# Gait dynamics following variable and constant speed gait training in individuals with chronic stroke

By: Christopher K. Rhea, Clinton J. Wutzke, Michael D. Lewek

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**Abstract:**

Variable practice may be beneficial for learning novel motor patterns. The purpose of this study was to determine the effect of a variable practice intervention during treadmill walking on the dynamic properties of gait. Using a counterbalanced design, 16 subjects with hemiparesis following chronic stroke performed 20 min of treadmill walking in constant speed training (CST) and variable speed training (VST) conditions. The dynamic properties of the hip and knee sagittal plane angles for two minutes before (pre-data) and two minutes after (post-data) CST and VST were examined using detrended fluctuation analysis and sample entropy. A main effect for time was observed for sample entropy of the knee angle; no other differences were observed between the pre/post data for the CST or VST conditions. While variable practice conditions are intended to promote movement errors for improved learning, we were unable to detect immediate changes in movement variability as a function of practice condition following a single session of gait training for individuals post-stroke.

**Keywords:** Gait | Stroke | Nonlinear dynamics | Kinematics

**Article:**

## 1. Introduction

Hemiparetic stroke affects gait by increasing paretic limb variability compared to the non-paretic side [1]. Increased variability in gait parameters has traditionally been associated with a lack of locomotor control [2]and increased fall risk [3]. However, there is an important distinction between the amount of variability and the structure of variability [4], [5], [6] and [7]. In brief, the amount of variability is a summary statistic that defines the average variation from the mean. The structure of variability defines the moment-to-moment changes in the behavior as it evolves over time and has led to the identification of particular movement signatures in healthy and pathological populations [4], [5], [6] and [7]. Healthy adults exhibit a flexible movement strategy characterized by a stable movement pattern with adaptive variation. This signature has been theoretically related to movement adaptability [6], [8] and [9] – often described as the functional capacity to appropriately avoid or recover from visual or physical perturbations. Following injury, aging or disease, the structure of variability deviates away from the healthy movement signature and can present as a more random or more rigid gait pattern, thus affecting movement adaptability.

Detrended fluctuation analysis (DFA) [10] and measures that estimate K–S entropy have been used extensively to quantify patterns within gait [11] and [12]. These metrics differ, as DFA quantifies the presence of long-range correlations over a variety of time scales (i.e., patterns early in the data set repeat later in the data set), while entropy metrics such as sample entropy (SampEn) index the number of times a short (two or three data point) template is repeated throughout the data set at a single time scale. Thus, by quantifying the long-range correlations (DFA) and regularity (SampEn), the movement signature prior to and following an intervention can be examined to determine whether a change in gait dynamics (and potentially movement adaptability) is observed.

Our prior work suggested that allowing variability during practice improves movement consistency after training [1]. The purpose of this study was to determine if variable practice can alter the structure of variability following a single session of training. This is important because the retention and transfer of motor skills may be enhanced by variable or random practice conditions [13]. In contrast, constant training conditions are thought to cause the central nervous system to habituate to the consistent sensory stimulation experienced throughout training [14]. While multiple training sessions would likely lead to an enhanced training effect, gait dynamics have been positively influenced following a single training session using variable practice conditions [15] and [16]. Therefore, we hypothesized that a single session of variable practice would positively influence the gait dynamics of subjects with hemiparetic stroke by increasing long-range correlations and decreasing regularity (i.e., increasing complexity) in gait patterns, creating a more adaptive and functional form of locomotion.

## 2. Methods

Sixteen subjects following chronic (>6 months) stroke with resultant hemiparesis participated (9M/7F; age: 56 ± 10 years; height: 1.76 ± 0.11 m; weight: 80.7 ± 15.9 kg; paretic side: 10R/6L; time since stroke: 61 ± 64 months; comfortable overground gait speed:

0.71 ± 0.25 m/s). Study protocol and written informed consent was approved by the IRB at UNC-Chapel Hill. Using a counterbalanced design, each participant performed two 20-min sessions of gait training separated by 8 ± 2 days (range 3–14 days due to scheduling difficulties). During each session, participants walked on a dual-belt 'instrumented' treadmill (Bertec Corp., Columbus, OH) for either a constant speed training (CST) or variable speed training (VST) condition. Rest breaks were provided, as necessary. During the CST condition, subjects maintained a constant speed for the entire 20 min session (CST treadmill vel: 0.81 ± 0.24 m/s). During the VST condition, subjects performed the first 5 min of walking at 100% of CST. During the subsequent 15 min, we simultaneously altered the treadmill belt speeds each minute to 60, 80, or 100% of CST speed (Fig. 1). After each 20-min training session, subjects sat in a chair for 30 min and then walked for five more minutes for retention testing at 100% of CST speed. Minutes three and four in both the training portion (pre-data) and the retention test (post-data) were used for analysis, allowing for the comparison of kinematics over two continuous minutes of walking before and after the intervention. An eight-camera motion capture system (Vicon/Peak, Los Angeles, CA) recorded the trajectories of bilaterally placed retro-reflective markers at 120 Hz. Sagittal plane hip and knee angles were calculated with Visual3D (C-Motion, Germantown, MD). Only data from the paretic side were considered for this study and data were not filtered prior to the DFA and SampEn ($m = 3$, $r = 0.2$, $\tau = 15$) analyses to avoid artificially influencing the underlying dynamic properties. Four separate 2 × 2 (condition x time) repeated measures AVOVAs ($\alpha = 0.05$) were used to compare pre-data to post-data within the CST and VST trials to examine the influence of the intervention, one for each metric (DFA or SampEn) and joint (hip angle or knee angle).

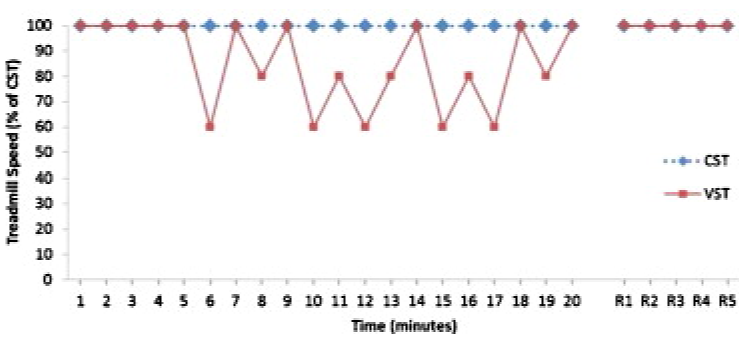


**Fig. 1.** Treadmill speed over the 20 min session for the constant speed training (CST) and variable speed training (VST) conditions. The VST speed fluctuated as a function of each participants CST speed. A constant treadmill speed (100% of CST) was used for all 5 min of the retention test (R1–R5) in both conditions.

## 3. Results

No interactions or main effects were observed within DFA for the hip or knee angles (all $p > 0.05$, Fig. 2). No interactions or main effects were observed within SampEn for the hip angle ($p > 0.05$). No interaction or main effect for condition was observed within SampEn for the knee angle ($p > 0.05$), although a main effect for time was observed for SampEn of the knee angle ($F_{1,15} = 5.06$, $p = 0.04$), with lower values detected in the post-data after both conditions ( Fig. 3).

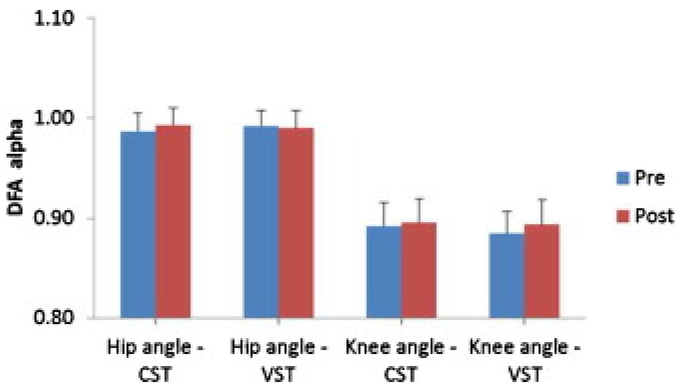


**Fig. 2.** Alpha value of the detrended fluctuation analysis (DFA). A lower alpha value indicates fewer long-range correlations. No differences were observed in the pre/post data for the hip or knee in the constant speed training (CST) or the variable speed training (VST) (all $p > 0.05$).

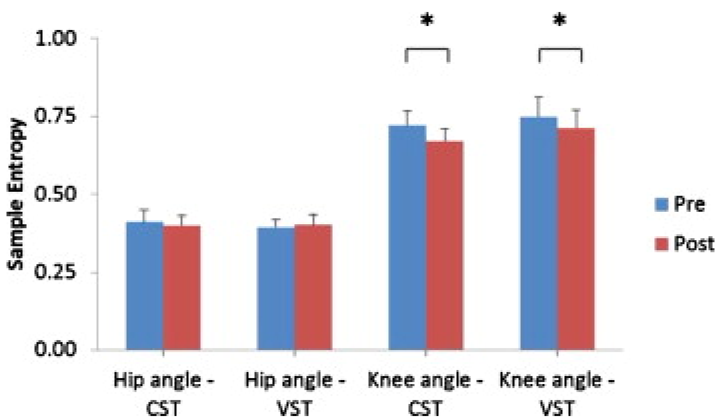


**Fig. 3.** Sample entropy (SampEn) for all conditions, with a lower value indicating a more regular pattern. No differences were observed in the pre/post data for the hip or knee as a function of the condition (CST or VST) (all $p > 0.05$). The asterisks represent a main effect for time at the knee, with SampEn decreasing following both conditions ($p = 0.04$).

## 4. Discussion

This paper examined the influence of variable practice on gait dynamics, using constant speed practice as the control condition. While SampEn of the knee was influenced by practice time, the hypothesis that a single session of variable practice would promote more favorable changes in movement variability was not supported by these data. Whereas multiple training sessions are typically required to elicit changes in movement patterns, a single training session can positively influence gait dynamics [15] and [16]. Here, a single session was likely unable to induce a practice type effect due to the frequency of changes to practice condition. Previous research prescribed stride-to-stride variability by having participants synchronize heel-strikes to either a visual [15] or auditory [16] ”noisy” metronome which mimicked the dynamic patterns found in the stride intervals of young, healthy adults [8]. As a result, gait dynamics were positively influenced by having participants synchronize to the “noisy” metronomes. In the current study, we prescribed a change in gait speed every minute (VST), which did not influence gait dynamics differently than CST. Future work should immerse patients with stroke in interventions that alter gait variability on a stride-to-stride basis over single and multiple training sessions.

## Conflict of interest

The authors have nothing to disclose related to any financial and personal relationships with other people or organizations that could inappropriately influence (bias) our work.


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