prior to recovery limb ground contact, i.e. the rotational spring at the rigid segment reversed the angular momentum before the linear spring contacted the ground.

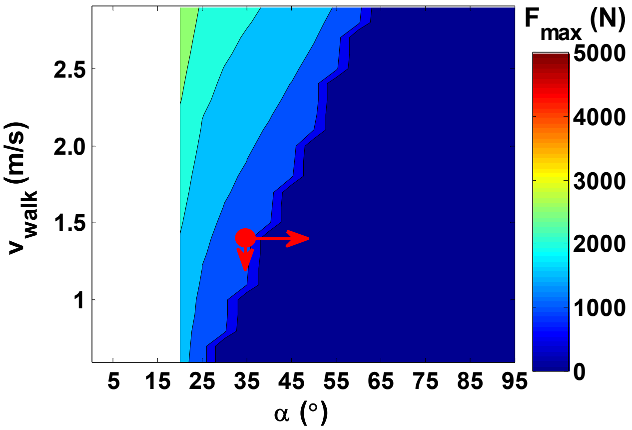

Figure 2: F_{max} for different α and v_{walk} values. The red arrows indicate deviations of one standard deviation in α and v_{walk} from a set mid-range value.

For the medium α values an increased v_{walk} resulted in an increased F_{max}. For large α values successful recovery was possible before the recovery limb contacted the ground (F_{max} = 0 N). As a larger α corresponds to a more forward placement of the recovery limb, there was more time available to reduce the forward angular momentum of the body before ground contact of the recovery limb, resulting in a lower F_{max}.

Table 1: F_{max} for mid-range α and v_{walk}, and for a one SD increase in α or v_{walk} from this mid-range.

F_{max} (N)

mid-range value	α + 9°	v_{walk} -0.2 m/s
1260	0	1141

The maximum force required for successful recovery (F_{max}) was more sensitive to a one SD increase in α (larger recovery step length) from the mid-range value than to a one SD decrease of v_{walk} (Fig. 2, Table 1). A one SD increase in α resulted in an F_{max} of 0 N. Therefore successful recovery was achieved prior to recovery limb ground contact and no force was required in the recovery limb.

These results suggest that a combination of recovery limb force and recovery limb placement limits successful recovery. Recovery limb placement is influenced by the reduction of the body forward angular momentum by the initial stance limb [6], response time and recovery limb movement velocity. The simulation results showed that recovery limb positioning influences the force required to recover successfully from a trip. They also showed that appropriate recovery limb positioning is essential to recover successfully in situations close to the limits of successful trip recovery. When interpreting the simulation modelling outcomes it has to be kept in mind that the model is a simplification of reality. The simulations predict only trends of trip recovery behavior.

CONCLUSIONS

Simulations with an inverted pendulum model showed that the force required in the recovery limb to recover successfully from a trip is more sensitive to recovery limb positioning than to walking velocity.

Recovery success is often limited in older adults, as they generally have a small recovery limb force potential, and therefore cannot generate high F_{max} values. In addition, older adults are limited in their recovery limb movement speed and therefore cannot achieve the highest α values. Our simulations imply that older adults would benefit most from a faster response time and increased limb movement speed in order to achieve a sufficiently large recovery step length.

Some studies have shown that slip and trip recovery responses may be improved by training [7]. The results of this study suggest that trip training should focus on both speed and strength aspects of tripping responses.

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