O0006

Using zero-moment point to predict single versus multiple step recovery from forward loss of balance

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Abstract

Introduction

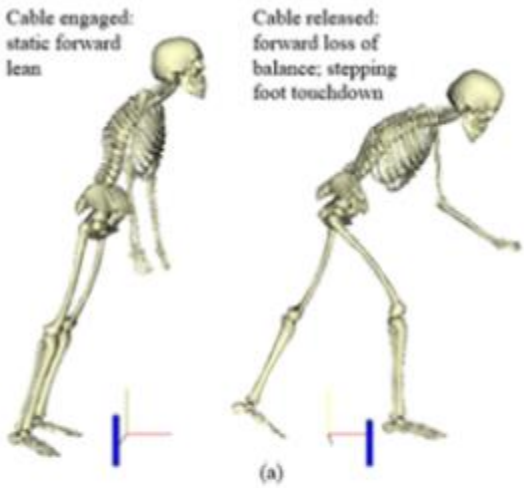
Protective stepping is a natural response for preventing falls. Successful balance recovery is complex, and sometimes multiple steps are necessary [1]. *In silico* simulations could play a critical role in falls prevention since they can be used to investigate scenarios that are difficult to analyze experimentally [2]. It is a challenge to model the feedback-driven decision-making processes involved in executing stepping response(s) in simulations of balance recovery [3]. In robotics Zero-Moment Point (ZMP) is used to measure stability [4] for AI decision-making regarding balance. We will determine the utility of replacing biofeedback with ZMP by identifying differences in outcome measures between three cohorts: older multi steppers (OMS), older single steppers (OSS), and younger single steppers (YSS).

Methods

We used experimental data (200 Hz) from 14 subjects standing with feet shoulder width apart, tilted forward via cable in parallel with the floor until 20% of body weight was recorded by a series-connected load cell [1] (Fig. 1a). Subjects were then released and instructed to take a single step. We calculated the ZMP using pelvis residual forces and moments taken from inverse dynamics and body kinematics. We reported stepping foot overtaking the forward component of the ZMP as a percentage of the step movement to normalize results across trials. Distance between the step foot placement at contact and ZMP was also calculated.

Results

OMS brought the stepping foot past the ZMP later during balance recovery (92.9% ± 6.2) (Fig. 1b). Both single stepper cohorts overtook the ZMP with at least 20% of the step left to complete (older: 80.4% ± 1.9; younger: 73.8% ± 18.3). The OMS cohort was compared by *t*-test to both OSS and YSS and was statistically different at a 5% significance level with $p = 0.0049$ and $p = 0.0317$, respectively. OSS compared to YSS was not statistically different at this significance level. OMS had less than half the distance between step placement and ZMP as compared to single steppers.



Cohort	Subject	% Step	Mean	Displacement (cm)	Mean (cm)
Older Multi Steppers	1	93.4	92.9 ± 6.2	15.8	12.8 ± 6.0
	2	92.4		18.7	
	3	81.7		17.4	
	4	100.0		2.7	
	5	96.9		9.1	
Older Single Steppers	6	81.8	80.4 ± 1.9	21.5	30.4 ± 5.7
	7	77.4		29.8	
	8	79.4		38.4	
	9	80.5		27.0	
	10	83.0		34.3	
Younger Single Steppers	11	81.0	82.9 ± 2.6	32.5	25.2 ± 6.4
	12	84.4		30.5	
	13	86.3		18.0	
	14	79.8		19.8	

(b)

Fig. 1: (a) Depiction of experimental setup before and after cable release showing ground frame axes. The ZMP locations are marked by the blue cylinders. (b) Table reporting results for subjects in each cohort. Instance where stepping foot overtakes ZMP is given as a percentage of step motion. Displacement between ZMP and step foot at the conclusion of the motion is reported in centimeters.

Discussion

In humans, somatosensory feedback provides recognition of failure to recover balance by single step and results in multiple steps. Simulations can be improved by modeling the recognition and adaptation process using a threshold trigger in lieu of biofeedback. ZMP is well suited to for this, since measures of swing foot position in relation to ZMP can predict when multiple steps are necessary. In future work, we will use ZMP to smoothly transition between control strategies for predicting single versus multi step responses.

Acknowledgements

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References

1. Graham D, et al., *Exp. Gerontology*. **66**:39-46, 2015.
2. Afschrift M, et al., *Gait & Posture*. **59**:122-127, 2018.
3. Aftab Z, et al., *PLoS ONE*, **11**(3), 2016.
4. Vukobratović M, et al., *Humanoid Robot.*, **1**(1):157-173, 2004.