CHANGES IN STEP PERIOD DURING WALKING SPEED TRANSITIONS

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INTRODUCTION

Constant speed walking is well understood in healthy adults [1]. However, most people walk in short bouts, naturally transitioning between speeds [2]. Gait transitions between walking speeds have not yet been quantified sufficiently. Because spatial and temporal gait parameters vary for steady walking at different speeds [3], they can be used to quantify the transition behavior as one gait pattern morphs into another following a change in walking speed. This work begins to explore how healthy individuals anticipate and transition between speeds by studying step period near speed transitions.

METHODS

One healthy adult female walked on a split-belt instrumented treadmill at five speeds spanning a comfortable walking range (about 1.2 to 1.6 m/s). These speeds were normalized by leg length and gravity to give evenly-spaced nondimensionalized speeds of 0.40, 0.43, 0.47, 0.50, and 0.53. The subject first completed constant speed trials during which she walked at a single speed for one minute (approximately 100 steps) each. The subject also completed ten speed transition trials during which she walked on the treadmill as it transitioned between the five speeds. Three are analyzed here. Every nine steps, the treadmill sped up or slowed down to switch to a different speed until all 20 possible transitions had been executed. The magnitude of the transition was defined as the absolute difference between the two speeds. Fig. 1 shows both a small and large magnitude transition. The subject was notified of the next speed change three steps prior via a bar chart with both the current and next speed shown. For each nine-step constant-speed interval in the speed transition trials, a steady-state step period was calculated by averaging the step periods of the last five steps. For comparison purposes, the mean and

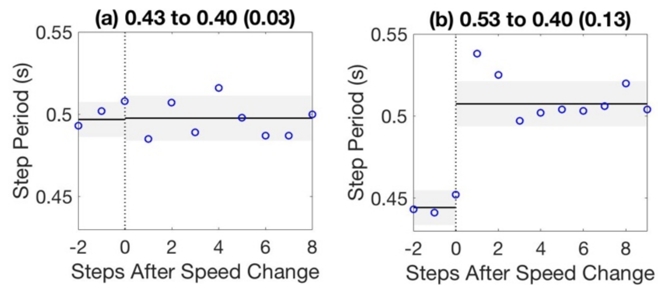

Figure 1: Representative (a) small and (b) large magnitude speed changes. After the speed changes at step 0, step period converges to a new value for the large transition but remains nearly unchanged for the small transition.

standard deviation of step period were also calculated for each of the constant speed walking trials. These means will be referred to as the steady-state and constant speed step periods, respectively. The constant speed and steady-state step periods were compared to analyze steady-state consistency. To determine the mode of convergence as the subject transitioned between speeds, the step period for the first step after the treadmill changed speed (T_1) was compared to the steady-state step period. If T_1 was within one constant speed standard deviation of the steady-state step period, the subject matched the new gait and showed immediate convergence. The subject overshot (or undershot) if the absolute difference between T_1 and the old steady-state mean was larger (or smaller) than the difference between the new and old steady-state means. The transitions were then grouped by magnitude to determine the typical transition strategy. To determine if the subject anticipated the transitions, the steps between the notification and transition were qualitatively assessed for deviations from the steady-state step period.

RESULTS AND DISCUSSION

The steady-state step periods are generally within one standard deviation of the constant speed step periods (Fig. 2). While this is not necessarily a large difference, it is not a trivial difference either. As the speed increases, the steady-state step period decreases slightly more than the constant speed step period. Particularly at the fastest speed, this subject walked with a shorter step period than she preferred during the constant speed walking trials. These results suggest that the subject generally converged to a gait similar to the constant speed gait even when switching between speeds fairly rapidly. There was no significant difference between the steady-state periods for speed increases versus decreases. There are some outliers present, which might be due to a large anticipatory step shortly before the treadmill speed changes. In approximately one third of the transitions, after notification about the upcoming speed change, the step period diverged from the steady state mean. In most cases, the direction of the deviation matched the following transition. An example of this phenomenon is visible in Fig. 1b for step 8. The subject was notified that they would be transitioning to a slower speed on step 6. In response, the subject may have anticipated the longer step period and begun to adjust the gait before the treadmill actually changed speed on step 9. The subject's transition behavior varied depending on the transition magnitude. For large transitions, the steady-state step period changed from before the transition to after the transition, and the step period converged to the new state (Fig. 1b). For small transitions, however, the steady-state values before and after the transition sometimes only slightly changed (Fig. 1a), suggesting that the subject

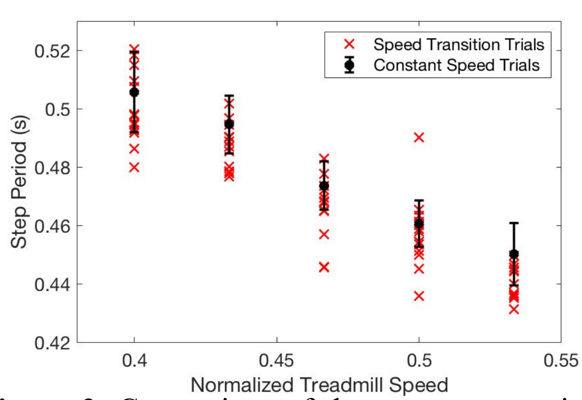

Figure 2: Comparison of the mean step period for the constant speed walking trials to each of the individual steady-state step period values from the speed transition trials. The error bars indicate one standard deviation.

Table 1: Percent of transitions that initially **Over**shot, **Under**shot, or immediately **Conv**erged to steady state. Transitions are grouped by magnitude.

Magnitude	Over	Under	Conv
0.0333	45.8	4.2	50.0
0.0667	61.1	22.2	16.7
0.1000	58.3	25.0	16.7
0.1333	100	0	0

maintained step period and altered step length to accommodate small changes in speed. These observations are supported by differences in the mode of convergence for different transition magnitudes (Table 1). Most notably, for the largest transitions, the subject overshot the final steady-state value every time. For the mid-range transition magnitudes, the subject overshot the steady-state value for over half of the transitions but undershot or immediately converged for a significant number of trials. For the smallest magnitude transitions, the subject immediately converged for about half of the transitions and overshot for the other half.

CONCLUSIONS

The mode of convergence is related to the speed change magnitude, with overshoot occurring more frequently in larger transitions and balancing with rapid convergence in small speed changes. This subject converged to similar steady-state step periods regardless of if she transitioned between speeds or walked at a constant speed. In many instances, she performed an anticipatory step before the speed change occurred. Future work includes investigating these findings with more subjects and analyzing step length and joint kinematics.

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