Perturbation-dependent selection of postural feedback gain and its scaling

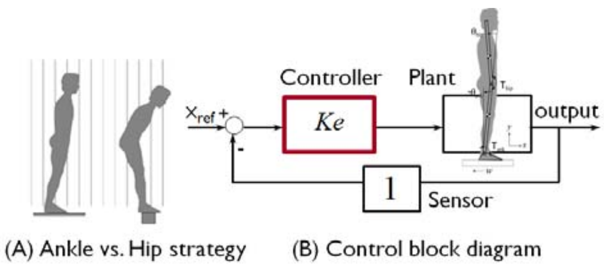
Sukyung (Sue) Park
Mechanical Engineering Dept., KAIST, Korea
sukyungp@kaist.ac.kr

1 Introduction

Postural responses adaptively make an adjustment in response to various magnitudes and types of perturbation, to various lengths of support surface, behavioral goals, expectations of upcoming perturbation, etc. Researchers found two distinct muscle activation patterns and named it as ankle vs. hip strategy. Ankle strategy was observed when subjects are under less challenging perturbation environment, whereas the hip strategy was employed for larger perturbations [1]. Why human changes postural strategy with perturbation, instead of just employing one and go for it? How to quantify postural strategy change in control point of view? In this study, we examined whether the change of postural strategy could be quantified by feedback control and its gain scaling.

2 Methods

We collected the data of human postural balancing subjected to 1) various magnitudes of backward support translations as well as 2) forward push by falling pendulum. Young healthy, healthy elderly, and the subjects with Parkinson's diseases were participated after submitting informed consent. We proposed a linear feedback control model to quantify postural strategy change (Fig. 1). Musculoskeletal system was modeled as a double inverted pendulum and sensor dynamics were assumed to be fast enough. The dynamics of closed-loop system is then determined by the feedback gain **K**, which was identified by fitting the joint torque and joint angle data.



$$\mathbf{T} = \mathbf{K}_{2by4} \cdot \mathbf{\Theta}$$

$$\mathbf{T} = [T_{ank} \quad T_{hip}]^T, \mathbf{\Theta} = [\theta_{ank} \quad \theta_{hip} \quad \omega_{ank} \quad \omega_{hip}]^T \qquad (1)$$

Figure 1*. (A) Postural responses described as ankle vs. hip strategy (B) Block diagram of feedback control that describes human upright postural feedback control.

3 Result

As perturbation magnitude increases, ankle torques were suppressed while hip torques were uniformly scaled, which was projected as a gradually scaled feedback gain (Fig. 2). Since the feasible ankle torques are limited in magnitude, the reduced gain helps the subjects maintain balance within maximum ankle torque constraints. Gain scaling, which was consistently observed from the healthy elderly, could quantify the transition from ankle to hip strategy with perturbation. However, PD patients weren't able to adjust feedback gain with perturbation and were led to step at smaller perturbation than what healthy elderly was able to handle. For the forward perturbation, the feedback gain also scaled with perturbation magnitude (Fig. 2), while having different scaling trends of hip gain to hold a greater impulse applied to the upper limb.

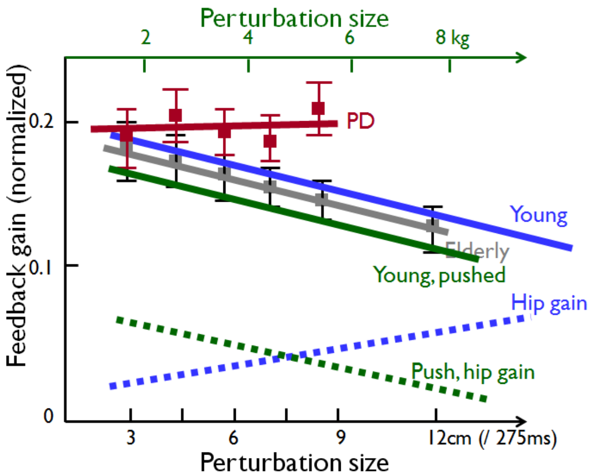


Figure 2*. Feedback gain as a function of perturbation
*All figures were adapted from [2]~[4]

4 Conclusion

We conclude that the nervous system may be aware of body dynamics being subjected to various perturbations and constraints, and may select the perturbation-dependent feedback gain that satisfy postural stability and biomechanical constraints, such as feasible joint torques.

References
[1] F. Horak et. al., Exp. Brain Res, 1990
[2] S. Park et. al., Exp. Brain Res, 2004
[3] S. Kim et. al., J Neurophys, 2009
[4] S. Kim et. al., J Biomech, 2012