Gait Modification when Decreasing Double Support Percentage with Feedback

Daniel S. Williams and Anne E. Martin
Pennsylvania State University
Email: dmw5737@psu.edu, aem34@psu.edu

1 INTRODUCTION

Humans naturally modify the percentage of time they spend in the double support (DS) phase of gait as they modulate their speed, but this change is done unconsciously. As speed increases, the DS phase decreases, both in time and as a percentage of step duration. In addition, peak knee angle increases, and the range of motion at the hip and ankle increases [1, 2]. However, it is unknown which changes are explicitly due to a change in DS percentage and which are adaptations to the change in speed. In this study, subjects directly modulated their DS percentage while holding speed constant, and the change to their gait was analyzed. The analysis of these changes can be used to better understand the role of the DS period in gait.

2 METHODS

The results presented herein are part of a larger study. Kinematic data (Vicon, Oxford, UK) were collected from 8 health adults (4 male) walking on a split-belt instrumented treadmill (Bertec, Columbis, OH). Subjects chose a slow, comfortable pace; this speed was used for all four one-minute trials and this natural step frequency was specified in two trials. Subjects then walked with a normal or decreased DS fraction and were given time to adapt to each gait before data collection. During the first two trials, one for each DS condition, a metronome dictated step frequency and visual feedback indicated DS fraction. During the last two trials, no feedback was provided. The order of the trials within each block was randomized. Normal DS with feedback is the control condition because it ensures the gait's spatial temporal values are identical to normal walking before subjects modified their gait. Comparisons are with respect to this trial. All values presented are statistically significant at $\alpha = 0.05$.

3 RESULTS AND DISCUSSION

As expected, when walking with a normal DS percentage, most subjects ($7/8$) maintained their normal step frequency within $\pm 8\%$, and feedback had almost no effect on gait. All subjects decreased their DS fraction with feedback, and most (7/8) decreased their DS fraction without feedback. The one trial in which a subject did not decrease DS percentage is omitted. When shortening DS percentage with feedback, all subjects maintained their normal step frequency within $\pm 8\%$. When shortening DS percentage without feedback, step frequency did not significantly change. The DS percentage decreased by $24\% \pm 7\%$ (feedback) and $25\% \pm 10\%$ (no feedback). DS time decreased by $23\% \pm 8\%$ (feedback) and $24\% \pm 11\%$ (no feedback) and single support (SS) time increased by $13\% \pm 7\%$ (feedback) and $13\% \pm 14\%$ (no feedback). Even without the step cadence constraint, subjects maintained the same DS and SS times to achieve the same DS percentage.

FOOT HEIGHT When decreasing DS percentage, swing foot height increased (Fig. 1). The peak height of the swing foot, measured at the heel, increased by $27\% \pm 20\%$ (feedback) and $26\% \pm 17\%$ (no feedback). The timing of the peak foot height relative to the total step time did not significantly change. This change indicates that subjects chose to lift their feet higher to increase the time spent in SS, rather than slow their

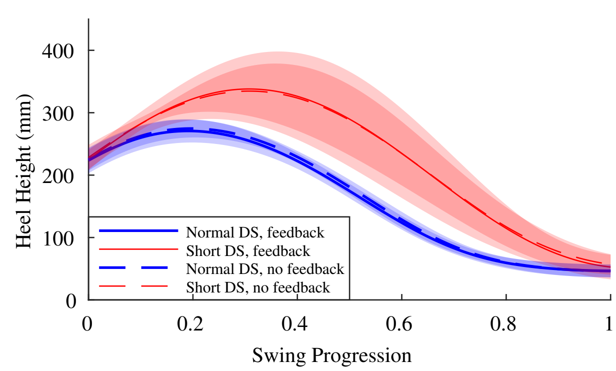

Figure 1: Swing foot height over normalized swing period. Shaded areas represent one standard deviation. Reducing the DS percentage increased swing foot height.

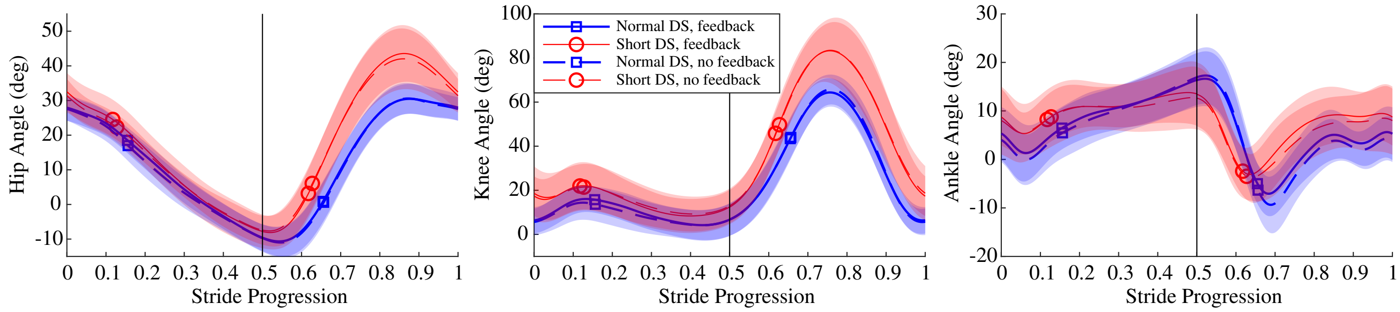

Figure 2: Joint angles. Markers represent contralateral and ipsolateral toe off, the vertical line represents contralateral heel strike, and the shaded areas represent one standard deviation from the mean. Conscious modification of the DS period affected a noticeable change in joint angle trajectories while feedback had almost no effect.

foot velocity and maintain the same foot trajectory.

KINEMATICS Hip angle from heelstrike to contralateral heelstrike was similar between conditions (Fig. 2). Hip flexion from contralateral heelstrike through the swing phase increased, with the peak hip angle increasing by $44\% \pm 27\%$ (feedback) and $45\% \pm 25\%$ (no feedback). Similar to the hip angle, the knee angle from heelstrike to contralateral heelstrike was similar between conditions, although the shortened DS gaits have more knee flexion on average. Knee flexaion from contralateral heelstrike through the swing phase significantly increased, with the peak knee angle increasing by $31\% \pm 21\%$ (feedback) and $35\% \pm 19\%$ (no feedback). Interestingly, the knee angle at contralateral toe off did not change as much, only increasing by $6 - 10\%$. This suggests that toe-off may be driven by the trailing knee angle [3]. When shortening DS percentage, ankle range of motion decreased by $17\% \pm 11\%$ when walking with feedback but did not significantly change when walking without feedback. This parameter had the largest difference between the feedback and no feedback trials, but the difference was not statistically significant. In both cases, peak dorsiflexion shifted earlier so that it occurred just before toe off. Removing feedback allowed changes to step frequency, but also removed task performance feedback. This subtraction did not significantly affect swing foot height or joint kinematics compared to the short DS without feedback trial. Thus, most subjects $(7/8)$ used the same gait for the trial without feedback that they learned in the trial with feedback rather than finding a new optimum gait. One explanation for this similarity is that subjects learned a valid gait during the feedback trial. Because humans are biased toward repeated motions [4], subjects naturally chose the gait they learned in the earlier trial. The changes in the joint trajectories when reducing DS percentage are similar to changes made when walking faster [2], but consciously shortening the DS percentage resulted in a more substantial change during swing and a less substantial change during stance. This may be because average hip velocity must match average walking speed. Altering stance leg kinematics will also alter hip velocity, thus making it difficult to maintain the given walking speed. In contrast, adjusting swing leg velocity is much easier [5].

4 CONCLUSIONS

To accommodate a shortened DS fraction without changing walking speed, subjects increased swing knee flexion, reduced ankle range of motion, and increased swing foot height. The changes are distinct from those made when increasing walking speed and affect the swing leg far more than the stance leg.

REFERENCES

[1] Murray, MP. *Am J Phys Med Rehab* **46**, 290–333, 1967.
[2] Han, Y & Wang, X. *Sci China Technol Sci* **54**, 983–991, 2011.
[3] Holden, JP, et al. *Clin Biomech* **12**, 375–382, 1997.
[4] Verstynen, T & Sabes, PN. *J Neurosci* **31**, 10050–10059, 2011.
[5] Martin, AE, et al. *Int J Robot Res* **33**, 1530–1543, 2014.