

INDIVIDUAL LIMB MECHANICAL ANALYSIS OF GAIT FOLLOWING STROKE

^{1,2}Caitlin E. Mahon, ²Dominic J. Farris, ^{1,2}Gregory S. Sawicki and ¹Michael D. Lewek

¹University of North Carolina at Chapel Hill, Chapel Hill, NC, USA

²North Carolina State University, Raleigh, NC, USA

email: mahon.caitlin@gmail.com

INTRODUCTION

Total mechanical work and net metabolic cost of gait can be minimized when the timing and magnitude of the leading limb's negative mechanical work is equal to the trailing limb's positive mechanical work during double-support [1]. Following stroke, greater mechanical work requirements reduce metabolic efficiency [2]. We propose this is, in part, the result of inter-limb mechanical asymmetries.

We hypothesize that: (1) mechanical asymmetries between limbs will be greater in individuals with reduced gait functional ability. Based on analyses conducted on patient populations with similar impairments [3,4] we further hypothesize that: (2) gait following stroke will exhibit less positive power production from the paretic limb during the trailing double-support (DST) phase, greater negative power production from the non-paretic limb during the leading double-support (DSL) phase to redirect the COM, and greater positive power production from the non-paretic limb during the single-support (SS) phase to raise the COM (each in comparison to the contralateral limb).

METHODS

We recruited 26 individuals who presented with chronic (>6 months post-stroke) hemiparesis following unilateral, non-cerebellar brain lesion due to stroke. Individuals were stratified into "functional" groups based on self-selected overground speed: 13 high function (>0.8 m/s), 6 moderate function (0.5 m/s-0.8 m/s), and 7 low function (<0.5 m/s). The individual limbs method (ILM) [1] was used to calculate external mechanical power performed on the COM by the paretic and

non-paretic limbs, during treadmill walking at a maintainable training speed.

Ground reaction forces, collected from a one-minute trial on a dual-belt treadmill, and vertical force from handrail support (when produced) were included in net force data prior to calculation of COM acceleration. Because the ILM assumes symmetric gait, and spatiotemporal asymmetries are often exhibited following stroke, the ILM was adjusted by: (1) assuming symmetry over strides, instead of steps, and (2) subtracting average COM acceleration over a trial from instantaneous COM acceleration prior to integration.

Five separate two-way (limb x functional group) ANCOVAs were performed ($\alpha=0.05$) to examine differences in peak instantaneous mechanical power (P_{inst}) during (1) DST and (2) DSL and average mechanical power (P_{avg}) during (3) DST, (4) DSL and (5) SS, using treadmill speed as a covariate (all outcome variables were normalized to body mass). For the post-hoc analysis, adjusted means were computed and a Bonferroni adjustment was applied to account for multiple comparisons.

RESULTS AND DISCUSSION

Figure 1: The two-way ANCOVA analyzing peak P_{inst} during DST showed the paretic limb produced a significantly less positive P_{inst} peak than the non-paretic limb ($p<.0005$); no main effect for functional group ($p=.163$); and an interaction effect between limb and functional group ($p=.050$). Post-hoc analyses revealed the greatest difference between limbs (i.e., greatest asymmetry) existed for the moderate group and the least difference between limbs (i.e., least asymmetry) existed for the low group after applying the treadmill speed covariate (non-paretic/paretic adjusted means, (W/kg): high:

1.10/0.65; moderate: 1.10/0.45; low: 1.00/0.95). The two-way ANCOVA analyzing peak P_{inst} during DSL showed the non-paretic limb produced a significantly less negative P_{inst} peak than the parietic limb ($p=.047$); no main effect for functional group ($p=.288$); and no interaction effect between limb and functional group ($p=.944$).

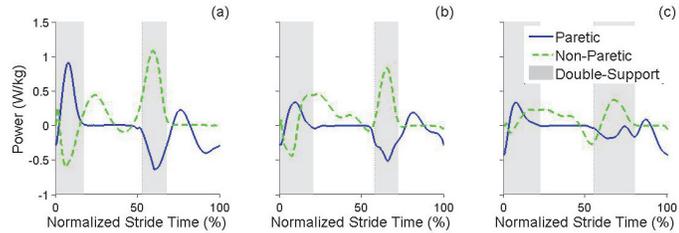


Figure 1: Normalized, mean P_{inst} for (a) high, (b) moderate and (c) low functional groups. Normalized Stride Time 0 indicates beginning of non-paretic limb DSL phase.

Figure 2: The two-way ANCOVA's analyzing P_{avg} produced during DST, DSL and SS, respectively, showed the parietic limb (compared to the non-paretic limb) produced significantly less positive P_{avg} during DST, and the non-paretic limb (compared to the parietic limb) produced significantly less negative P_{avg} during DSL and significantly greater positive P_{avg} during SS ($p<.0005$, $p<.0005$, $p<.0005$); no main effect for functional group ($p=.120$, $p=.452$, $p=.077$); and no interaction effect between limb and functional group ($p=.093$, $p=.453$, $p=.467$).

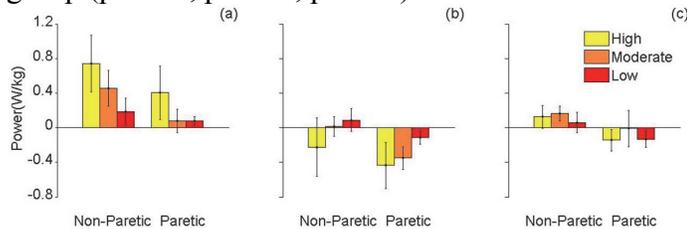


Figure 2: Total P_{avg} plotted over (a) DST, (b) DSL and (c) SS.

Although we observed significant mechanical asymmetries between limbs across all functional groups during each phase of the stride, we were surprised that these asymmetries were not significantly different *between* groups. The lone exception was peak P_{inst} during DST, for which asymmetry between limbs was larger in the moderate group compared to the low group. These results suggest that individuals with lower function

do not exhibit less mechanical power production and absorption from solely the parietic limb, but from both limbs, compared to individuals with higher function.

Our second hypothesis was partially confirmed. We observed less positive peak P_{inst} and P_{avg} of the parietic limb (compared to the non-paretic limb) during DST. Although this may be due to the parietic ankle plantar-flexors producing less propulsive power than the non-paretic ankle plantar-flexors, further work is needed to confirm this.

We observed less negative peak P_{inst} and P_{avg} of the non-paretic limb (compared to the parietic limb) during DSL, contrary to our hypothesis. This may be due to step length asymmetry between limbs, which has been positively correlated with negative work production during heel-strike [5]. In our subjects, a greater mean parietic step length was exhibited across all functional groups.

There was greater positive P_{avg} for the non-paretic limb (compared to the parietic limb) during SS, as expected. Initiation of positive power production by the non-paretic limb immediately prior to SS was exhibited by the moderate and low groups (Figure 1) resulting in net positive P_{avg} values during DSL. Although this may be a compensation for less propulsive power produced by the trailing parietic limb or early initiation of power production to raise the COM, further work is needed to confirm this.

CONCLUSIONS

Robust differences in mechanical power produced between limbs exist, yet we observed little evidence of greater asymmetry in mechanical power production with reduced gait functional ability.

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