Speed-based Changes To Walking Stability And Economy May Explain Preferred Walking Speed After Stroke

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BACKGROUND

The preferred walking speed (PWS) of healthy individuals is typically the most economical and stable[1]; however, the PWS of individuals post-stroke is not the most economical. Indeed, if made to walk faster, individuals post-stroke consume less energy per meter walked[2], suggesting that non-energy based optimization strategies underlie their selection of PWS. It is not clear if the complementary relationship between walking stability and the energy cost of walking that is seen during healthy bipedalism exists in the face of the impairments characteristic of post-stroke hemiparesis.

OBJECTIVE

The objective of this study was to evaluate the effect of changing walking speed on both the walking stability and energy cost of walking of individuals post-stroke.

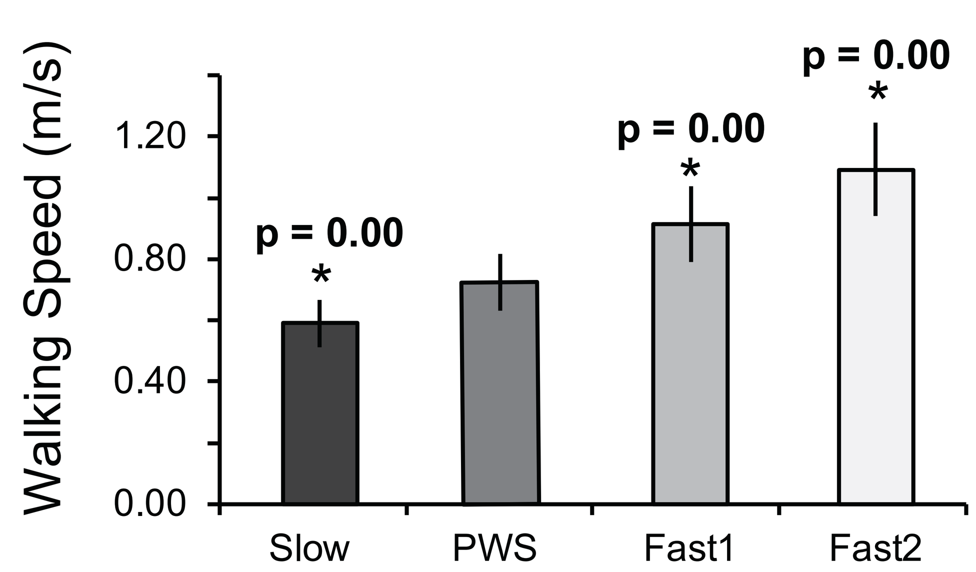
HYPOTHESIS

We hypothesized that walking stability and the energy cost of walking would have antagonistic relationships with walking speed such that walking faster than PWS would be less energetically costly, but more unstable and irregular, and walking slower than PWS would be more energetically costly, but less unstable and irregular.

METHODS

Seven individuals post-stroke were outfitted with a full body marker set and an indirect calorimetry system. They completed four 2-min walking trials on an instrumented treadmill, each at one of four different **walking speeds** tested in random order:

- **PWS** self selected, Preferred Walking Speed
- **Slow** a speed ~20% slower than PWS
- **Fast1** a speed ~20% faster than PWS
- **Fast2** a speed ~50% faster than PWS



Energy cost of walking was computed as mass (kg) and speed (m/min) normalized oxygen consumption (ml O_2) to yield the cost of transport (ml O_2/kg/m).

Stability was measured based on the motion of the body's center of mass (CoM), which was determined by taking the weighted average of the individual segment CoMs. Three approaches characterized stability in both medio-lateral and vertical directions:

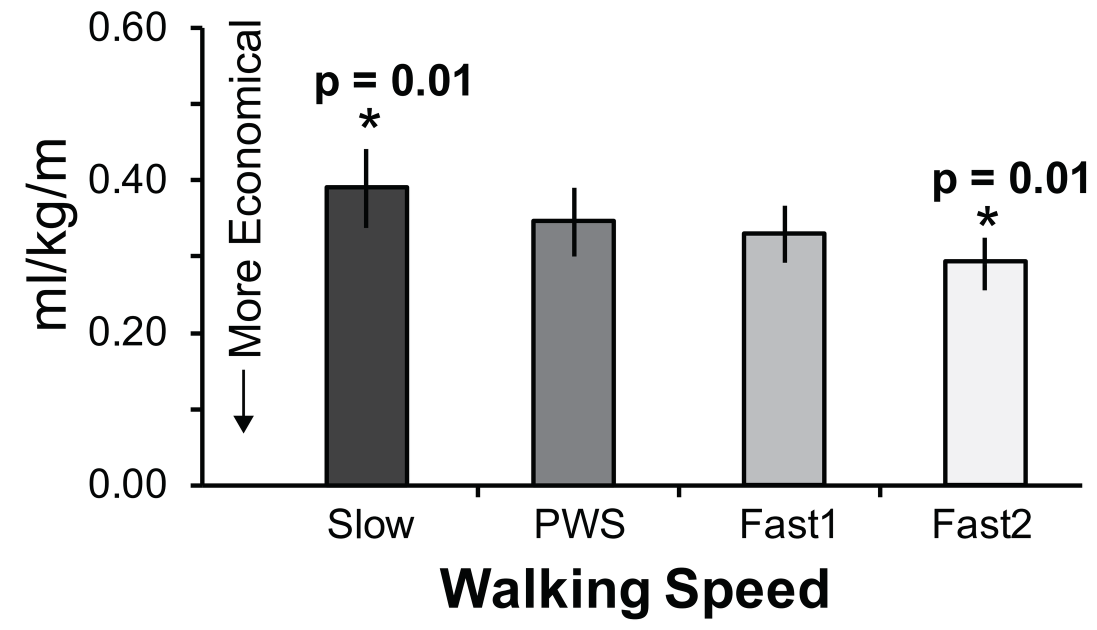
- **SE** gait regularity as measured by the sample entropy of the CoM[3]
- **LyE** dynamic structure of variance as measured by the maximum Lyapunov exponent of the CoM motion[4]
- **MOS** mechanical stability as measured by the margins of stability of CoM motion relative to the base of support[5]

Pairwise comparisons compared Slow, Fast1, and Fast2 to PWS (p<0.05). Data was processed using Visual3D and analyzed using Matlab 2018b. Group means and standard errors are shown in figures.

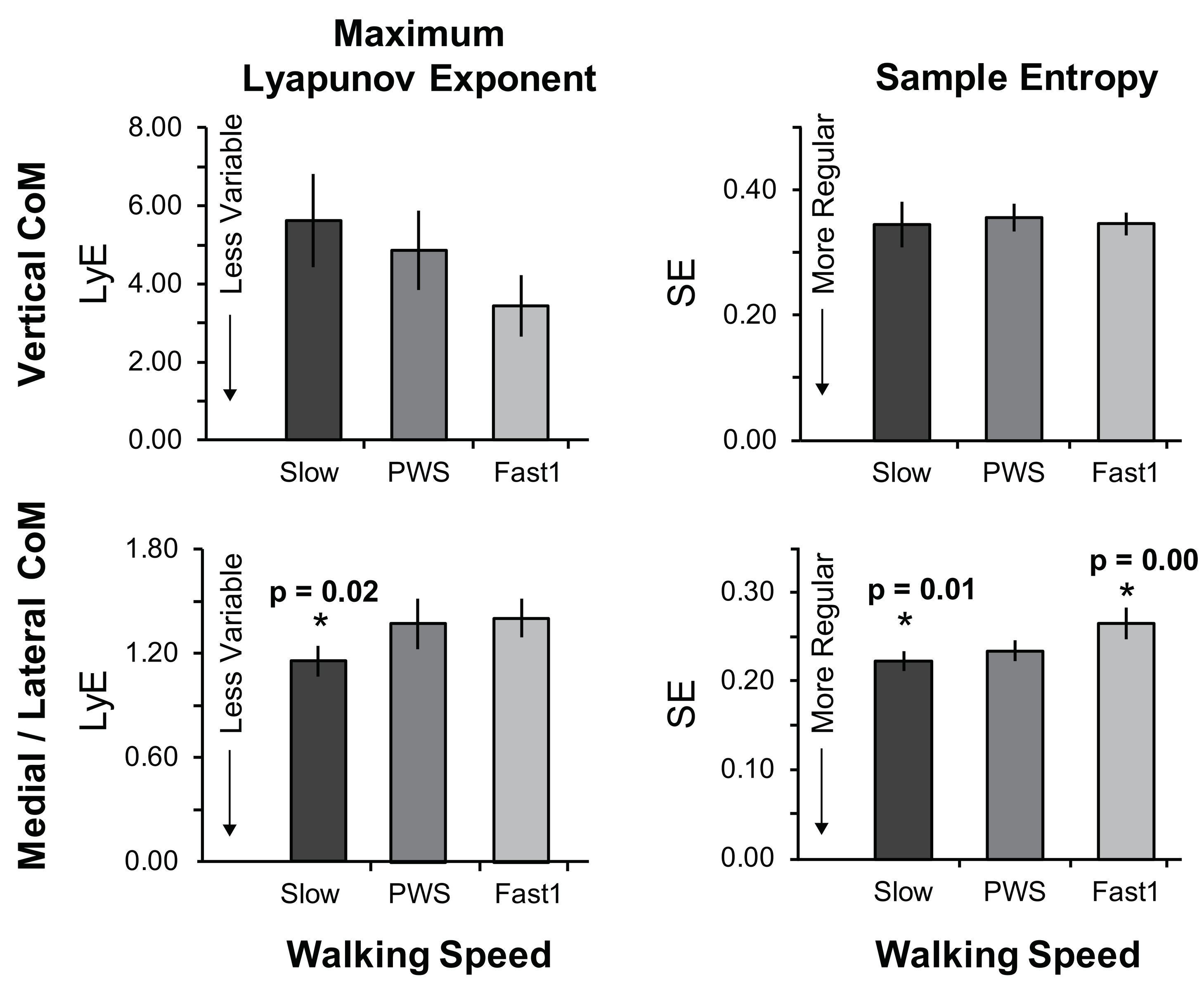
RESULTS

WALKING ECONOMY

As hypothesized, as speed decreased from PWS, energy expenditure per meter walked increased by 13% (Slow versus PWS). In contrast, as speed increased, energy expenditure per meter walked decreased by 16% (Fast2 versus PWS).



DYNAMIC STRUCTURE OF COM MOTION



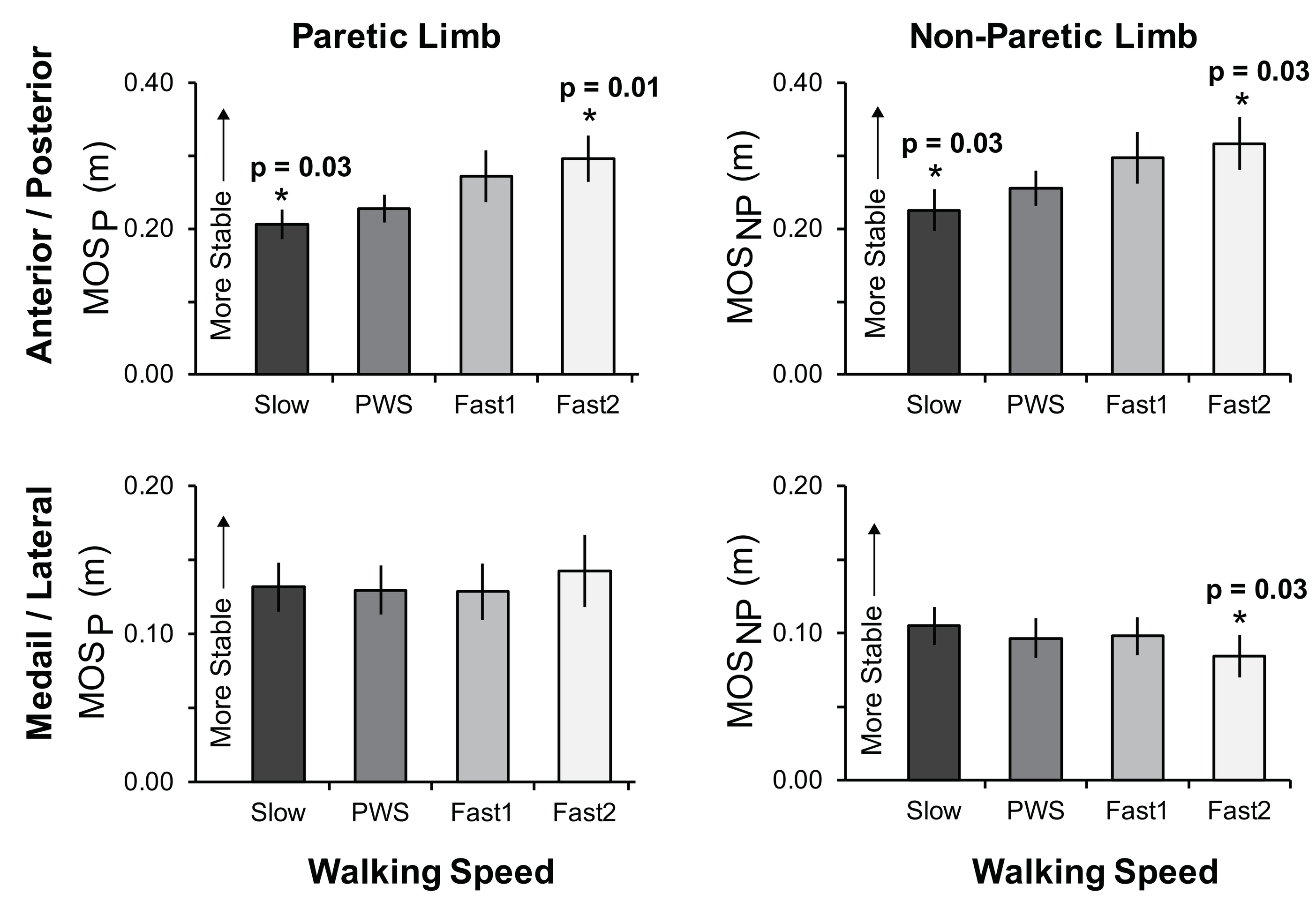
No significant changes were observed in the variability (LyE) or regularity (SE) of the CoM's vertical motion.

In contrast, CoM motion in the mediolateral direction was 16% less variable and 5% more regular during the Slow trial (versus PWS) and 10% more irregular during the Fast1 trial (versus PWS).

MARGINS OF MECHANICAL STABILITY

As hypothesized, mediolateral MOS during non-paretic limb steps (MOS_{NP}) was 12% less mechanically stable at Fast2 (versus PWS).

In contrast, changes in anterioposterior MOS for both the paretic and nonparetic steps were consistent with the changes in walking economy. That is, respectively, MOS_P and MOS_{NP} were 10% and 12% less mechanically stable during the Slow trial (versus PWS) and 30% and 24% more mechanically stable during Fast2 (versus PWS).



CONCLUSIONS

Previous investigations of persons post-stroke have examined the relationship between walking speed versus walking stability[4] and the energy cost of walking[2] separately. This study reveals that the complementary relationship between walking stability and the energy cost of walking commonly observed during healthy locomotion is not present after stroke. **The preferred walking speed of people post-stroke appears to balance, not optimize, stability and the energy cost of walking.**

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REFERENCES

1. Holt KG, Jeng SF, Ratcliffe R, Hamill J. Energetic Cost and Stability during Human Walking at the Preferred Stride Frequency. *Journal of Motor Behavior*. 1995;27(2):164–178.
2. Reisman DS, Rudolph KS, Farquhar WB. Influence of speed on walking economy poststroke. *Neurorehabilitation and neural repair*. 2009;23(6):529–34.
3. Decker LM, Cignetti F, Stergiou N. Wearing a safety harness during treadmill walking influences lower extremity kinematics mainly through changes in ankle regularity and local stability. *Journal of neuroengineering and rehabilitation*. 2012;9(1):8.
4. Kao P-C, Dingwell JB, Higginson JS, Binder-Macleod S. Dynamic instability during post-stroke hemiparetic walking. *Gait & posture*. 2014;40(3):457–63.
5. Hof AL. The "extrapolated center of mass" concept suggests a simple control of balance in walking. *Human Movement Science*. 2008;27(1):112–125.