How Humans Adapt Lateral Stepping Regulation

Anna C. Render
Department of Kinesiology
Penn State University
University Park, PA USA
acr313@psu.edu

Joseph P. Cusumano
Dept. of Engineering Science & Mechanics
Penn State University
University Park, PA USA
jpc3@psu.edu

Jonathan B. Dingwell
Department of Kinesiology
Penn State University
University Park, PA USA
dingwell@psu.edu

***Abstract* — *Regulation templates* show that human lateral stepping dynamics exhibit strong control of step width, and weak control of lateral body position between steps in normal walking. We hypothesized that when given goal-directed feedback, humans balance task-specific tradeoffs between these variables. Given explicit task goals, humans systematically vary lateral stepping regulation in ways predicted by our multi-objective control model.**

Keywords* — *Lateral Stepping, Goal-Directedness, Variability

I. Introduction

Humans regulate foot placement over consecutive steps, to maintain balance and achieve other goals while walking [1]. For normal (unrestrained and unperturbed) walking, healthy humans modulate left and right lateral foot placements (z_{Ln}, z_{Rn}) to trade off regulating lateral body position (z_{Bn}) and step width (w_n) [2]:

$$\begin{bmatrix} z_{Bn} \\ w_n \end{bmatrix} = \begin{bmatrix} \frac{1}{2} & \frac{1}{2} \\ -1 & 1 \end{bmatrix} \begin{bmatrix} z_{Ln} \\ z_{Rn} \end{bmatrix} \quad (1)$$

But for real-world walking [3], humans have to continually adapt their stepping regulation. Here, we determined the extent to which humans can modify how they regulate z_{Bn} and w_n from step-to-step when given explicit goal-directed feedback.

II. Methods

Twenty-four healthy adults (12M/12F; age 18-35) walked on a treadmill in a virtual environment (Fig. 1A) for 3 conditions: normal walking (NOR), maintaining absolute lateral position (POS) on the treadmill, and maintaining constant step width (WID). During POS and WID, participants were instructed to minimize errors with respect to the goal function:

$$F_q = q_n - q^* = 0, \quad (2)$$

where $q \in \{z_B, w\}$ and $q^* \equiv$ the desired goal value. Participants were given explicit visual feedback at each step (Fig. 1B). For each condition, stepping time series of z_{Bn} and w_n were extracted. For each time series, variability (σ) and statistical persistence (DFA α; reflecting step-to-step regulation) were calculated.

III. Results

When given POS feedback (Fig. 1C; left), participants significantly decreased variability of z_B compared to NOR. Changes in statistical persistence (α) of z_B also indicated tighter step-to-step regulation of z_B. In addition, α of w significantly *in*creased compared to NOR, reflecting weaker step-to-step regulation of step width when more tightly regulating position.

When given WID feedback (Fig. 1C; right), participants significantly decreased variability of w compared to NOR. DFA α of w remained near α=0.5, reflecting continued tight step-to-step regulation of w. In addition, α of z_B significantly *in*creased compared to NOR, reflecting weaker step-to-step regulation of lateral position when more tightly regulating step width.

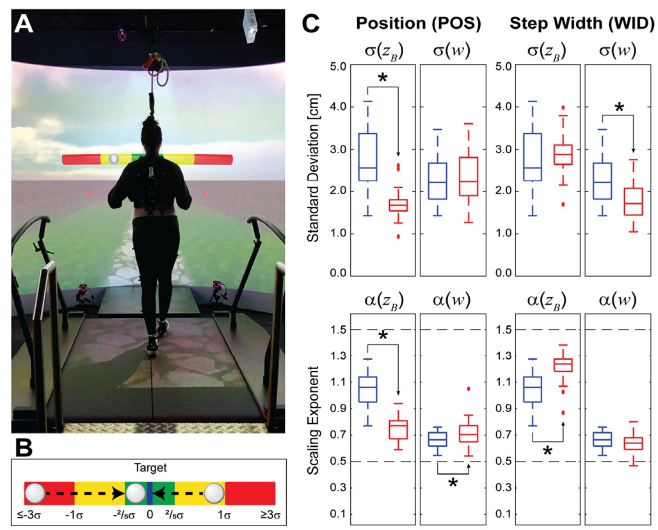

Fig. 1: **A**: Participant walking in VR. **B**: Schematic of visual feedback. **C**: Results for Maintaining Position (left; POS) and Maintaining Step Width (right; WID). Variability (top; σ) and statistical persistence (bottom; α) of z_B and w between normal walking (blue) and POS/WID conditions (red). Asterisks denote statistically significant differences ($p < 0.05$).

IV. Discussion / Conclusions

In normal walking, humans use multi-objective control of lateral stepping movements to trade-off regulating lateral position vs. step width [2]. Given explicit feedback of task performance relative to the prescribed goal function (2) for each $q \in \{z_B, w\}$, humans increased step-to-step regulation of the prescribed q to decrease variability in that q. In doing so, humans decreased step-to-step regulation of the complimentary (but non-prescribed) lateral stepping variable.

Therefore, to accomplish each prescribed walking task, humans exhibited distinct task-specific tradeoffs between w and z_B. These experimental results are in substantial agreement with predictions from our simple computational model, or lateral stepping *regulation template* [2]. Humans adapt lateral foot placement from each step to the next in systematic and predictable ways that depend on specific task goals.

References

[1] SM Bruijn, JH van Dieën, *J. Roy. Soc. Interface*, v.15, pp.1-11, 2018.

[2] JB Dingwell, JP Cusumano, *PLoS Comp. Biol.*, v.15, pp.e1006850, 2019.

[3] JS Matthis et al, *Curr. Biol.*, v.28, pp. 1224-1233.e5, 2018.

Work funded by NIH Grants 1-R21-AG053470 and 1-R01-AG049735.