QUANTIFICATION OF COORDINATIVE VARIABILITY OF HIP-ANKLE JOINTS FOR SEDENTARY AND ACTIVE YOUNG GROUPS

G. A. G. De Villa[1], R. S. Gomide[1,2], E. M. Mesquita[1] and M. F. Vieira[1]

Bioengineering and Biomechanics Laboratory, Federal University of Goiás, Goiânia, Brazil[1]

Federal Institute Goiano – UnU Trindade, Trindade, Brazil[2]

The aim of the present study was to quantify the variability of joint coordination, during gait, of young sedentary and active at different speeds (preferred walking speed (PWS), 120% of PWS and 80% of PWS) using the previously reported modified Vector Coding technique. Thirty young people participated in this study, of which 15 practiced physical activities at least an hour a day and three times a week, and 15 were sedentary. For data collection they executed a protocol of one-minute walking on a treadmill at each speed, in a randomized order. For the Hip-Ankle joint pair, the coordination was computed during four phases of the gait (first double support, single support, second double support and swing phase), in the sagittal plane. The data were analyzedanalysed using a customized Matlab code. There were no statistical differences for the Hip-Ankle coordination between groups.

KEYWORDS: variability, hip-ankle, young, active, sedentary, vector coding.

INTRODUCTION: Human biology requires an appropriate and constant amount of physical activity to ensure good health and well-being (Malm et al., 2019)(Malm et al., 2019). The practice of physical activity by young adults is related to better social interaction, lower risk of diseases with aging, among other advantages (Aaron et al., 1995).
The gait is a cyclical movement and unique to each individual. The amplitude of movement and its variability are common features used to assess the movement. While coordination provides a measure of the relative time and magnitude of the movement between segments/joints (Hafer, J. F.;Boyer, 2017; Sparrow et al., 1987), coordination variability has a functional role that express the different measures the varied patterns and transitions of movement an individual can uses during locomotion (Hafer, J. F.;Boyer, 2017). Changes in coordination variability can point to are related to the degree of adaptability that the individual needs to respond to new limitations/perturbations in the task (Floría et al., 2019).
The aim of this study was to estimate the coordinative variability between the Hip-Ankle joints of two groups of young people (sedentary and active), while walking on a treadmill at different speeds, using the modified vector coding (VC) technique (Robert Needham, Roozbeh Naemi, 2014). We hypothesized that (1) active young people present greater coordination variability in relation to the other group, as greater coordination variability indicates greater adaptability of individual's motor system, (2) and the phases of support would have lower values for the sedentary group.

METHODS: A total of 30 young adults, 15 sedentary and 15 actives participated in this study (68.88±15.90(kg), 1.71±0.18(m), 23.9±5.05(years)). Young adults were classified as active if they practice physical activity at least one hour a day, three times a week.
Sixteen retroreflective markers were fixed at specific anatomical points according to the Vicon lower limb plug-in-gait model (Vicon, Oxford Metrics, Oxford, UK) for data collection. A 3D capture system containing 10 infrared cameras operating at 100 Hz was used to capture kinematic data. The data were filtered using a low-pass, zero-lag, fourth order Butterworth filter with a cut-off frequency of 8 Hz. The kinematic data were analyzed with a custom MatLab code (R2020a, MathWorks, Natick, MA).
The preferred walking speed (PWS) on the treadmill was determined according to a reported protocol (DINGWELL, J. B.; MARIN, 2006). A four-minute walk on the treadmill was allowed for familiarization, followed by two minutes of rest. After this period, the participants performed

three walks of 1 minute each, in the PWS, 120% of the PWS and 80% of the PWS, in random order, with a 1 minute of rest between them.
The Hip-Ankle joint pair was analyzed for 20 strides, normalized to 100 points each, for each one-minute walking trial. Joint angles were calculated in relation to the laboratory's global coordinate system. The analysis was performed in the sagittal plane. Then, coupling angles were calculated using the previously reported modified vector coding technique, in four phases of the gait cycle: first double support (0 to 10% of cycle) (FDS), single support (11 to 50% of cycle) (SS), second double support (51 to 60% of cycle) (SDS) and swing phase (61 to 100% of cycle) (SG).
The repeated measures analysis of variance (ANOVA) with mixed design was used to compare the two groups, the main effect of speed and the interaction effect between groups and speed, followed by a post-hoc test with Bonferroni correction in the cases where the main or interaction effect was significant. Statistical analysis was performed using SPSS software, version 23 (SPSS Inc., Chicago, IL, USA), with a significance level set at $\alpha < 0.05$.

RESULTS: Regarding Table 1, comparing the two groups, there were no significant differences for Group, Speed or Groups vs Speeds.

Table 1: Coordination variability of Hip-Ankle pair.

Effect	Phases of Gait	F	p	η^2
Group	*FDS*	0.255	0.621	0.018
	SS	0.598	0.452	0.041
	SDS	0.413	0.531	0.029
	SG	0.367	0.555	0.026
Speed	*FDS*	1.221	0.289	0.08
	SS	1.691	0.203	0.108
	SDS	0.159	0.824	0.011
	SG	0.79	0.389	0.053
Group x Speed	*FDS*	1.907	0.167	0.12
	SS	0.79	0.452	0.053
	SDS	1.412	0.261	0.092
	SG	0.823	0.38	0.056

Figure 1 show the mean hip and ankle joint angles for the three speeds and the two groups. For the FDS and SG gait phases the joint pair rotated in the same direction being in-phase, however, in the SS and SDS gait phases being in anti-phase (Figure 1).

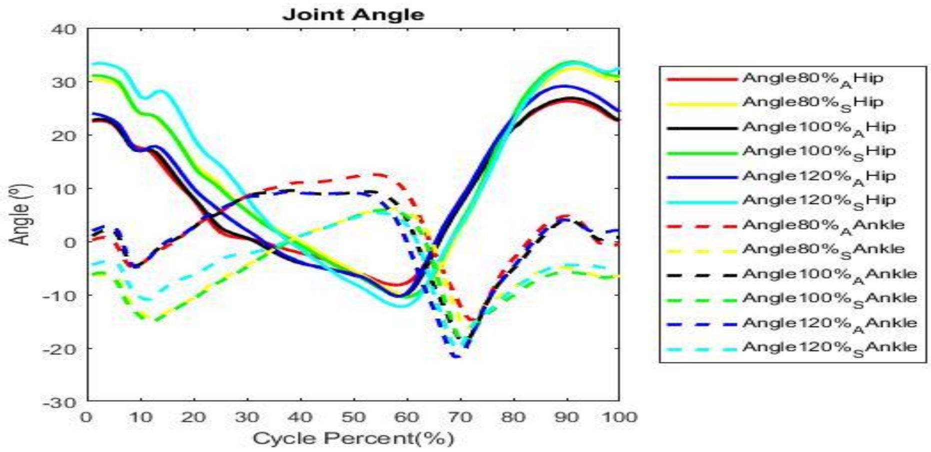

Figure 1: Mean hip and ankle joint angles at the different speeds and groups.

Figure 2 show the mean CAV for the Hip-Ankle pair, for the three speeds.

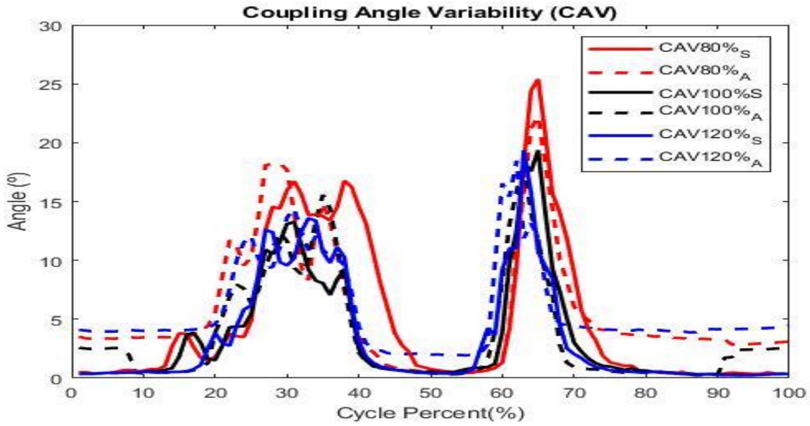

Figure 2: Coupling angle variability (CAV) for the Hip-Ankle joint pair at 120% and 80% of preferred walking speed (PWS).

DISCUSSION: The groups presented similar results, showing that the level of physical activity of the active's group was not enough to produce significant changes in Hip-Ankle coordination variability during walking. Thus, the hypotheses that active young people present greater coordination variability in relation to the other group, and the phases of support would have lower values for the sedentary group, were not confirmed.

The results showed that the coordinative variability and the values of the coordination patterns were not sensitive to gait speed in the two analyzed groups. Floria et al. (2019) studying the gait of recreational runners, concluded that no effect of speed was observed on coordination variability in the range of ± 15% around the preferred speed (Floría et al., 2019), what does not agree with the results related to speed with Bayley et al. (2018) who concluded that a 20% change in speed changes angular data in young people; however, the study focused at body segments and not joints (Bailey et al., 2018).

Despite not revealing statistical differences, the values in red in Figure 2 indicate that higher values of CAV and Gamma occurred, respectively, for the condition of 80% PWS. This agrees with the findings of Bailey et al. (2018) who observed increasing in coordination variability with decreasing speed (Bailey et al., 2018).

Finally, some limitations of the study need to be highlighted. First, we examined the pattern of inter-articular coordination and its variability only in the sagittal plane; however, they need to be quantified in other planes of movement, for a better understanding of the coordination. Another limitation is the comparison between gait data analysis techniques that address studies that quantify coordination variability, vector coding (Celestino et al., 2019; R. Needham et al., 2014; R. A. Needham et al., 2020; Pataky et al., 2013) or continuous relative phase(Lamb & Stöckl, 2014; Miller et al., 2010).

CONCLUSION: There was no significant main effect of groups, speed and interaction effect between group and speed in this study. It is reported in the literature that changes in walking speed produce changes in the range of motion or relative time of the analysed segments which, in turn, change the variability of coordination during the single stance phase. However, there were no differences in the present study, even varying 20% of the PWS for the joint pair analyzed. Future studies can investigate the relationship between the level of physical activity and speed for this joint pair increasing this percentage of speed variation, the exercise practice time of the group of practitioners, among other factors.

REFERENCES

AARON, D. J., DEARWATER, S. R., ANDERSON, R., OLSEN, T., KRISKA, A. M., & LAPORTE, R. E. (1995). Physical activity and the initiation of high-risk health behaviors in adolescents. *Medicine & Science in Sports & Exercise*, *27*(12), 1639???1645. https://doi.org/10.1249/00005768-199512000-00010

Bailey, J. P., Freedman Silvernail, J., Dufek, J. S., Navalta, J., & Mercer, J. A. (2018). Effects of treadmill running velocity on lower extremity coordination variability in healthy runners. *Human Movement Science*, *61*, 144–150. https://doi.org/10.1016/j.humov.2018.07.013
Celestino, M. L., van Emmerik, R., Barela, J. A., Gama, G. L., & Barela, A. M. F. (2019). Intralimb gait coordination of individuals with stroke using vector coding. *Human Movement Science*, *68*, 102522. https://doi.org/10.1016/j.humov.2019.102522
Chang, R., van Emmerik, R., & Hamill, J. (2008). Quantifying rearfoot–forefoot coordination in human walking. *Journal of Biomechanics*, *41*(14), 3101–3105. https://doi.org/10.1016/j.jbiomech.2008.07.024
Chiu, S. F., & Chou, L. S. (2012). Effect of walking speed on inter-joint coordination differs between young and elderly adults. *Journal of Biomechanics*, *45*, 275–280.
DINGWELL, J. B.; MARIN, L. C. (2006). Kinematic variability and local dynamic stability of upper body motions when walking at different speeds. *Journal of Biomechanics*, *39*, 444–452.
Floría, P., Sánchez-Sixto, A., Harrison, A. J., & Ferber, R. (2019). The effect of running speed on joint coupling coordination and its variability in recreational runners. *Human Movement Science*, *66*, 449–458. https://doi.org/10.1016/j.humov.2019.05.020
Ghanavati, T., Salavati, M., Karimi, N., Negahban, H., Ebrahimi Takamjani, I., Mehravar, M., & Hessam, M. (2014). Intra-limb coordination while walking is affected by cognitive load and walking speed. *Journal of Biomechanics*, *47*(10), 2300–2305. https://doi.org/10.1016/j.jbiomech.2014.04.038
Hafer, J. F., & Boyer, K. A. (2018). Age related differences in segment coordination and its variability during gait. *Gait & Posture*, *62*, 92–98. https://doi.org/10.1016/j.gaitpost.2018.02.021
HAFER, J. F.;BOYER, K. A. (2017). Variability of segment coordination using a vector coding technique: Reliability analysis for treadmill walking and running. *Gait & Posture*, *51*, 222–227.
Harbourne, R. T., & Stergiou, N. (2009). Movement Variability and the Use of Nonlinear Tools: Principles to Guide Physical Therapist Practice. *Physical Therapy*, *89*(3), 267–282. https://doi.org/10.2522/ptj.20080130
Heiderscheit, B. C., Hamill, J., & van Emmerik, R. E. A. (2002). Variability of Stride Characteristics and Joint Coordination among Individuals with Unilateral Patellofemoral Pain. *Journal of Applied Biomechanics*, *18*(2), 110–121. https://doi.org/10.1123/jab.18.2.110
J.F., K. A. H., S., F., K.A., H., & Boyer. (2016). Changes in coordination and its variability with an increase in running cadence. *Journal of Sports Sciences*, *34*(15), 1388–1395. https://doi.org/10.1080/02640414.2015.1112021
Lamb, P. F., & Stöckl, M. (2014). On the use of continuous relative phase: Review of current approaches and outline for a new standard. *Clinical Biomechanics*, *29*(5), 484–493. https://doi.org/10.1016/j.clinbiomech.2014.03.008
Malm, C., Jakobsson, J., & Isaksson, A. (2019). Physical Activity and Sports—Real Health Benefits: A Review with Insight into the Public Health of Sweden. *Sports*, *7*(5), 127. https://doi.org/10.3390/sports7050127
Miller, R. H., Chang, R., Baird, J. L., van Emmerik, R. E. A., & Hamill, J. (2010). Variability in kinematic coupling assessed by vector coding and continuous relative phase. *Journal of Biomechanics*, *43*(13), 2554–2560. https://doi.org/10.1016/j.jbiomech.2010.05.014
Needham, R. A., Naemi, R., Hamill, J., & Chockalingam, N. (2020). Analysing patterns of coordination and patterns of control using novel data visualisation techniques in vector coding. *The Foot*, *44*, 101678. https://doi.org/10.1016/j.foot.2020.101678
Needham, R., Naemi, R., & Chockalingam, N. (2014). Quantifying lumbar–pelvis coordination during gait using a modified vector coding technique. *Journal of Biomechanics*, *47*(5), 1020–1026. https://doi.org/10.1016/j.jbiomech.2013.12.032
Pataky, T. C., Robinson, M. a., & Vanrenterghem, J. (2013). Vector field statistical analysis of kinematic and force trajectories. *Journal of Biomechanics*, *46*, 2394–2401. https://doi.org/10.1016/j.jbiomech.2013.07.031
Robert Needham, Roozbeh Naemi, N. C. (2014). Quantifying lumbar-pelvis coordination during gait using a modified vector coding technique. *Journal of Biomechanics*, *47*, 1020–1026.
Sparrow, W. A., Donovan, E., van Emmerik, R., & Barry, E. B. (1987). Using Relative Motion Plots to Measure Changes in Intra-Limb and Inter-Limb Coordination. *Journal of Motor Behavior*, *19*(1), 115–129. https://doi.org/10.1080/00222895.1987.10735403