EFFECTS OF VOLUNTARY CHANGES IN STEP WIDTH AND STEP LENGTH ON MARGINS OF STABILITY DURING HUMAN WALKING

Patricia M. McAndrew Young and Jonathan B. Dingwell

1Department of Biomedical Engineering, University of Texas, Austin, TX, 78712; email: mcandrew@mail.utexas.edu
2Department of Kinesiology, University of Texas, Austin, TX, 78712

SUMMARY
We studied the effects of changes in gait characteristics, specifically step width and step length, on control of stability during walking in humans. We found that walking with wider steps increased individuals dynamic margins of stability both laterally and anterior-posteriorly. Comparatively, step length manipulations yielded no affect on anterior-posterior stability and only increases in step length caused changes in lateral stability. Our results indicate that adopting different gait characteristics can significantly affect dynamic stability of human walking and further exploration of the use of the margin of stability measure is warranted to understand motor control during walking.

INTRODUCTION
Stability analysis of human gait ranges from observation by trained medical personnel to the use of nonlinear techniques, which directly quantify stability of mechanical systems. Gait parameters, such as step width (SW) and step length (SL), and gait parameter variability are understood by some to estimate stability as opposed to quantifying it directly [1]. However, wider and shorter steps have generally been associated with cautious walking patterns.

Hof et al. [2] proposed the use of dynamic margins of stability (MOS), which relate the motion of the center of mass (COM), or the extrapolated center of mass (XcoM), to the edge of an individual’s base of support (BOS). MOS are directly related to SW and step time (ST) [3] and thus link gait characteristics to mechanical systems and definitions of stability. Rosenblatt and Grabiner [4] demonstrated that MOS do not vary significantly between walking platforms suggesting that foot placement could be used to maintain a constant MOS. In terms of gait characteristics, this would indicate that SW and ST would be changing proportionately [4].

The purpose of the present study was to determine if simple, voluntary adoption of “cautious” gait characteristics, such as wider or shorter steps, could elicit changes in human stability during walking. We hypothesized subjects would (1) have increased MOS when walking with wider and shorter steps and (2) have greater variability in MOS and (3) take a greater percentage of unstable steps while walking differently from their normal gait.

METHODS
Fourteen healthy young adults completed three 3-minute trials of treadmill walking under each of 6 conditions. Three conditions manipulated step width: normal walking (NO) and walking with wide steps (WI) or narrow steps (NA), and three conditions manipulated step length: normal walking with a metronome (NM) and walking with long (LO) or short (SH) steps. Kinematic data for the head, trunk, pelvis, arms, legs and feet were collected at 60 Hz using 10 Vicon MX cameras.

Means and standard deviations of step width (SW), step length (SL) and step time (ST) were calculated for each trial. A 14-segment model was created for each subject using Visual3D (C-motion, Inc.) and used to estimate COM position. COM velocity was calculated as the first derivative of COM position. MOS were calculated as the difference between the XcoM and edge of the BOS as described by Hof et al. [1] using custom-made scripts in Matlab (Mathworks, Inc.). In the AP direction, MOS\textsubscript{ap} was the perpendicular distance between the XcoM and the line joining the toe markers. In the ML direction, MOS\textsubscript{ml} was the lateral distance between the XcoM and the lateral heel marker of the foot in heelstrike. Positive MOS indicate that the XcoM projection is within the BOS.

Two-way analysis of variance (condition x subject) with a Bonferroni correction was used to assess statistical significance. P-values < 0.05 were considered significant.

RESULTS AND DISCUSSION
During the WI and NA conditions, participants SW were significantly wider and narrower than during NO (p < 0.001), conditions manipulated step width: normal walking (NO) and walking with wide steps (WI) or narrow steps (NA), and three conditions manipulated step length: normal walking with a metronome (NM) and walking with long (LO) or short (SH) steps. Kinematic data for the head, trunk, pelvis, arms, legs and feet were collected at 60 Hz using 10 Vicon MX cameras.

Means and standard deviations of step width (SW), step length (SL) and step time (ST) were calculated for each trial. A 14-segment model was created for each subject using Visual3D (C-motion, Inc.) and used to estimate COM position. COM velocity was calculated as the first derivative of COM position. MOS were calculated as the difference between the XcoM and edge of the BOS as described by Hof et al. [1] using custom-made scripts in Matlab (Mathworks, Inc.). In the AP direction, MOS\textsubscript{ap} was the perpendicular distance between the XcoM and the line joining the toe markers. In the ML direction, MOS\textsubscript{ml} was the lateral distance between the XcoM and the lateral heel marker of the foot in heelstrike. Positive MOS indicate that the XcoM projection is within the BOS.

Two-way analysis of variance (condition x subject) with a Bonferroni correction was used to assess statistical significance. P-values < 0.05 were considered significant.

Figure 1. Mean step width, step length and step time. Error bars indicated standard deviation of the mean. * indicated statistical significance at p < 0.05.
respectively (Figure 1). During the LO and SH conditions, participants steps were significantly longer and shorter than NM \( (p \leq 0.001) \). SW variability increased significantly when walking with wider, longer and shorter steps \( (p < 0.05) \). All voluntary changes in gait parameters caused increased SL variability \( (p < 0.001) \).

Step length manipulations yielded no significant change in MOS_{ap} \( (p = 0.709 \text{ and } 1.000 \text{ for LO and SH, respectively}) \) or MOS_{ap} variability \( (p = 1.000) \) (Figure 2). Long steps were associated with increased MOS_{ml} and MOS_{ml} variability \( (p = 0.001) \) whereas short steps caused no changes in MOS_{ml} or MOS_{ml} variability \( (p = 1.000) \).

![Figure 2. Mean MOS_{ml} and MOS_{ap}. Error bars indicated standard deviation of the mean. * indicate statistical significance at p < 0.05.](image)

That simple voluntary changes in gait characteristics can notably alter dynamic stability is significant. Note that an “unstable” step as defined here (i.e., MOS < 0) does not necessarily imply an unavoidable fall, but will require an active correction to prevent one. The greater percentage of unstable steps one takes, the more corrective actions an individual will have to take to prevent falling. This would become challenging for individuals with impairments to their ability to respond, such as decreased strength or response time.

**CONCLUSIONS**

“Cautious” walking is generally associated with wider and shorter steps. Our study indicates that voluntarily walking with wider steps was associated with increases in stability both laterally and anterior-posteriorly despite increased step width variability. Shorter steps caused no significant changes in margins of stability laterally or anterior-posteriorly. Our results seem promising for use in gait rehabilitation and indicate that further evaluation of MOS as a measure of human stability is warranted.

**ACKNOWLEDGEMENTS**

Partially supported by ASB Student Grant-in-Aid Award (to PMMY) and NIH Grant #1-R21-EB007638-01A1 (to JBD).

**REFERENCES**