Spaciotemporal Gait Analysis of the Geriatric Wearing an Orthopedic Walking Boot Versus a Fixed, Ankle-Foot Orthosis to Investigate How Balance and Gait Variability are Affected to Minimize Fall Risk

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Introduction

Elderly gait stability is largely influenced by variations in sagittal alignment, gait width, gait phase, and vertical displacement. High levels of variation within the gait are indicative of instability and an increased fall risk. Spinal sagittal alignment impacts the postural balance and deteriorates directly with age [1]. Studies show a correlation between the ratio of the thoracic and lumbar angles to fall risk caused by overcompensation of related muscles and decline in spinal functions [2]. Changes in gait parameters influence the margins of stability experienced by elderly during the gait cycle. Controlled ankle movement (CAM) boots alter normal gait patterns, causing the elderly to experience increased step width to compensate for instability [3]. Studies have shown that elderly patients experience longer single and double support phases compared to the swing phase, resulting in increased instability [6]. Functional leg length discrepancy (FLLD) is defined as a condition of asymmetrical leg length due to pelvic tilt, not necessarily a result or compensation of a true bone length difference. FLLD causes a shift in weight towards the shorter limb, resulting in a decrease in stability during the gait cycle [9]. In this study, a spatiotemporal gait analysis of elderly subjects wearing CAM boots and ankle-foot orthotics (AFO) was performed to investigate how balance and gait variability are affected by each device to minimize the fall risk of elderly patients.

Participants

- Male and females within the age range of 60-90
- Subjects required to walk 120 meters without assistance of a walking device

Exclusions:

- Women below shoe size 6
- Men above shoe size 13.5
- Wear ankle-foot-orthotics for pre-existing conditions
- Diagnosis of hemiparesis or gait affecting disorders
- Underwent surgery within last six months

Table 1 show the general questionnaire health data form results

***Table 1**: Subject health data*

Subject Number	Age	Gender	Hours of Sleep	Physically Active	Recently Exercised	Surgery	R/L/HAT/NA	History of Falling	Fall in Last 6 Months	Past Boot	Birth	No.
1	71	Female	7-9	4-6	NO	0	N/A	NO	NO	NO	N/A	N/A
2	76	Male	4-6	7+	NO	0	N/A	NO	NO	NO		
3	80	Female	7-9	0-1	NO	0	N/A	NO	NO	NO	Vaginal	1
4	83	Male	4-6	7+	YES	0	N/A	NO	NO	YES		
5	68	Male	4-6	4-6	NO	1	R	NO	NO	YES		
6	68	Female	7-9	4-6	NO	0	N/A	NO	NO	NO	Vaginal	1
7	69	Female	7-9	0-1	NO	10	HAT	NO	NO	NO	N/A	N/A
8	76	Female	7-9	2-3	NO	1	Both	NO	NO	YES	Vaginal	2
9	75	Male	7-9	7+	NO	0	N/A	NO	NO	NO		
10	73	Male	7-9	7+	YES	0	N/A	NO	NO	NO		
11	70	Female	7-9	2-3	NO	9	L	YES	YES	YES	Vaginal	2
12	79	Female	4-6	2-3	NO	0	N/A	NO	NO	NO	Vaginal	1
13	71	Male	7-9	4-6	NO	0	N/A	NO	NO	NO		
14	79	Female	7-9	7+	NO	0	N/A	NO	NO	NO	Vaginal	2
15	80	Male	7-9	7+	YES	0	N/A	NO	NO	NO		

1-Hammer-Toe/Bunion
9-Meniscectomy
10-Spinal Fusion Surgery

1-Cesearean
2-Vaginal
3-N/A

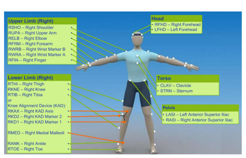
Materials and Methods

Materials

- 39 Vicon Nexus 2.12.1 with Full-Body Plugin Gait.Ai markers (14.0 mm sphere B&L Engineering Pearl Markers) shown in **Figure 1 and 2**
- Vero 2.2 Vicon 8-camera motion capture system
- 2 AMTI OPTIMA BMS464508-2K force plates
- VINCA DRGA-0605 Electronic Digital Brake Rotor Gauge 6-inch calipers
- Avia Avi-Verge control shoes shown in **Figure 3**
- Walker Genesis 3 strap tall CAM boot (sizes range from small to large) shown in **Figure 3**
- Acute TayCo XAB Ti-100-3-R orthotic brace (sizes range from small to large) shown in **Figure 3**

Methods

- Participants marked with reflective markers (adhering to Full-Body Plugin Gait.Ai placement requirements)
- Vicon 8-camera system calibrated by having participant stand with one foot equally placed in each of the two ATMI force plates in "motor bike pose" to collect static files
- Participants practice walking to establish confidence in gait interval
- 12 trials total are run in a randomized order to reduce fatigue in data: three control, three CAM walking boot, three fixed TayCo XAB brace, three range of motion (ROM) TayCo XAB brace



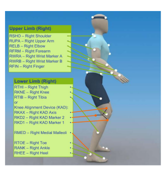


Figure 1 (Left): Plug-in Gait Marker set front view

Figure 2 (Right): Plug-in Gait Marker set left view

Equations

Hypotheses:

Subjects will experience the most instability walking in the CAM boot due to variable force distribution and increased hip offset caused by FLLD.

The ROM TayCo will provide the most stability to geriatrics due to increased ankle mobility and decreased FLLD compared to the CAM boot.

Equations:

- Cadence = number of step/ time (minutes)
- Walking speed = distance traveled (meters)/ time (seconds)
- Average = Sum of observations / Total number of observations
- Standard deviation = sqrt((1/n-1)*∑(X−μ)^2)
  - n = number of observations
  - X = the value in the data distribution
  - μ = mean of the observations

*Figure 3: Shows equipment used by subjects while walking in trials. **Left**: control shoe, **Center**: TayCo XAB brace, **Right**: CAM walking boot*

Results

Figures 4 a – d show the static calibration and center of mass (COM) for each modality. **Tables 2 a – d** display the spatiotemporal data for all modalities.

- Cadence values for the ROM TayCo brace (109 ± 58.3 steps/min), fixed TayCo brace (112 ± 81.4 steps/min), and CAM boot (87.0 ± 9.95 steps/min) were shown to decrease compared to the control shoe (136 ± 133 steps/min), indicating a relationship between the overall cadence and reduction in ankle mobility.
- The ROM showed the least amount of variance in walking speed when compared to the control (ROM: 1.03 ± 0.21 m/s; Control: 1.03 ± 0.30 m/s). The CAM boot, alternatively, showed a significant decrease in walking speed (0.78 ± 0.30 m/s).
- The presence of the fixed and ROM TayCo braces did not appear to impact step width variation. The CAM boot showed a marginal difference in step width value (0.20 ± 0.042 m) compared to the control shoe value (0.16 ± 0.043 m).
- Data showed an inverse relationship between ankle mobility and stride time, with a decrease in ankle mobility resulting in an increase in stride time. The stride times were as follows: Control shoe: 1.15 ± 0.37 s; ROM brace: 1.23 ± 0.21 s; Fixed brace: 1.30 ± 0.23 s; CAM boot: 1.36 ± 0.15 s.
- Data showed no significant changes in stride length between the control shoe and TayCo braces. The CAM boot had a small decrease in stride length (1.03 ± 0.34 m) compared to the control shoe (1.17 ± 0.40 m).

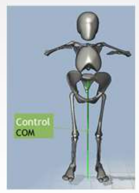


***Figure 4a**: Static calibration stance for control shoe*

***Table 2a**: Spatiotemporal data for control shoe*

Control	Left	Right
Cadence	136 ± 133 steps/min	
Cadence	164 ± 229 steps/min	175 ± 279 steps/min
Double Support	0.23 ± 0.13 s	0.65 ± 0.51 s
Foot Off	55.2 ± 9.11 %	63.9 ± 5.27 %
Limp Index	0.86 ± 0.13	0.82 ± 0.33
Opposite Foot Contact	50.1 ± 3.45 %	49.0 ± 6.50 %
Opposite Foot Off	15.2 ± 3.98 %	41.1 ± 41.6 %
Single Support	0.43 ± 0.058 s	0.099 ± 0.51 s
Step Length	0.61 ± 0.12 m	0.63 ± 0.14 m
Step Time	0.61 ± 0.100 s	0.61 ± 0.075 s
Step Width	0.16 ± 0.046 m	0.16 ± 0.043 m
Stride Length	1.14 ± 0.42 m	1.17 ± 0.40 m
Stride Time	1.13 ± 0.36 s	1.15 ± 0.37 s
Walking Speed	1.02 ± 0.29 m/s	1.03 ± 0.30 m/s

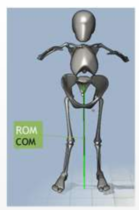


***Figure 4b**: Static calibration stance for ROM brace*

***Table 2b**: Spatiotemporal data for ROM brace*

ROM	Left	Right
Cadence	109 ± 58.3 steps/min	
Cadence	99.1 ± 13.4 steps/min	99.5 ± 14.1 steps/min
Double Support	0.25 ± 0.16 s	0.56 ± 0.48 s
Foot Off	54.3 ± 11.3 %	63.9 ± 6.58 %
Limp Index	0.87 ± 0.17	0.91 ± 0.30
Opposite Foot Contact	46.0 ± 9.04 %	47.7 ± 6.72 %
Opposite Foot Off	14.6 ± 5.60 %	31.7 ± 39.0 %
Single Support	0.45 ± 0.086 s	0.22 ± 0.47 s
Step Length	0.61 ± 0.092 m	0.63 ± 0.10 m
Step Time	0.66 ± 0.14 s	0.65 ± 0.11 s
Step Width	0.16 ± 0.044 m	0.17 ± 0.040 m
Stride Length	1.12 ± 0.40 m	1.25 ± 0.18 m
Stride Time	1.23 ± 0.18 s	1.23 ± 0.21 s
Walking Speed	0.92 ± 0.34 m/s	1.03 ± 0.21 m/s

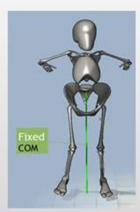


***Figure 4c**: Static calibration stance for fixed brace*

***Table 2c**: Spatiotemporal data for fixed brace*

Fixed	Left	Right
Cadence	112 ± 81.4 steps/min	
Cadence	97.2 ± 14.5 steps/min	95.7 ± 21.4 steps/min
Double Support	0.33 ± 0.067 s	0.45 ± 0.22 s
Foot Off	61.0 ± 6.89 %	62.8 ± 5.69 %
Limp Index	0.96 ± 0.14	0.92 ± 0.28
Opposite Foot Contact	46.3 ± 9.96 %	47.2 ± 11.5 %
Opposite Foot Off	14.4 ± 2.64 %	23.2 ± 28.9 %
Single Support	0.47 ± 0.054 s	0.35 ± 0.41 s
Step Length	0.59 ± 0.12 m	0.59 ± 0.090 m
Step Time	0.67 ± 0.12 s	0.66 ± 0.074 s
Step Width	0.16 ± 0.044 m	0.17 ± 0.033 m
Stride Length	1.08 ± 0.26 m	1.15 ± 0.29 m
Stride Time	1.26 ± 0.17 s	1.30 ± 0.23 s
Walking Speed	0.87 ± 0.24 m/s	0.93 ± 0.33 m/s

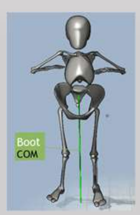


***Figure 4d**: Static calibration stance for CAM boot*

***Table 2d**: Spatiotemporal data for CAM boot*

Boot	Left	Right
Cadence	87.0 ± 9.95 steps/min	
Cadence	89.6 ± 12.2 steps/min	89.4 ± 9.61 steps/min
Double Support	0.32 ± 0.21 s	0.60 ± 0.42 s
Foot Off	55.7 ± 18.1 %	62.5 ± 5.10 %
Limp Index	0.93 ± 0.23	0.83 ± 0.22
Opposite Foot Contact	50.0 ± 6.77 %	45.7 ± 5.65 %
Opposite Foot Off	13.0 ± 2.08 %	29.0 ± 31.6 %
Single Support	0.54 ± 0.063 s	0.26 ± 0.40 s
Step Length	0.52 ± 0.18 m	0.52 ± 0.16 m
Step Time	0.67 ± 0.092 s	0.74 ± 0.083 s
Step Width	0.20 ± 0.044 m	0.20 ± 0.042 m
Stride Length	1.05 ± 0.32 m	1.03 ± 0.34 m
Stride Time	1.36 ± 0.17 s	1.36 ± 0.15 s
Walking Speed	0.79 ± 0.28 m/s	0.78 ± 0.30 m/s

Survey Data

Figure 5 displays the hypotheses and significance level for the One-Way ANOVA. **Figure 6** displays the Post Hoc Dunnett's significance tables for three out of five questions for which significance was shown when the modality groups were compared to the control. **Figure 7** displays a histogram of the standard error of the participants compared to the population mean. **Table 3** displays the Tinetti's Falls Efficacy Survey results showing all participants scored less than 20 points indicating no fear or risk of falling. Below details questions 1 – 5 used in the Likert Survey.

Method

Null hypothesis	All means are equal
Alternative hypothesis	Not all means are equal
Significance level	α = 0.05

Equal variances were assumed for the analysis.

***Figure 5**: Figure above shows methods used to analyze all data for a One-Way ANOVA hypothesis.*

Question 1: Which modality was the most comfortable?

Question 2: Which modality did you feel most likely to fall?

Question 3: Which modality's size impacted your ability to walk?

Question 4: Which modality provided the most support?

Question 5: Which modality was the easiest to walk in?

Factor	N	Mean	Grouping
Q1 Shoe (control)	15	4.000	A
Q1 ROM	15	4.467	A
Q1 Fixed	15	3.867	A
Q1 Boot	15	2.333	

Factor	N	Mean	Grouping
Q2 Shoe (control)	15	1.467	A
Q2 Boot	15	2.600	
Q2 ROM	15	1.667	A
Q2 Fixed	15	1.667	A

Factor	N	Mean	Grouping
Q5 Shoe (control)	15	4.467	A
Q5 ROM	15	4.267	A
Q5 Fixed	15	4.067	A
Q5 Boot	15	2.733	

***Figure 6**: A Post Hoc Dunnett's test was used to determine the significance of a one-way ANOVA of the varying modalities compared to the control. Questions 1, 2, and 5 showed significance with a 95% confidence interval.*

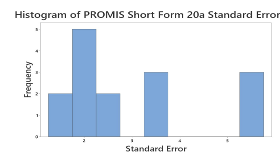


Figure 7: The 15 participants had physical function standard error ranging from +1.5 - +5.7 above the population mean

***Table 3**: Subject data from Tinetti's Falls Efficacy Survey. > 70 Fear of Falling; >80 Risk of Falling; All Subjects < 20.*

No. of Subjects	Score
11	10
2	12
1	14
1	16

Conclusion

- The fixed and ROM status of the TayCo brace did not appear to affect overall stability during the gait cycle.
- Subjects reported experiencing the most instability wearing the CAM boot.
- CAM boot showed decreases in overall cadence, walking speed, and stride length, contributing to an increased sense of instability.
- Wearing ROM and fixed TayCo braces did not produce an increase in step width variation, indicating higher levels of stability.
- The ROM TayCo showed the least amount of variance of the three tested devices compared to the control.
- Data showed similarities between the step width and walking speed of the ROM TayCo and the control shoe, supporting the claim that the ROM TayCo provides the most stability for geriatrics.

Future Work

- Further work can be done to determine the impact of each brace on FLLD.
- Run the experiment with EMG sensors to collect muscle activation data.

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