# Ramp perturbation tests are too simple to identify realistic controller in human standing balancing

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## Introduction

Humans use feedback control to maintain balance. In the past two decades, research has been done trying to mathematically explain healthy human's responses under perturbation[1-4]. Ramp perturbation tests are typically used to identify simple linear control models.

### Hypothesis:

- More complex feedback control models are needed to explain human standing balance.
- Ramp perturbation tests are too simple to identify more complex feedback controllers.

### Objective:

- Develop realistic control models and perform experiments to identify controller parameters.

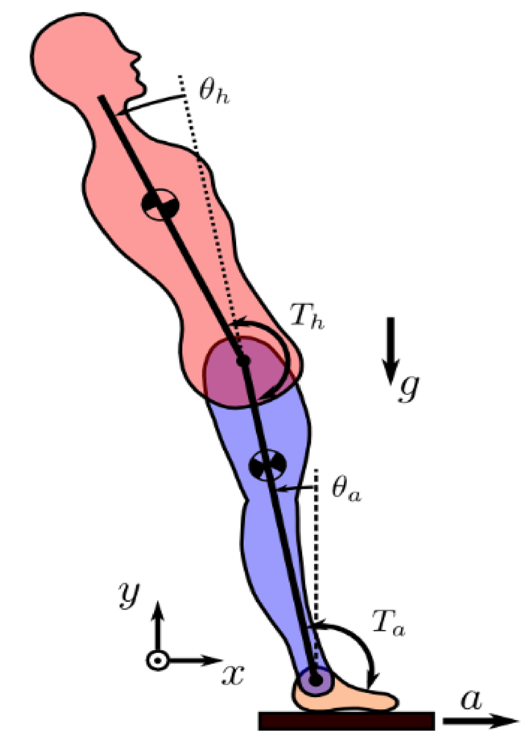



**Fig 1. Free body diagram of plant model.**

## Methods

### *Plant Model and Controller type*

Plant model

Torque driven two-link planar inverted pendulum with a randomly accelerating base (Fig 1).

Controller types

1. Full state proportional-derivative (PD) controller:

$$\tau = K_{p,2\times4} \cdot (X - X_{ref})$$

2. Full state PD with both passive and neural active control:

$$\tau = (K_{p,2\times4} + \frac{1}{T_{2\times1} \cdot s + 1} \cdot K_{a,2\times4}) \cdot (X - X_{ref})$$

### *Ramp perturbation*

Thirty trials of ramp surface perturbation were designed with different peaks acceleration, velocity, and displacement.

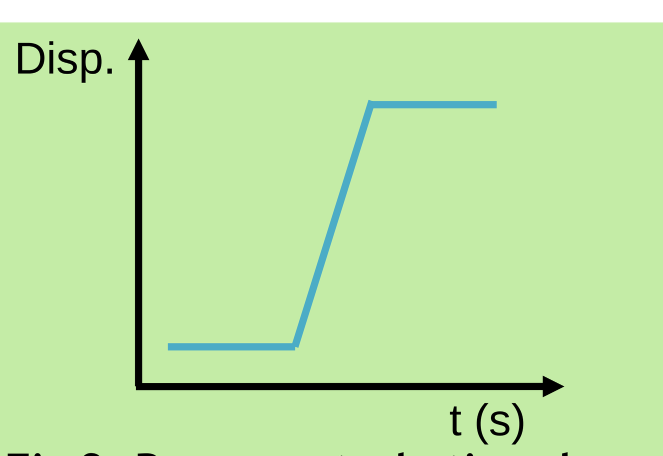



**Fig 2. Ramp perturbation shape**

**Table 1. Range of parameters of 30 ramp surface perturbations**

| Acceleration Range($m*s^{-2}$) | Velocity Range($m*s^{-1}$) | Disp. Range(m) |
|---|---|---|
| 0~8 | 0~0.5 | 0~0.18 |
| 0~5 | 0~0.45 | 0~0.9 |

### *Experiment setting*

- Motion Capture and Treadmill (Fig 3).
- 25 markers attached to subjects.
- 30 trials of perturbations are randomly applied to subjects in about 1 hour.


**Fig 3. Experimental environment**

### *Direct collocation*

Objective: $min\, J(\theta)$,

$$J(\theta) = \sum_{i=1}^{N} h[X_{mi} - X_i]^2, \text{where } \theta = [X_1, \cdots, X_N, K]$$

Subject to the plant dynamics: $f_c(X_i, X_{i+1}, a_i, a_{i+1}, K) = 0, \quad i = 1 \cdots N$

Initial guess: $\theta_0 = [X_{m1} \ldots X_{mN}, random(K)]$

Multiple optimizations were repeated for each trial using random initial guesses for the controller parameters. The controller which generated the best trajectory fit with experimental data was selected, to minimize the risk of finding a local optimum.

## Results

Comparing to controller type one, the best trajectory fit of controller type two is better (lower root means square, RMS) among all the trials. With controller type two, the lowest RMSs of all the trials are below 0.7 degree.

Fig 4 shows the lowest RMSs of each trial with two controller types. Fig 5(a) and 5(b) shows the best fit of controller type one and two, respectively, of one trial (dash green line blocked in Fig 5).

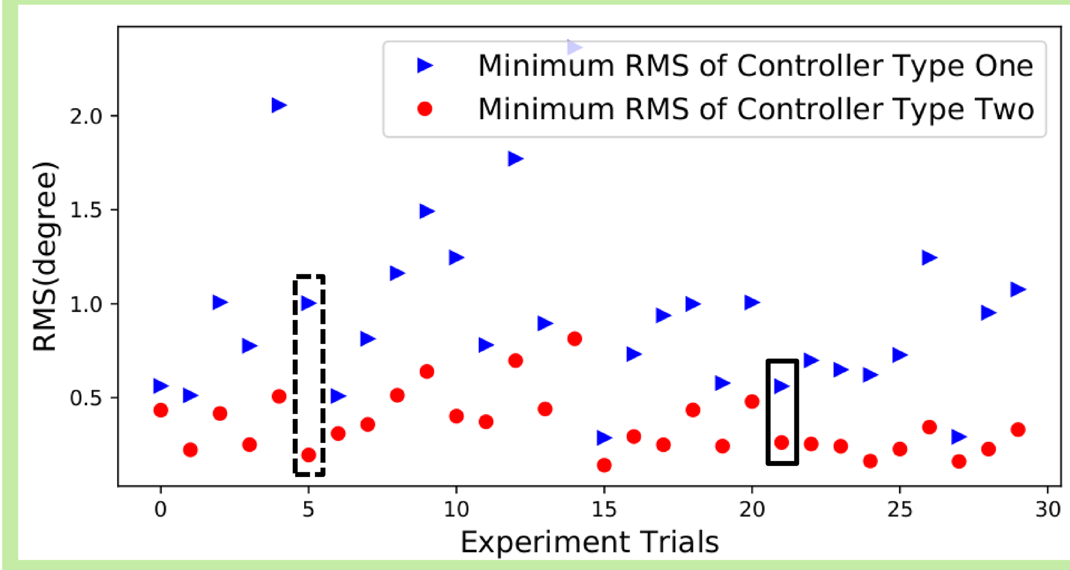



**Fig 4. Lowest RMSs of each ramp perturbation trial with two controller types.**

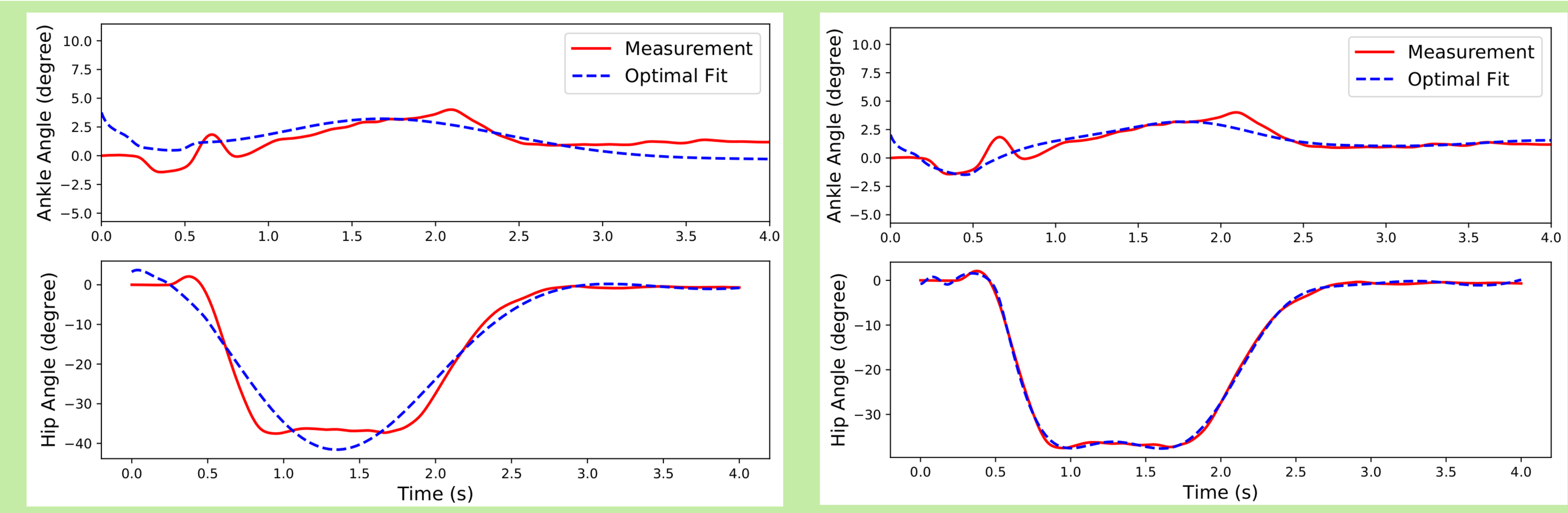



**Fig 5. (a) Best fit of one ramp perturbation using controller type one. (b) Best fit of one ramp perturbation using controller type two.**

However, with controller type two, the controller identification result is not unique. Fig 6 shows two very good trajectory fits with controller A and B in one trial(sold line block in Fig 5). Even though they both fit the data equally well, the controller parameters are quite different (Table 2).

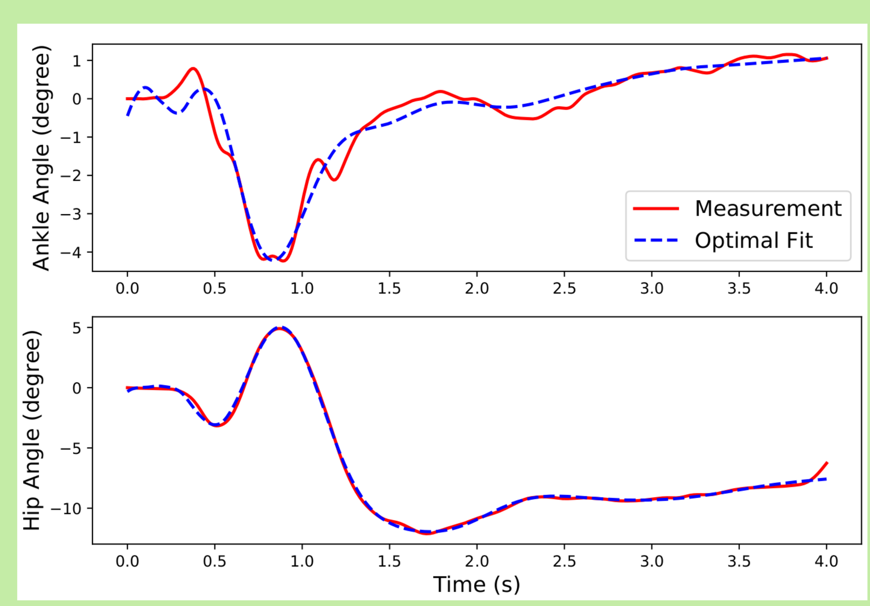
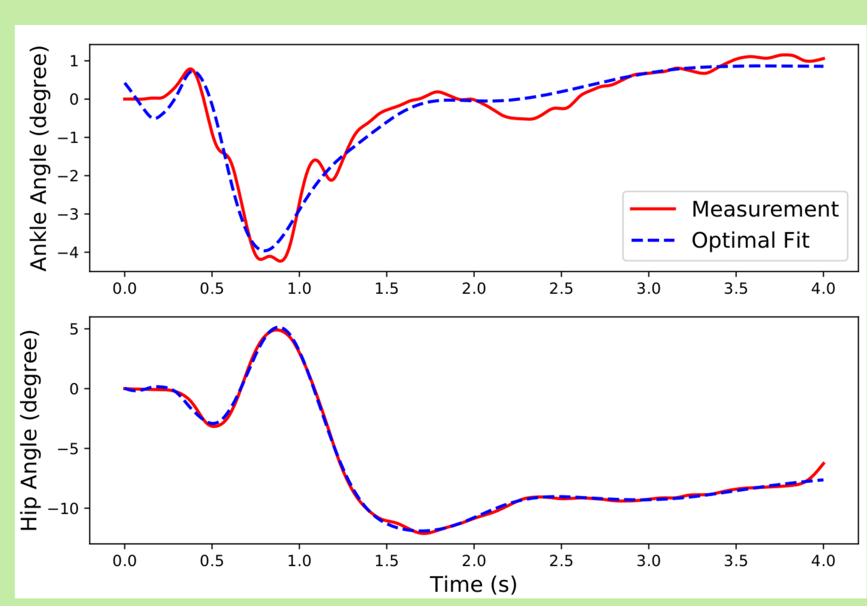



**Fig 6. (a) Trajectory fit of controller A**




**(b) Trajectory fit of controller B**

**Table 2. Controller parameters of controller A and B**

| Name (unit) | Cont. A | Cont. B |
|---|---|---|
| RMS error (deg.) | 0.2621 | 0.2624 |
| $T_a$ (s) | 0.14 | 0.78 |
| $T_h$ (s) | 0.14 | 0.46 |
| $\theta_{a_{ref}}$ (deg.) | -8.2 | -49 |
| $\theta_{h_{ref}}$ (deg.) | -4.1 | -6 |
| $K_{p11}$ | 27.2 | 14 |
| $K_{p12}$ | 132.2 | 811 |
| $K_{p13}$ | 598.2 | 1996 |
| $K_{p14}$ | 19.1 | 424.9 |
| $K_{p21}$ | 0 | 0 |
| $K_{p22}$ | 19.6 | 131 |
| $K_{p23}$ | 117.4 | 327.2 |
| $K_{p24}$ | 4.6 | 65 |
| … | … | … |

## Conclusion/Future Work

Conclusion

- Complex control model gives better fit of healthy human response under ramp perturbation.
- Ramp perturbation tests are too simple to identify realistic controllers.

Future work

- Identify realistic controller of experimental data under long time random perturbation.

## References

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