GAIT INITIATION: UNDERSTANDING BIOMECHANICS OF NON-STEADY MODULATIONS

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INTRODUCTION

The assumption of steady-state gait has been used broadly in the study of human walking. While this has provided us with a simplified model of the system to work with, walking is an inherently non-steady motor output. Changing direction and speed of locomotion under normal and perturbed conditions is a control problem requiring real-time solutions from the nervous system. Recently we showed that perturbed walking exhibits control strategies not observable by applying common analysis methods to transient data (e.g. averaging over consecutive gait cycles) [1]. Equally important we believe is the understanding of the control process in transient phases of normal walking such as gait initiation and termination.

Gait initiation has been explored in a few studies in the past with analysis of changes in the ground reaction forces (GRFs) and kinematics [2-4]. It has been shown that people achieve their steady-state speeds within the first three steps during which center of pressure moves laterally. It is also known that this phase of the gait involves activation of tibialis anterior (TA) with a concurrent relaxation of bicep femoris and gluteus medius [5]. What is not clear however is the transient changes in muscle activations as a function of the phase of gait. A phase advance or a phase delay can reveal control strategies used during the initiation process. As a result, this study was designed to quantify transient patterns of muscle activity as a function of phase during each step.

METHODS

Fourteen college students (eight males) walked on an instrumented treadmill (Forcelink, Culemborg, Netherlands) for this experiment. Each trial started with a velocity ramp that went from zero to 1.3 ms^{-1} in 3 sec thus creating an acceleration of 0.43 ms^{-2}. The values for speed and acceleration were chosen based on reports of preferred walking speeds and accelerations in humans [6,7]. This acceleration phase was followed by 270 sec of walking at the steady speed of 1.3 ms^{-1} before the subject went through a deceleration ramp of 3 sec to come to a full stop. Kinematics was captured by tracking trajectories of twenty-seven reflective markers on the body using a motion capture system (Motion Analysis, CA, USA). A wireless sixteen channel TRIGNO system (DELSYS, MA, USA) was used to capture EMG signals from fourteen muscles. Data was recorded at the sampling rate of 1000 Hz.

We have developed a new method of organizing the gait data appropriate to analyze changes in initial steps during acceleration [8]. The start and the end of a step are defined as the anteroposterior alignment of the heel markers of both feet. Unlike the classical definition of a step which starts from heel-strike, our definition ensures the first step of movement which starts from both feet aligned to have the same temporal features as the following steps. Additionally, each leg during each step takes only the role of a leading leg (the leg that initiates the movement forward) or a trailing leg (the leg that has to catch up). This method has also the advantage of positioning the important events such as the heel-strike and the toe-off toward the middle of a step rather than at one end of the spectrum and this makes the understanding of modulations happening around these points easier.

RESULTS AND DISCUSSION

The step time, as well as timings of heel-strike and toe-off, reached their steady-state values within the first three steps (Figure 1). The initial step of the leading leg showed a delayed heel-strike while the initial step of the trailing leg went through a delayed toe-off. Transient modulations of TA activity in the figure for the leading leg shows an increase in the activity around heel-strike (i.e. blue dots) and in the trailing leg TA activity increases after toe-off to provide support during the foot clearance.

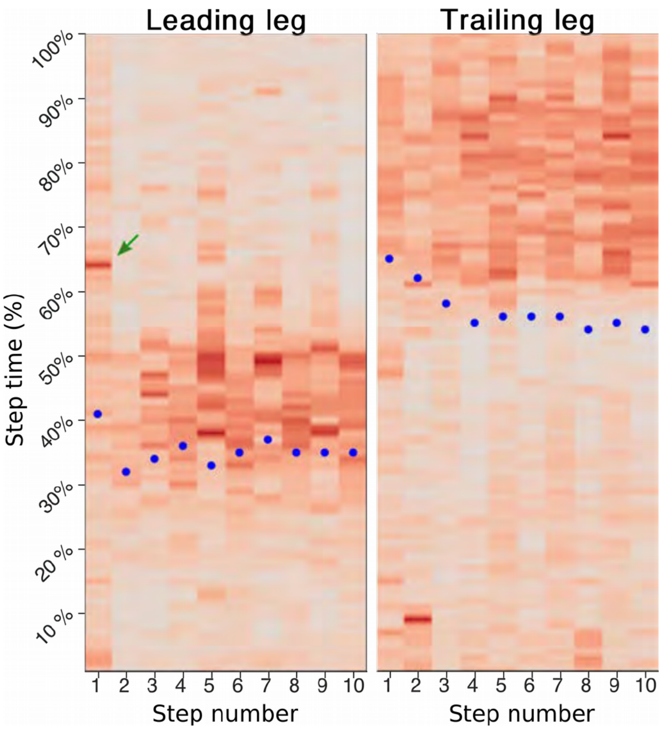

Figure 1: Transient modulation of TA activity during the first 10 steps after gait initiation. The horizontal axis shows the step number and the vertical shows the percentage of step time. The color is used as the third dimension to mark the changes in amplitude. *Left:* Changes during the steps for the leading leg averaged over subjects. The blue dots mark the timing of heel-strike for each step. The green arrow shows the peak of activity in the first step. *Right:* Changes during the steps for the trailing leg averaged over subjects. The blue dots mark the timing of toe-off for each step.

The activity of plantarflexors (see [8]) started to increase after the heel-strike for the leading leg and peaked before toe-off for the trailing leg. Quadriceps showed increased activity around heel-strike and hamstrings activities peaked during the late swing. These trends are in agreement with the roles traditionally assumed for different muscle groups in support and progression during steady-state walking. However, we also observed deviations from steady-state behavior for TA. Subjects consistently showed a delayed peak during the first step of the leading leg (the green arrow in the figure). Lack of a significant increase in the activity of TA around heel-strike is expected during the first step since the limb is experiencing low initial velocities and impact forces at the beginning compared to the following steps. However, an increase in the activity between heel-strike and mid-stance does not fit in the conventional role of TA which is stabilizing foot and ankle upon the impact during heel-strike. Further investigation is required to elucidate the role of TA in progression during transient modulations of gait. Of particular interest is a comparison of the changes presented here to those happening in gait termination.

The significance of the results presented here lies in the critical role of transient modulations in maintaining stability in gait initiation. Older adults and patients are at high risks of fall during this inherently non-steady phase of walking. A better understanding of functional roles of different muscles involved in this process is required in developing novel therapeutic approaches and designing new assistive devices.

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