# A Robotic Study: The Contribution of Crossed Inhibitory Response to Stability in Biped Hopping

Xiangxiao Liu*, Andre Rosendo**, Hirofumi Shin*, Shuhei Ikemoto*, Masahiro Shimizu* and Koh Hosoda*
*Department of Engineering Science, Osaka University, Osaka Prefecture, Japan
*liuxx416@gmail.com*
**Department of Engineering, The University of Cambridge, Cambridge UK

## 1 Introduction

In the human body, a lot of peripheral neural networks realize local feedback. a famous one is stretch reflex, the stretch information is fed back to the excitation of the muscle through the muscle spindle. The stretch reflex has been widely investigated in locomotion, such as hopping [1]. Crossed spinal networks were also found in our body, which is an inhibitory/facilitating network from one leg to the contralateral one through the spinal cord. In the complicated crossed spinal networks, the crossed inhibitory responses were investigated relatively in recent, in passive pedaling [2], walking [3], sitting [4], and hopping [5]. Such local networks obviously modulate the locomotion behavior of a human, but the relation between them is not fully understood because the whole body networks are very complicated.

This report describes an experiment of a bipedal robot to investigate the contribution of crossed inhibitory response on stretch reflex to stability in hopping. Constructive experiment with a robot can exclude effects of higher feedback such as postural reflex, which enable us to estimate qualitative contribution to the behavior.

## 2 Method

A biped musculoskeletal robot was used in the investigation. Each leg was equipped with nine representative muscles in a human leg [6]. McKibben was used as an actuator. The locomotion control was originally generated from the data of muscle electromyography in human hopping [7]. With this control, the robot can jump up at a height of 20cm with releasing from a height of 15cm.

In the soleus muscles, the stretch reflex was originally replicated as 70ms air supplement after touch down in landing. To mimic the crossed inhibitory response, the first touch down foot sent a signal to decrease the air supplement of the soleus stretch reflex in the contralateral leg (No Inhibition: -0ms, Weak Inhibition: -35ms and Strong inhibition: -70ms).

The hopping experiment was implemented by dropping the robot in various attacking angles. We measured the rolling inclination of touch down ($\theta_{td}$) and the variation of the rolling inclination ($\Delta\theta$) between touch down and lifting off (shown in Fig. 1). $\theta_{td} < 0$ represents landing with left inclination and $\theta_{td} > 0$ represents landing with right inclination. Moreover, $\Delta\theta > 0$ indicates that the robot turns to the medial direction and the stability is improved. While $\Delta\theta < 0$ means turning to the lateral side and the rolling stability deteriorates. The higher $\Delta\theta$ represents the stronger posture recovery ability. A one-way ANOVA (repeated measures analysis of variance) was performed to access the amplitudes of $\Delta\theta$. If the F value is larger than 2.5, a Tukey's HSD (Tukey's honestly significant difference) was implemented as post hoc comparison.

## 3 Results

Figs. 2(a)-(c) show the results of No Inhibition, Weak Inhibition and Strong Inhibition respectively. For each case, we conducted over 100 hopping trials (No Inhibition: 109, Weak Inhibition: 114 and Strong Inhibition: 117) and the results were divided into six groups based on the $\theta_{td}$. In each sub-figure, a circle represents a hopping trial with $\theta_{td}$ in horizontal ordinate and $\Delta\theta$ in vertical ordinate. The higher $\Delta\theta$ represents the better stability. Triangle marks show the mean of $\Delta\theta$ of the trials in each $\theta_{td}$ group. Fig. 2(d) displays and compares the $means \pm SD$ (standard deviation) of $\Delta\theta$. The details of one-way ANOVA and Tukey's HSD results are also shown in Fig. 2(d). We can conclude from the results that in landing with inclination, compared to No Inhibition, the $\Delta\theta$ was gradually increased by increasing the crossed inhibitory response. This trend indicates that the rolling stability can be improved by the crossed inhibitory response.

### References

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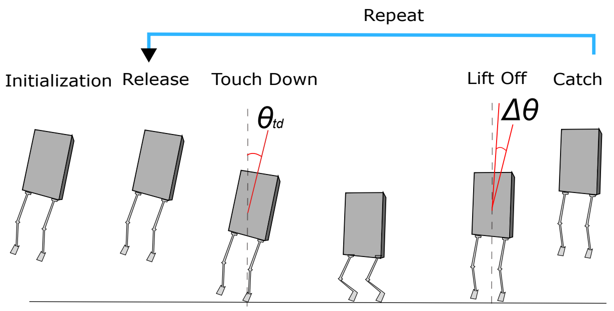


**Figure 1:** The experiment was implemented by dropping the robot to the ground in various attacking rolling angles. $\theta_{td}$ and $\Delta\theta$ were recorded to evaluate the stability effect.

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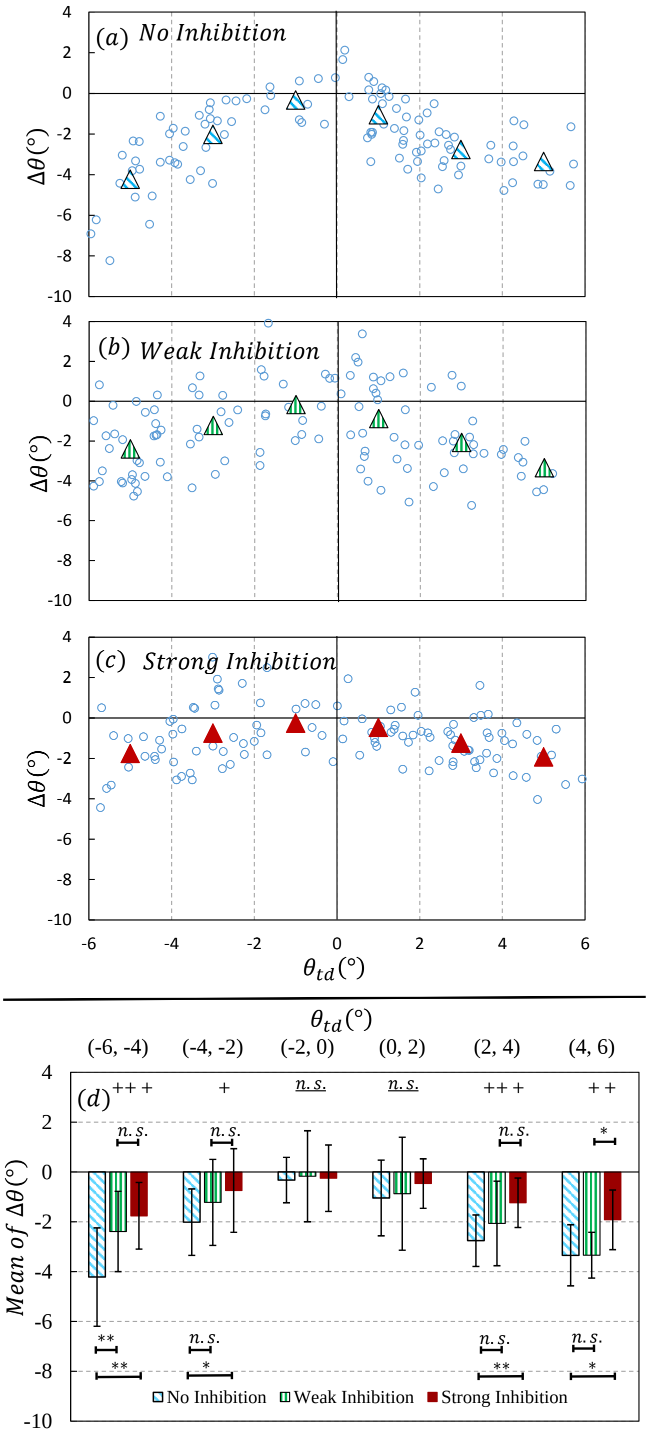


**Figure 2:** (a)-(c) display the $\Delta\theta$ from the three crossed inhibitory response levels. A blue circle represents a hopping trial and triangles demonstrate the mean of $\Delta\theta$ in each $\theta_{td}$ group. (d) compares the $\Delta\theta$ among different crossed inhibitory response levels in each $\theta_{td}$ group. Higher $\Delta\theta$ means stronger stabilization. Error bars donate the standard deviation. In ANOVA test, plus marks (+) show significant difference ($+P < 0.05, ++P < 0.01 and +++P < 0.001$) and n.s. means non-significance. In subsequent Tukey's HSD correlation, *n.s.* illustrates non-significance and asterisks donate $P < 0.05(*), P < 0.01(**)$ and $P < 0.001(***)$.