

# TRIP RECOVERY STRATEGY SELECTION IN YOUNGER AND OLDER ADULTS AND THE ASSOCIATED PHYSICAL DEMANDS

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## INTRODUCTION

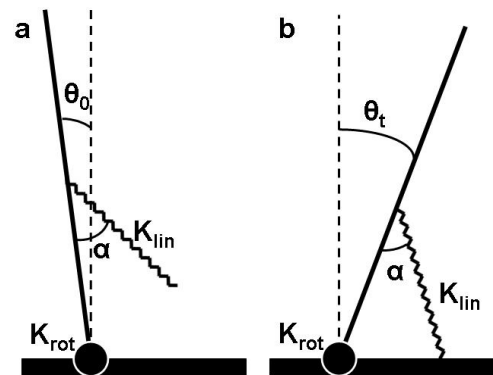
About one third of older adults fall at least once a year, with tripping as the main cause [1]. There are two main strategies that people use to prevent falling due to a trip: an elevating and a lowering strategy [2]. Strategy selection depends on the timing of the trip stimulus within the swing phase of the walk [3]. Early swing perturbations result in elevating and late swing perturbations result in lowering strategy recoveries [3]. Around mid-swing, there will be a ‘strategy overlap’ phase where strategy selection is not mechanically obvious. Previous studies showed that older adults more often adopt a lowering strategy than younger adults [4], but it is not understood why. The older adults may become incapable or unwilling to use an elevating strategy as this strategy may be more demanding when perturbed later in swing. The aim of this study was to investigate whether an elevating strategy recovery becomes more demanding when perturbed later in swing.

## METHODS

A combined experimental and simulation modelling approach was used. Experimental methods were similar to those described previously [5]. Briefly, female participants were recruited into a ‘younger’ ( $n=8$ ) or an ‘older’ group ( $n=7$ ). Trips were induced in random walking trials at varying points during the swing phase. Kinematic data were collected at 200 Hz with a CODA CX1 system (Charnwood Dynamics Ltd., UK). Kinematic data were processed as described in [5]. The percentage of the swing phase at which trips were induced ( $\%_{\text{swing}}$ ) was calculated relative to the average swing duration of all walking trials. The recovery limb angle at contact was calculated ( $\alpha_{\text{exp}}$ , defined like  $\alpha$  in Fig. 1).

An inverted pendulum model of trip recovery (Fig. 1) was developed to investigate how timing of

the trip stimulus and placement of the recovery limb influenced the force required by the recovery limb for successful recovery using an elevating strategy. The model was developed in Simmechanics (Mathworks Natick, MA) and comprised a rigid segment with a mass ( $m_{\text{body}}=61$  kg). A rotational spring, with stiffness  $K_{\text{rot}}$ , at the base simulated the reduction of the body’s forward angular momentum by the initial stance limb. A massless linear spring, with stiffness  $K_{\text{lin}}$ , attached to the rigid segment by a fixed hinge joint (hip) at an angle  $\alpha$ , simulated the reduction of the body’s forward angular momentum by the recovery limb during the first recovery step. It was assumed that at a trip the linear momentum of walking (at 1.7 m/s) would be directly translated into angular momentum. Recovery was successful when the angular momentum was reversed ( $\dot{\theta} < 0^\circ/\text{s}$ ). 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.

Perturbations were initiated with  $\%_{\text{swing}}$  between 30% and 90% (corresponding to  $\theta_0 = -8^\circ$  and  $\theta_0 = 16^\circ$ ), and  $\alpha$  between  $0^\circ$  and  $90^\circ$ . When perturbed later in swing the swing limb will be further in front of the body; however there will be less time available for placement of the recovery limb.

We therefore expected recovery step length (and therefore  $\alpha$ ) to vary with  $\%_{\text{swing}}$ .  $K_{\text{lin}}$  and  $K_{\text{rot}}$  were estimated from experimental trials (15 kN/m and 1850 Nm/rad, respectively).

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

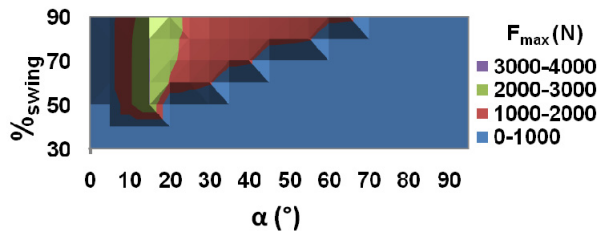
## RESULTS AND DISCUSSION

$\%_{\text{swing}}$  was calculated for 61 trip trials of the younger adults (59% elevating strategies) and 89 trials of the older adults (20% elevating strategies). Both younger and older adults used an elevating strategy when perturbed in early swing ( $\%_{\text{swing}} < 40\%$ ), and almost always used a lowering strategy when perturbed in late swing ( $\%_{\text{swing}} > 80\%$ ); subjects used both strategies when perturbed in early mid-swing ( $\%_{\text{swing}}$ : 40-60%) (Table 1). Responses to perturbations in late mid-swing ( $\%_{\text{swing}}$ : 60-80%) differed between younger and older adults; older adults always adopted a lowering strategy, while younger adults also adopted elevating strategies (Table 1).

**Table 1:** The percentage use of elevating strategy recoveries by younger and older adults in response to perturbations in different phases of swing.

	Younger	Older
<b>Early swing</b>	100%	100%
<b>Early mid-swing</b>	86%	54%
<b>Late mid-swing</b>	26%	0%
<b>Late swing</b>	0%	6%

Younger adults showed a positive correlation ( $r = 0.706$ ,  $p = 0.002$ ) between  $\alpha_{\text{exp}}$  and  $\%_{\text{swing}}$  during elevating strategy recoveries, which means subjects took larger recovery steps when perturbed later in swing. This correlation was not present in the older adults ( $r = -0.208$ ,  $p = 0.516$ ).



**Figure 2:**  $F_{\text{max}}$  for varying  $\alpha$  and  $\%_{\text{swing}}$ .

The simulations showed that an increased  $F_{\text{max}}$  (maximum force in the recovery limb) was required

to recover successfully when perturbed later in swing (increasing  $\%_{\text{swing}}$ ). An increased recovery step (increased  $\alpha$ ), like the younger adults showed when perturbed later in swing, reduced the  $F_{\text{max}}$  value required to recover successfully. (Fig. 2)

In summary, we showed that the shift to adopting a lowering strategy instead of an elevating strategy is made earlier for older ( $\%_{\text{swing}} \approx 60\%$ ) than for younger adults ( $\%_{\text{swing}} \approx 80\%$ ). We propose that an elevating strategy would be more effective but more difficult than a lowering strategy recovery when individuals are perturbed later in swing. This is based on the assumptions that for an elevating strategy: (1) there is more time available to counteract the forward angular momentum by the initial stance limb, as described by [6]; and (2) the recovery limb is lifted over the obstacle and placed more anterior relative to the body center of mass (CM), providing a larger moment arm to reduce the body's forward angular momentum [6]. It becomes however more difficult to elevate the swing limb over an obstacle when perturbed later in swing, as the body CM moves more anterior to the center of pressure. This may be why the older adults did not increase  $\alpha_{\text{exp}}$  with  $\%_{\text{swing}}$ . The simulations confirmed that an elevating strategy recovery becomes more difficult later in swing, as larger forces were required in the recovery limb.

## CONCLUSIONS

Older adults did not use an elevating strategy when perturbed during late mid-swing (60-80%), while younger adults adopted either an elevating or a lowering strategy. Simulations with an inverted pendulum model showed that recovery limb strength and step length may be the limiting factor for the use of an elevating strategy in mid and late swing. This suggests that strengthening of the appropriate muscle groups is essential in fall prevention practice.

## REFERENCES

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