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# Gait differences between individuals with post-stroke hemiparesis and non-disabled controls at matched speeds

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**Abstract**

Treadmill walking was used to assess the consistent gait differences between six individuals with post-stroke hemiparesis and six non-disabled, healthy controls at matched speeds. The hemiparetic subjects walked on the treadmill at their comfortable speeds, while each control walked at the same speed as the hemiparetic subject with whom he or she was matched. Kinematic and insole pressure data were collected from multiple, steady-state gait cycles. A large set of gait differences found between hemiparetic and non-disabled subjects was consistent with impaired swing initiation in the paretic limb (i.e., inadequate propulsion of the leg during pre-swing, increased percentage swing time, and reduced knee flexion at toe-off and mid-swing in the paretic limb) and related compensatory strategies (i.e., pelvic hiking and swing-phase propulsion and circumduction of the paretic limb). Exaggerated positive work associated with raising the trunk during pre-swing and swing of the paretic limb, consistent with pelvic hiking, contributed to increased mechanical energetic cost during walking. A second set of gait differences found was consistent with impaired single limb support on the paretic limb (i.e., shortened support time on the paretic limb) and related compensatory strategies (i.e., exaggerated propulsion of the non-paretic limb during pre-swing to shorten its swing time). Other significant gait differences included asymmetry in step length and increased step width. We conclude that consistent gait differences exist between hemiparetic and non-disabled subjects walking at matched speeds. The differences provide insights, concerning hemiparetic impairment and related compensatory strategies, that are in addition to the observation of slow walking speed.
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*Keywords:* Gait; Stroke; Biomechanics; Speed; Symmetry

## 1. Introduction

Gait in individuals with post-stroke hemiparesis is characterized by reduced speed, cadence, stride length, and joint angular excursions [1,2]; asymmetry in temporal, spatial, kinematic, and kinetic gait variables [3-6]; and increased mechanical energetic cost [7,8]. The improvement of these gait deviations has been stressed in gait rehabilitation, since it may improve locomotor performance in hemiparetic individuals. However, many of these deviations may be consistent with slower walking in non-disabled individuals and simply restate the observation that hemiparetic individuals walk slower than normal. The gait differences between hemiparetic and non-disabled individuals while walking at the same speeds may provide insights, concerning hemiparetic impairment and related compensatory strategies, that are in addition to the observation of slow walking speed.

In this pilot study, we compared the gait of individuals with post-stroke hemiparesis and non-disabled controls while they walked on a treadmill at matched speeds. Treadmill walking facilitated the matching of speed between hemiparetic and non-disabled subjects and the comparison of kinematic and insole pressure data from multiple, steady-state gait cycles. We hypothesized that consistent gait differences would exist between the hemiparetic and non-disabled subjects at matched speeds.

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## 2. Methods

### 2.1. Subjects

Six individuals with a single cerebrovascular accident and resultant hemiparesis were selected from the VA Palo Alto Health Care System outpatient population. Inclusion criteria for this study were (1) a single stroke at least 6 months prior to study, (2) ability to walk independently overground with use of an ankle foot orthosis (AFO) or assistive device, and (3) ability to advance the paretic limb independently while walking on a treadmill. Each subject's lower extremity functional motor level was quantified using the Fugl-Meyer Assessment of motor function [9]. Six non-disabled individuals were recruited to serve as gender, age (within ±10 years), height (within ±6 cm), and weight (within ±12 kg) matched controls for the hemiparetic subjects. The non-disabled controls exhibited normal joint range of motion and muscle strength and had no apparent gait abnormalities. Subject characteristics are presented in Table 1, ordered by the hemiparetic subjects' comfortable walking speeds on the treadmill. All procedures were approved by the Stanford University administrative panels on human subjects and were consistent with the Declaration of Helsinki.

### 2.2. Instrumentation

Subjects wore a Medical Harness (Robertson Mountaineering, Henderson, NV) attached to an overhead support as they walked on a Rehabilitation Treadmill (Biodex Medical Systems, Shirley, NY). During treadmill walking, the harness did not provide body weight support but served as a safety catch if subjects were to fall. Pedar insole pressure sensors (Novel, Munich, Germany) were placed inside the subjects' shoes to determine foot contact. For subjects who wore an AFO, the sensors were placed inside the AFO.

Bilateral kinematics were captured at 50 Hz using a Qualisys Motion Analysis System (Qualisys Inc., East Windsor, CT), incorporating five digital ProReflex cameras. Eight clusters of three reflective markers were located on the upper trunk and pelvis and right and left thighs, shanks, and feet and calibrated to anatomical reference points to define each segment's position and orientation. A voltage signal coinciding with each camera exposure initialization was used to synchronize the insole pressure readings.

### 2.3. Protocol

The hemiparetic subjects walked on the treadmill at their comfortable speeds (range: 13–45 cm/s; Table 1) as determined during single pre-sessions where the subjects were familiarized to treadmill walking. Each non-disabled control walked at the same speed as the hemiparetic subject with whom he or she was matched. Hemiparetic subjects who normally wore an AFO walked with the AFO on the treadmill. All subjects were asked to hold onto the handrails as the treadmill belt accelerated and release hand hold once the prescribed speed was reached. After subjects achieved steady state without handrail hold, data was collected for 20 s. Two subjects failed to walk for 20 s without handrail hold, but data for at least five complete gait cycles were collected from these individuals.

### 2.4. Data reduction and analysis

The raw kinematic data were post-processed in MARey (Center for Locomotion Studies, Penn State University, State College, PA) to obtain knee flexion and ankle dorsiflexion angles; joint center trajectories of the hip, knee, and ankle; and anatomical trajectories of the acromion processes and tip of the second toe and heel of each foot. The joint center and anatomical trajectories were fitted to a seven-segment inertial model of each subject, consisting of a trunk (including the mass of the head and arms), two thighs, two shanks, and two feet (including the mass of the shoes), based on data collected by Dempster et al. [10]. Hip flexion/extension angle was defined to be the angle between the axes of the femur and trunk in the sagittal plane, which was defined by the mid-line between the hip joint centers and

Table 1
Hemiparetic (H1–H6) and non-disabled (N1–N6) subject characteristics

| | Subject no. | | | | | | |
|---|---|---|---|---|---|---|---|
| | H1/N1 | H2/N2 | H3/N3 | H4/N4 | H5/N5 | H6/N6 | Mean (S.D.) |
| Gender | M/M | M/M | F/F | M/M | F/F | F/F | |
| Age (years) | 52/60 | 66/60 | 64/67 | 68/72 | 56/58 | 56/49 | 60 (7)/61 (8) |
| Height (cm) | 170/176 | 175/172 | 161/161 | 158/159 | 167/161 | 169/163 | 167 (6)/165 (7) |
| Weight (kg) | 84/94 | 77/66 | 66/55 | 66/66 | 54/54 | 54/52 | 67 (12)/64 (12) |
| SSWS (cm/s) | 22/111 | 33/138 | 59/149 | 72/113 | 56/146 | 77/147 | 53 (22)/134 (17) |
| CTS (cm/s) | 13/13 | 31/31 | 36/36 | 36/36 | 45/45 | 45/45 | 34 (12)/34 (12) |
| Time post-stroke (months) | 28 | 20 | 45 | 122 | 8 | 40 | 44 (41) |
| Affected side | R | R | L | L | R | L | |
| LE Fugl-Meyer (max = 34) | 16 | 20 | 16 | 24 | 27 | 22 | 21 (4) |
| Assistive device (s) | AFO cane | Cane | AFO cane | AFO | Cane | | |

Individual characteristics and group means and standard deviations (S.D.). Abbreviations: LE, lower extremity; AFO, ankle-foot orthosis; SSWS, self-selected overground walking speed; CTS, comfortable treadmill speed.