IMPLICIT GUIDANCE TO DYNAMIC STABILITY IN RHYTHMIC BALL BOUNCING

Meghan E. Huber¹ and Dagmar Sternad¹,²,³,⁴
Bioengineering¹, Biology², Electrical and Computer Engineering³, Physics⁴
Northeastern University

AIM OF STUDY

While rhythmically bouncing a ball with a racket appears to be a simple task, it requires precise perceptually-guided coordination between racket and ball to be successful. In this task, subjects manipulate a real table tennis racket to rhythmically bounce a virtual ball to a target height in a 2D virtual environment. Stability analyses of the mathematical model of a bouncing ball showed that dynamic stability is indicated when the racket contacts the ball during the decelerating portion of the racket’s upward movement (Schaal et al. 1996; Sternad et al. 2001; Dijkstra et al. 2004). Dynamically stable performance implies that small errors converge back to stable performance without requiring active corrections, hence constituting a “smart” solution that skilled performers adopt. Previous studies have shown that practice is needed for subjects to learn to exploit dynamic stability.

We designed a manipulation to guide novice subjects to dynamically stable solutions earlier in practice.

BALL BOUNCING MODEL

The simple model consists of a planar surface moving sinusoidally up and down, and a ball that impacts the surface with instantaneous contact and follows ballistic flight between the 6th and the 8th racket-ball impact.

Vertical Racket Position

x(t) = A \sin(\omega t)

Dynamic Stability

The resulting ball bouncing map has a period-1 attractor which is locally linearly stable when the racket acceleration at impact, denoted by AC, is bounded by:

\(-2g(1+a^2)/(1+a^2) < AC < 0\)

MANIPULATION OF DYNAMIC STABILITY

By using the racket velocity 50 ms prior to impact instead of the racket velocity at impact to determine ball trajectory, the period-1 attractor shifts by 50 ms on the sinusoidal racket trajectory.

Dynamic stability can only be achieved with more negative racket acceleration at impact with the time-shifted racket velocity manipulation.

EXPERIMENTAL DESIGN

21 right-handed subjects performed seven blocks of the ball bouncing task, with each block consisting of 4 trials lasting 40s each. Subjects practiced 6 blocks with either no manipulation, time-shifted racket velocity, or random noise added to racket velocity. The random noise condition served as a control to show that the time-dependent nature of the manipulation is important.

All subjects performed block 7 under normal conditions to test retention.

HYPOTHESES

HYPOTHESIS 1

Subjects who practice with time-shifted racket velocity learn to hit with negative racket acceleration at impact earlier in practice.

HYPOTHESIS 2

Subjects who practice with time-shifted racket velocity retain negative racket acceleration at impact under normal conditions.

RESULTS

Subjects who practiced with time-shifted racket velocity manipulation hit with negative racket acceleration earlier in practice. H1

There was no significant change in racket acceleration at impact between blocks 6 and 7 when the manipulation was removed. H2

T-tests compared stability measures between the time-shifted racket velocity and control subjects in block 7.

Subjects who practiced with time-shifted racket velocity manipulation have more dynamically stable performance compared to control subjects.

CONCLUSIONS

Subjects who practiced with the time-shifted racket velocity learned to hit with negative acceleration at impact earlier. When the manipulation was removed, these subjects did not change their racket behavior and had more dynamically stable performance than the control subjects.

Thus, the time-shifted racket velocity manipulation can implicitly guide novice subjects to exploit dynamic stability earlier in practice.

With the time-shifted racket velocity manipulation, the ball bouncing task can potentially be used to treat coordination disorders specifically related to rhythmic behavior.