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Prediction of walking Asymmetry using Spatiotemporal Gait Parameters and Guidance for fall risk Prediction or Geriatric Care: Experimental Study for Indian Population

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Abstract

Gait analysis allows the quantitative assessment of gait to recognize its associated variation and disorders. The reliability of analysis gets augmented when being compared with standard documented normative dataset. The purpose of this study is to establish the spatiotemporal gait parameters for the normative dataset for Indian Population. Eighty healthy subjects aged between 20 and 70 years with no impairments affecting gait, recorded their Footfall on self-selected walking speed on GAITRite® Electronic walkway. Successive ten iteration of Barefoot and Comfortable (specific to person) shoe wear walk are Considered to generate one record. Mean, standard deviation, coefficient of correlation, 95% Confidence Interval, and 95% Prediction Interval are calculated using descriptive statistics. Healthy Gait is often characterized as symmetric to verify, bilateral spatiotemporal parameters are considered and mean, standard Deviation, Variance, and Min-Max ranges are obtained. Chosen Spatial and temporal characteristics are taken into consideration separately to demonstrate role in diverse test cases to get the result. Obtained singular and bilateral ranges are recorded for classification of Symmetry and Asymmetry and based on that algorithm is proposed for identifying Gait Asymmetry. Study of these ranges provides the guideline for geriatric care.

Keywords: Aging, Asymmetry, Gait, Spatiotemporal, Step length

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Introduction

Human mobility, a day-to-day activity performed by everyone provides numerous guidelines regarding gait related disease or disorders and the option for intervention of it, if necessary. Gait pattern is the cyclic occurrence of stance and swing phases in a systematic manner. Way of Walking or Gait pattern of each person depends on the demographic characteristics (ethnicity and age) and anthropometric items (height, weight, etc.).

Gait characteristics are considered as dynamic, during walk center of gravity need to be maintained. With the aging there are physiological changes in sensory motor control due to which the gait pattern shows gradual deviation, even though dichotomized by sex shows considerable distinction into same age group. Quantitative and qualitative gait analysis is adapted for clinical studies. For clinical analysis, getting information regarding all small instances of each gait cycle are beneficial. Receiving spatiotemporal gait parameters providing all possible information is possible with use of different recording techniques. This paper uses GAITRite® Electronic walkway to retrieve the spatiotemporal gait parameters from recorded footfalls. The walkway provided: Step length, stride length, step time, and stride time such numerous spatiotemporal parameters for analysis. Selecting appropriate parameter as a feature for required data analysis is going a crucial point. Understanding the relevance and relation amid various spatiotemporal gait parameters decided the % accuracy in prediction and able to provide appropriate guidelines based on available dataset for further analysis system. With advancement of data mining techniques getting precise information becomes easy if all related standard documented material is available. Considering influence of demographic characteristics, it becomes essential to have such record as per region considered for analysis to provide precision. Thus, defining what should be normal and for whom is critical task. Preserving normative details of gait spatiotemporal parameters are key task in all type of related analysis.

To be precise, to prepare the prediction mechanism for identifying asymmetry in walking or for possible fall risk prediction model and related geriatric care spatiotemporal features to be considered become significant. The spatial parameters are step length, stride length and stride width. While, temporal parameters as single support time, double support time, stance, and swing phase Cycle % are taken into consideration in the analysis presented in this paper. After selection of parameters, it is essential to understand the behavior of selected parameter, its dependency on other parameters or linking between different parameters. To take hold of the details about the mentioned issue, identifying the correlation among decided features becomes important. Furthermore, to establish the spatiotemporal parametric ranges for identifying Gait Asymmetry, it is essential to have the information regarding detail Gait Symmetry. As mentioned earlier based

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on demographic and anthropometric, "what to be considered Symmetric in case of Indian Population?" need to be determined. On a trial run, information of 80 healthy normal subjects is collected to establish the baseline. Selected subjects are in the age group of 20–70 years contributing to generate required standard database for training of the data analysis model.

Before performing classification with reference to symmetric or asymmetric walk it is important to know the reason of possible deviation. The causes of asymmetry are going to different person to person. The latest study shows that the use of Handheld Device (Mobile) leads to asymmetry in walk [1], which is a way different reason observed for such case. Identifying the asymmetry at early stage definitely help out in regaining original symmetric pattern. Other crucial part of analysis which would provide clinical assistance is, identifying early symptoms of few neurological or orthopedic disorders. Definitely, for such cases gait pattern analysis will provide supporting information. Observing asymmetry in elder persons will help out in the process of fall risk prediction up to certain extend if person is under observation. In continuation with fall risk predication, identifying level of asymmetry in geriatric care help out in preventive care to avoid major or minor orthopedic injuries associated with fall.

Previous Work

To establish training model for identifying standard ranges of spatiotemporal parameters for healthy human are taken care at different level across the globe. As specified earlier, demographic effect needs to be taken into consideration. In association with the demographic and related physiological parameters way of recording, use of technology and recording environment all have impact on reading. Literature review is presented in this section which will provide the guidelines considering each of the aforementioned option.

a. Oberg *et al*., "Basic gait parameters: reference data for normal subjects, 10–79 years of age." Uses the walkway for recording of gait pattern with different walking speed as slow, normal and fast. It provides the normalized values of mean, standard deviation, coefficient of variation, confidence interval (95%), and Prediction interval (95%) for the 233 normal subjects within age group of 10–79 years [2]
b. Monique, *et al*. "differences in gait parameters at a preferred walking speed in healthy subjects due to age, height and body weight." Uses 12 m walkway with force plates, age group considered within 19–90 years. Provides observation as, older health subjects maintain lower walking speed compare to younger healthy subjects. The variation in all the parameters is observed while compared as men and women subjects, women show 30% declination in walking speed and 40% declination in stride length. Over the multiple regression performed, it shows that walking speed and stride decrease with $p < 0.001$. Important finding specified is paper is that the height had a great correlation in both genders and influence is observed in young and old but, in contrary weight never shows any correlation and also stated Cadence is not corrected with age, height and weight [3].
c. Olivier, *et al*. "guidelines for assessment of gait and reference values for spatiotemporal gait parameters in older adults: the biomathics and Canadian gait consortiums initiative." Provides the guideline for spatiotemporal parameters for the age group 65 years and above using GAITRite Walkway. Analysis is performed considering age, Body Mass Index, sex, mean value and coefficient of variation [4]
d. Stacey and Thorpe. "A normative sample of temporal and spatial gait parameters in children using the GAITRite® electronic walkway." Generated normative database of children in age group 1–10 years using GAITRite Walkway. Correlation coefficients are calculated for left and right leg recordings of all bilateral parameters. Descriptive statistics were used to assess outlier of all dependent variable. Analysis put forward the observations as: Mean self-selected velocity increases with age. Normalized velocity increases for 1–4 years, mean cadence decreases with increase in age [5]
e. Moe-Nilssen *et al*., "Spatiotemporal gait parameters for older adults–an interactive model adjusting reference data for gender, age, and body height." Recording of the parameters is done using GAITRite walkway at the preferred walking speed, out of two left and right leg iteration outcome is considered. Stride length, stride width, stride and stance time, cadence, velocity, etc., parameters are retrieved [6]
f. Menz *et al*. "Age-related differences in walking stability." To understand the behavior of older to reduce fall risk prediction, accelerometers are fixed comfortable on subject and are advice to walk at comfortable speed with different surface type. Walking velocity, step length, cadence, and step time are the parameters considered and Analysis of Variance is used for results [7]
g. Smith *et al*., "Temporal-spatial gait parameter models of very slow walking." Data are recorded on treadmill with support of virtual environment setup for 30 adults. Eight temporal parameters are recorded on self-selected speed. The findings are specified as helpful data in case of lower extremity powered exoskeleton control [8]
h. Duque-Ramírez *et al*. "Gait parameters in a sample of healthy Colombian adults aged between 18 and 25 years: A cross-sectional study." Recording is done using eight infrared camera and VICON NEXSU for the age group of 18–25 years. Mean, Standard deviation, Confidence interval calculated specified that the normal values calculated among Colombian young adults is different than the normative ranges in other region of the globe highlighting the importance and relevance of considering the demographical characteristics consideration while performing clinical gait analysis [9]
i. Polk *et al*. "Limb dominance, foot orientation and functional asymmetry during walking gait." 37 subjects are tested for three different styles of walking as normal foot orientation, outward orientation of feet and straight orientation of feet. While comparing the spatiotemporal parameters on the basis of foot posture and limb dominance it has been observed that over the foot posture significant influence is observed in force and impulse components [10]
j. Shorter *et al*. "A new approach to detecting asymmetries in gait." Instead of following traditional method for the identification of walking asymmetry author considers asymmetry stimulated by joint bracing at knee and ankle. For the analysis two-way repeated ANOVA is used [11]
k. Gregg *et al*. "The basic mechanics of bipedal walking lead to asymmetric behavior." Emphasis on point that changes in environmental or physiological parameters can facilitate asymmetry in walking at high speed [12]
l. Plotnik *et al*. "Effects of walking speed on asymmetry and

bilateral coordination of gait." Author intent to study bilateral coordination changes due to gait speed modification. Vertical force is measured for three type of walk slow, usual and fast. To identify gait asymmetry left and right swing time and bilateral coordination is taken into consideration. Phase Coordination Index is calculated, stepwise regression specifies that slow gait related changes in phase coordination index are not related with Ground reaction force impact [13]

m. Wang *et al*. "Estimation of step length and gait asymmetry using wearable inertial sensors." Spatial asymmetry is monitored with motion capture system and step length is the selected feature for it. Data is recorded for slow, normal and fast walk for normal and impaired subjects for comparison [14]

n. Gouwanda *et al*., "Identifying gait asymmetry using gyroscopes—A cross-correlation and Normalized Symmetry Index approach." Uses cross correlation and normalizes symmetry index and compares with traditional method. States that Symmetry Index in Normal asymmetrical gait were different from normal gait. Symmetry Index normal minimum asymmetrical gait were found to be approximately 20% greater than Symmetry Index normal minimum in normal gait during pre-swing and initial swing [15].

From the reviewed literature, the major points taken into consideration are: Techniques used for recording purpose, method of recording, selection of subjects, size of the dataset used, classification and record maintenance as per age and sex, statistical tools use across the globe, provided ranges for normative database among various demographical population, etc. Taking into consideration all of these finding from the previous work, database of Indian population to be precise within Pune region of Maharashtra is recorded using GAITRite® Electronic walkway in collaboration with Deenanath Mageshkar Hospital and Research Centre, Pune. 80 healthy subjects within age group of 20–70 years including men and women have contributed in gait pattern recording. Received spatiotemporal parameters are selected as a feature and using descriptive statistics and regression, analysis is performed. Further section of the paper provides the details about findings and comparative analysis and details of a variety of Test Cases.

Experimental Setup

To understand the relevance and influence of various factors, normative database is generated for 80 healthy subjects. Selected subjects are within age group of 20–70 years. Selected subjects are interviewed to provide the idea regarding task to be performed and the intention of the recording. Basic physiological checkup is carried out before selection of the subject to assure the contribution of normal and healthy person in the dataset preparation. Ethical documentation and consent forms are recorded from each member to clarify the medical regulatory instructions. The recording setup is an indoor laboratory setup of GAITRite electronic walkway attached with camera for recording visuals and laptop for recording of footfalls. All subjects are advised to opt their self-walking normal speed and complete the recording process. Each subject completes the ten iterations of walking in the electronic walkway and being asked to count iteration on self with the intention of dual tasking. One set of ten iterations is recorded barefoot and next set of ten iterations with comfortable show wear. All the selected subjects have contributed without use of any supporting instrument for walk as well as without any handheld device like cell phone to assure the appropriate posture. To perform the gait analysis for the clinical purpose semi-subjective and objective methods are available. Role of objective type method such as using Walkway for recording have different set of advantages for the in-depth study of all spatiotemporal parameters [16,17].

Quantitative Reference Values of Spatiotemporal Gait Parameters

As described in the setup details, all subjects are guided and recorded footfall of 80 participants is taken into consideration for further analysis. Based on the operating techniques associated with GAITRite Walkway, the spatiotemporal parameters considered are listed in Table 1.

To prepare reference data for any type of analysis, the recording conditions is very important. Therefore, generated data from the statistical analysis might be used for interpretation of gait analysis carried out in similar laboratory conditions as guidelines for healthy subjects and for the comparison of healthy and impaired. Table 2 provides the generated reference values for mean (cm/s), standard Deviation (cm/s), coefficient of Variation, 95% confidence interval and 95% prediction interval considering barefoot walk. Based on the previous finding during the work, it has been observed that the influence of barefoot and comfortable shoe walk shows considerable variation in some spatiotemporal parameters. That is why the calculation of mean, standard deviation, 95% confidence interval and 95% prediction interval are calculated for with comfortable shoe walk by all subjects in a similar way as done for barefoot walk. Table 3 provides all the parameters with use of comfortable shoe wear. All the results are obtained through descriptive statistic and regression.

Tables 2 and 3 provide the results obtained for Indian population in close laboratory environment as a basic reference guideline for further work. For sure, with the increased count of participants within each selected group will refine the ranges obtained.

Selection of spatiotemporal Parameters for Gait Asymmetry

With the availability of reference quantitative information of normal subjects, the section starts with selecting the appropriate parameters to understand and define the relevance of these with

Table 1: Selected parameters for gait analysis

Type of characteristic	*Parameters*
Demographic	Sex
	Age (years)
	Ethnicity - Asian
Clinical	Height (cm)
	Weight (kg)
	Left and right limb length (cm)
Spatiotemporal	Step length
	Stride length
	Step length standard deviation
	Walking velocity
	Single support cycle % left
	Single support cycle % right
	Double support cycle %
	Swing % cycle
	Stance % cycle

Table 2: Reference data for normative subjects (Barefoot)

Age group (years)	*Number of participants (N)*	*Mean cm/s*	*Standard deviation cm/s*	*Coefficient of variation*	*95% Confidence interval*	*95% Prediction interval*
20–29	29	64.0	7.02	0.10	61.3–66.6	19.21–41.2
30–39	15	66.9	8.55	0.12	62.2–71.7	43.7–64.2
40–49	14	63.5	8.04	0.12	58.9–68.2	36.3–49.5
50–59	10	67.9	8.20	0.12	62.0–73.7	30.8–69.8
60–70	12	65.5	7.36	0.11	60.8–70.2	53.9–114.6

Table 3: Reference data for normative subjects (with shoe)

Age group (years)	*Number of participants (n)*	*Mean cm/s*	*Standard deviation cm/s*	*Coefficient of variation*	*95% Confidence interval*	*95% Prediction interval*
20–29	29	67.6	6.3	0.09	65.1–70.1	19.6–46.4
30–39	15	68.8	7.6	0.11	64.6–73.1	43.4–66.5
40–49	14	66.2	7.8	0.11	61.6–70.7	35.9–50.1
50–59	10	70.5	5.8	0.08	66.3–74.7	19.6–76
60–70	12	67.6	6.3	0.0.09	63.4–71.9	44.5–125.8

Gait Asymmetry. To define the asymmetry, it becomes essential to clarify symmetry Gait condition. As shown in Figure 1, the relationship between step and stride length in consecutive cycle over the period of time clarifies the waking symmetry and asymmetry concept.

Unknowingly human adapt the asymmetrical walking style in routine. The asymmetry observed at the initial level may be on lower scale but, following such style may result into some health-related issue. Basically, asymmetry walk is described as, observed variation in step length. The step length left to right and step length right to left covers different distance or if we describe it in terms of time duration then the time taken to complete the step with left to right leg and time taken for step with right to left leg is different leading to asymmetry in walk. These are the basic parameters which would specify information regarding asymmetry along with these inclusions of hip rotation angle, knee flexion, toe in – out angle, muscular movement of leg do provide information regarding asymmetry walk. However, mostly the concept of asymmetry in walking style is taken into consideration specifically in case of stroke patient in post recovery. Depending on the influence of the stroke on the left or right side of the body the balancing technique of the body disturbs and imbalance or stiffness of muscles leads to observable asymmetry in such patients. Another reason observed in leading asymmetry walk without any medical reason is tremendous weight gain. With the continuous weight gain person starts adopting duck walk style and indirectly starts towards asymmetrical walking.

To develop the basic guidelines for asymmetry, walk or geriatric care, descriptive statistic is extended for spatiotemporal parameters: Stride length, walking velocity, single support time, double support time, and swing and stance cycle. Obtained ranges are provided as a reference in Table 4. Contributing subjects are 80 with year wise count of 20–29 years (29), 30–39 years (15), 40–49 years (14), 50–59 years (10), and 60–70 years (12) including men and women.

As specified in Table 4 the mean, standard deviation and coefficient of variation are available for the normative dataset. Table 5 indicates the extended analysis of bilateral spatiotemporal parameters: step time, step length, stride length, swing time, and stance time describing the bilateral parameter results for 80 normative subjects calculate separately with the left and right leg footfall recordings.

Bilateral parameters specify descriptive details while considering calculation for identifying symmetry. Once

Table 4: Quantitative reference values of Spatiotemporal gait parameters

Age (years)	*20–29*	*30–39*	*40–49*	*50–59*	*60–70*
Walking velocity (cm/s)					
Mean cm/s	119.26	124.7	119.5	126.9	122.2
S.D	19.58	17.9	15.2	14.9	15.3
CoV	0.16	0.14	0.12	0.11	0.12
Stride length (cm)					
Mean cm/s	129.4	134.7	129.5	134.7	133.2
S.D	13.3	16.8	14.3	14.7	14
CoV	0.1	0.1	0.1	0.1	0.1
Single support time					
Mean cm/s	0.4	0.4	0.4	0.4	0.3
S.D	0.03	0.01	0.03	0.01	0.02
CoV	0.07	0.03	0.08	0.04	0.06
Double support time					
Mean cm/s	0.25	0.27	0.27	0.27	0.29
S.D	0.04	0.03	0.02	0.02	0.05
CoV	0.18	0.13	0.1	0.1	0.17
Stance % cycle					
Mean cm/s	61.4	62	62.7	62.2	63
S.D	2	2	1.14	1.4	1.5
CoV	0.03	0.03	0.01	0.02	0.02
Swing % cycle					
Mean cm/s	38.2	37.3	37.3	37.7	36.9
S.D	1.7	1.6	1.1	1.4	1.5
CoV	0.04	0.04	0.03	0.03	0.04

S.D: Standard deviation, CoV: Coefficient of variation

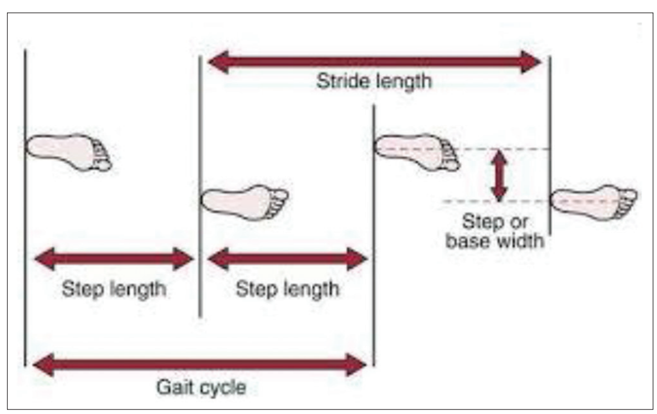

Fig 1: Step and Stride Length Gait Parameter

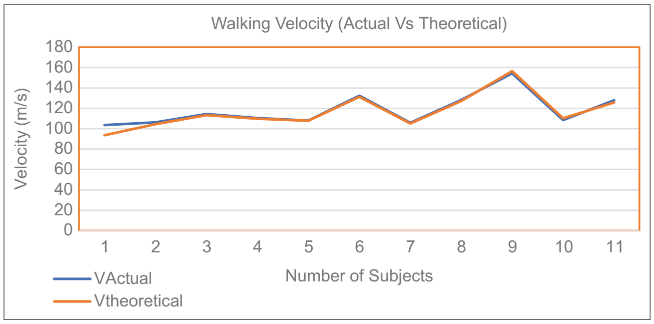

Figure 2: Actual and theoretical velocity

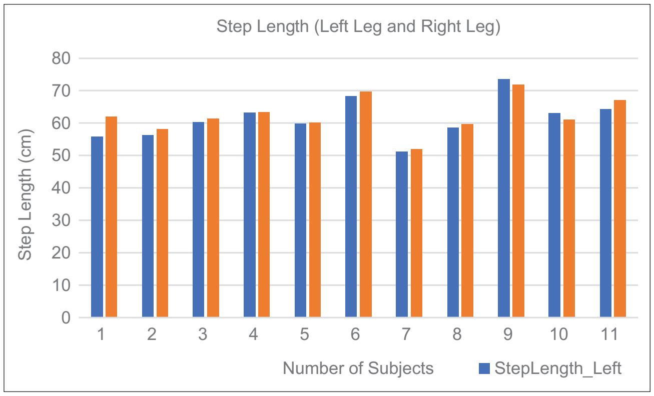

Fig 3: Variation in Step length (Left and Right)

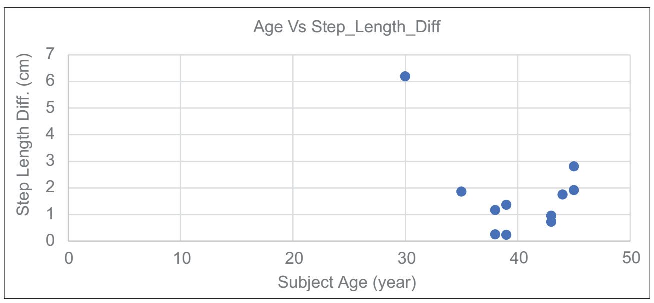

Figure 4: Step length difference as a function of age

symmetry is defined, deciding the ranges for asymmetry will become easy. Different statistical methods are specified to obtain the symmetry ranges, as using Ratio Index, Symmetry Index, Gait Asymmetry, and using symmetry angle [18]. Table 6 shows the ranges obtained for normative dataset for calculated Symmetry index using step length, step time, stride length, stance time, and swing time. Equation 1 specifies Symmetry index calculation.

Symmetry Index (SI) = Selected Bilateral Right leg parameter/ selected Bilateral left Leg parameter

$$SI = \frac{P_R}{P_L} \quad (1)$$

Here: PR- Parameter Right leg, PL- Parameter Left Leg

On the basic of selected parameters in Tables 4-6 algorithm to identify asymmetry in walking is proposed. Algorithm specifies two step execution using only spatial parameters and temporal parameters separately to understand the dominance of specific parameter in understanding the expected functionality.

a. Proposed algorithm for identifying asymmetry using spatial parameters

To obtain the acceptable ranges of walking asymmetry first algorithm specifies the data collection for different age group using spatial parameters only

b. Proposed Algorithm for Asymmetry Walk with Spatial parameters only

1. Select the range of step length left for all subject ()
2. Select the range of step length right for all subjects ()
3. Select the range of stride length for all subjects ()
4. Select range of cadence for all subjects ()
5. Compare step length left and step length right.
   - If both values are equal then walk is symmetrical, including standard deviation
   - If both values are not equal then its asymmetrical walk, including standard deviation
   - Supplementary information for identifying the asymmetry or symmetry is making sure in both cases the stride length needs to be same.

To obtain the acceptable ranges of walking asymmetry first algorithm specifies the data collection for different age group using temporal parameters only

Table 5: Quantitative data for gait asymmetry

Spatiotemporal parameters	*Left leg*					*Right leg*				
	Mean	*SD*	*Var*	*Min*	*Max*	*Mean*	*SD*	*Var*	*Min*	*Max*
Step time	0.53	0.03	0.001	0.44	0.61	0.54	0.06	0.003	0.43	0.96
Step length	65.2	7.32	53.6	50	85.8	65.8	6.9	48	50.2	85.4
Stride length	131.7	14.2	203	100	172.2	131.7	14.1	198.9	101.4	172.4
Swing time	0.4	0.02	0.0007	0.34	0.45	0.4	0.02	0.0008	0.34	0.49
Stance time	0.67	0.05	0.003	0.52	0.79	0.67	0.05	0.002	0.52	0.79

Mean (cm), SD: Standard deviation, Var: Variance

Table 6: Gait symmetry index for spatiotemporal parameters

Statistical Terms	*Step time SI*	*Step length SI*	*Stride length SI*	*Swing time SI*	*Stance time SI*
Mean	1.01	1.01	1	1	1
Standard deviation	0.09	0.04	0.02	0.03	0.02
Sample variance	0.009	0.001	0.0004	0.001	0.0006
Minimum	0.96	0.9	0.9	0.9	0.9
Maximum	1.8	1.12	1.1	1.2	1.1

All readings are for age group of 20–70 years with clubbed data of men and women

c. Proposed Algorithm for Asymmetry Walk using temporal parameters only:

1. Select single support % cycle left
2. Select single support % cycle right
3. Select double support time % cycle
4. Select swing % cycle
5. Select stance % cycle
6. Compare single support left and right
    a. Compare both including standard deviation, if equal then symmetry
    b. Compare both including standard deviation, if not equal then asymmetry
    c. Check double support time and verify complete cycle duration
7. Compare swing % cycle including standard deviation
8. Compare Stance % Cycle, including standard deviation
    d. If Stance and Swing % Cycle are out of range- asymmetry
    e. If Stance and Swing % Cycle within range – symmetry
9. Verify result obtained through Single and Double Support with stance and Swing Cycle result
10. Decide symmetry and asymmetry.

Algorithms are specified separately for spatial and temporal parameters; depending on the availability of features it might be selected. The best possible results would be obtained after considering both spatiotemporal parameters in decision making.

Results and Discussion

Available dataset is of normative, obtained statistical analysis had combined results for men and women. In spatiotemporal Symmetry Index calculation all subjects are treated without dividing them according to age or sex. Considering this aspect few case studies are tested as a supportive testing of defining symmetry and understanding asymmetry possibilities at different ends. To be precise while handling test cases one physiological factor is included: Measured limb length left and right. While performing initial measurement and fitness check of each subject, record of measured limb length of the left and right leg in maintained.

Test Case-1

Considered age group is 30–50 years including male and female subjects. While selecting subject, constraint regarding equal or

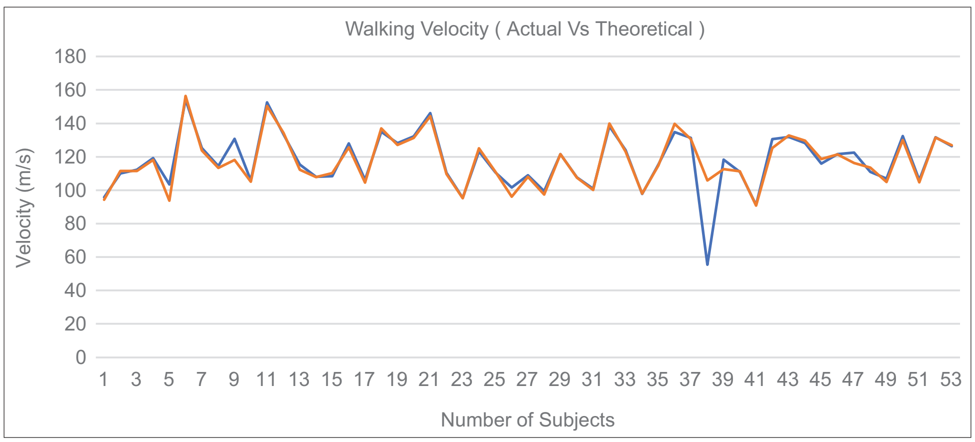

Figure 5: Theoretical and actual velocity for male group

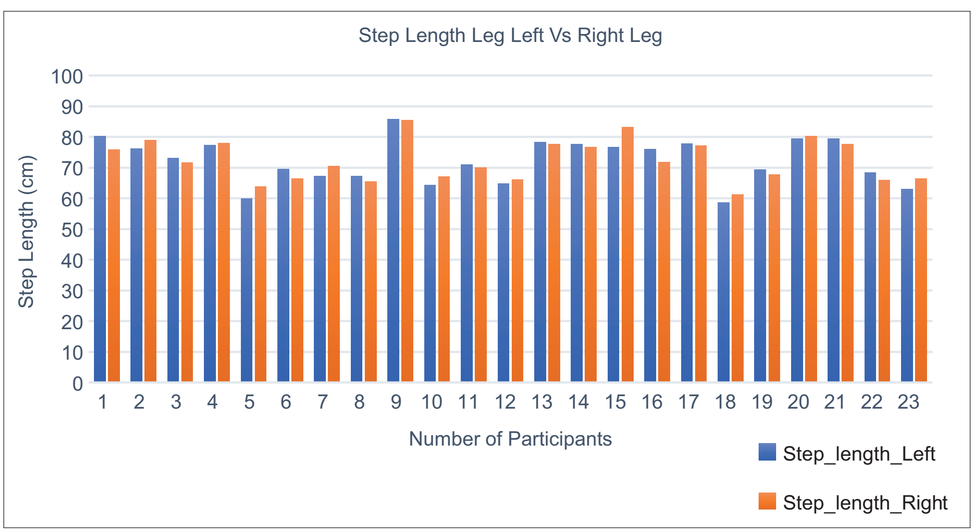

Figure 6: Step length left and right variation (Male Group)

unequal limb length is not considered. The actual and theoretical velocity is calculated and step length difference as a function of an age is tested. For the comparison purpose step length left and step length right are plotted. Figure 2 shows the actual and theoretical velocity showing correlation of 0.98.

Figure 3 shows the variation in step length left and step length right in terms of distance covered in consecutive iterations.

Figure shows the dominance of right leg in majority of cases in covering the distance. The observed variation is without consideration of measured limb length. It is a variation observed in group as a way of walking style. Test is extended to understand the effect of age and variation in step length difference observed.

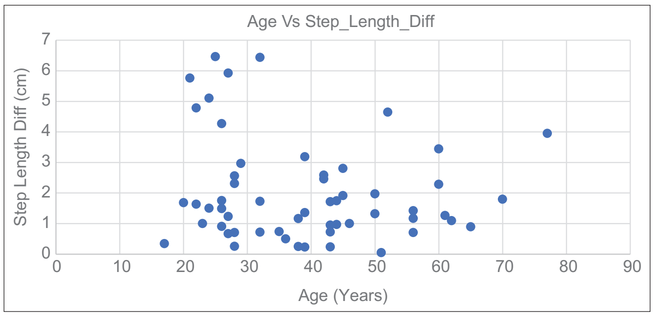

Figure 7: Step length difference as a function of age (Male group)

As shown in Figure 4, the maximum difference observed with the selected age group is up to 3 cm with only one outlier showing 6 cm difference.

Test Case-2

Considered age group is 20–70 years including only male subjects. While selecting subjects, constraint regarding equal or unequal limb length is not considered. The actual and theoretical velocity is calculated and step length difference as a function of an age is tested. For the comparison purpose step length left and step length right are plotted. Figure 5 shows the actual and theoretical velocity showing correlation of 0.98.

In next step, comparative chart is checked for step length left and step length right for the selected group. Figure 6 shows the observed variation in the values.

As selected participants are covering large age range, the effect of age on step length difference is calculated and got the result as shown in Figure 7.

The maximum range of variation observed across the selected age span goes up to 4 cm with few specific cased showing much more variation. Majority of subjects are within range of 3 cm.

Test Case-3

Considered age group is 20–70 years including only female subjects. While selecting subjects, constraint regarding equal or

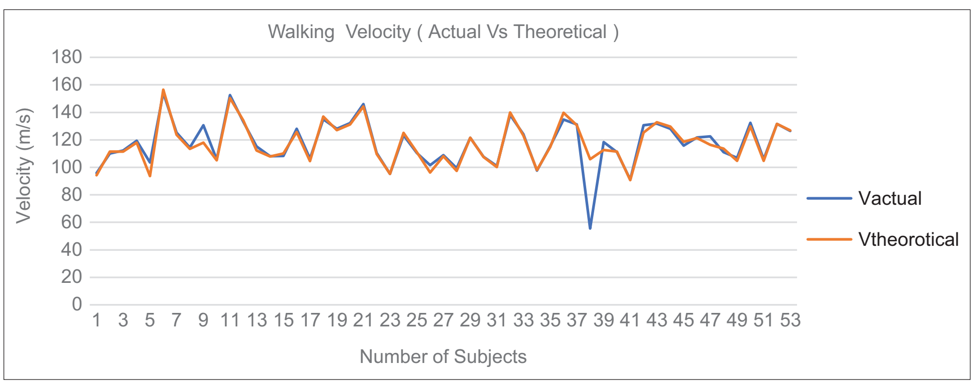

Figure 8: Velocity actual and theoretical (Female Group)

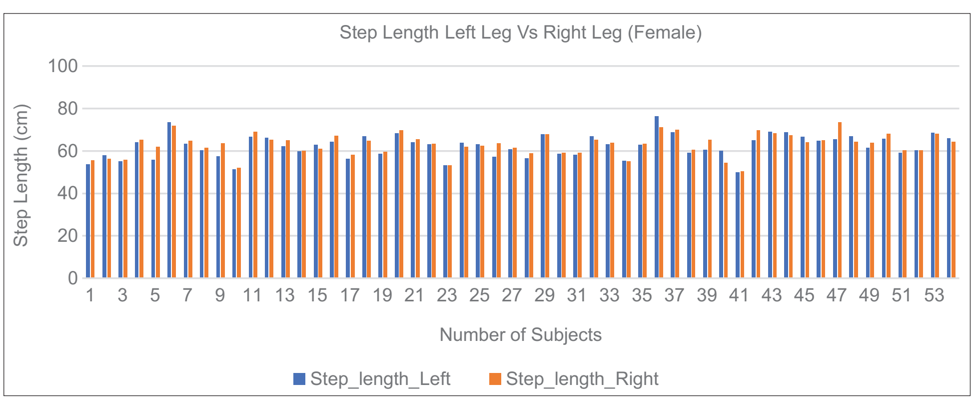

Figure 9: Step length (left versus right) female group

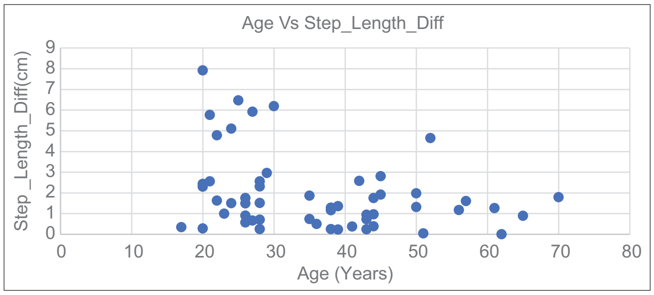

Figure 10: Age versus step length difference (female group)

unequal limb length is not considered. The actual and theoretical velocity is calculated and step length difference as a function of an age is tested. For the comparison purpose step length left and step length right are plotted. Figure 8 shows the actual and theoretical velocity showing correlation of 0.89.

In next step comparative chart is checked for step length left and step length right for the selected group. Figure 9 shows the observed variation in the values.

As selected participants are covering large age range, the effect of age on step length difference is calculated and got the result as shown in Figure 10.

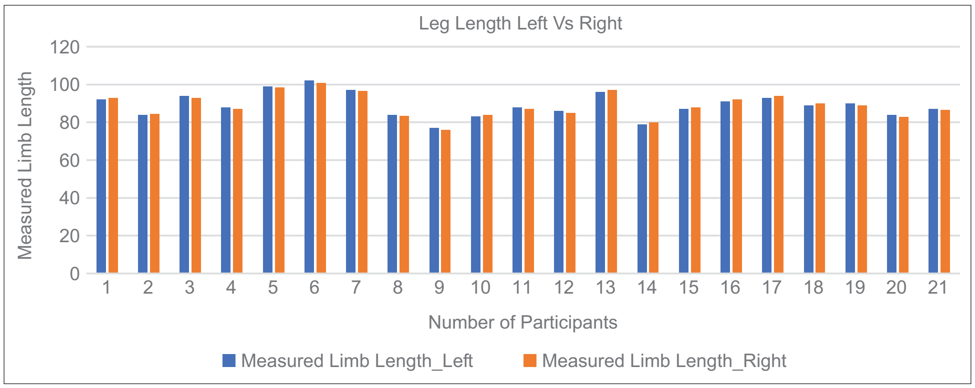

Figure 11: Measured leg length (left versus right)

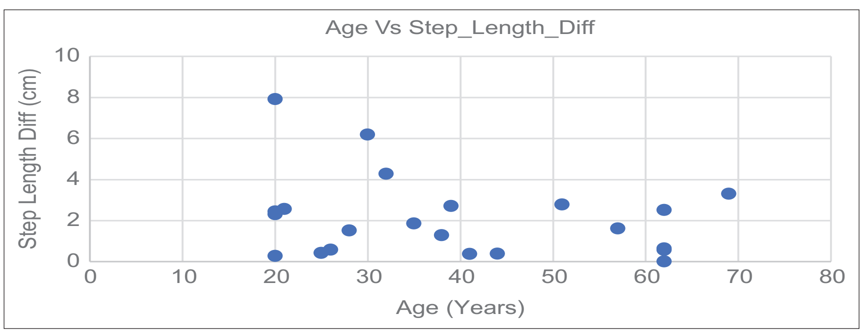

Figure 12: Step length difference as a function of age (Unequal leg length)

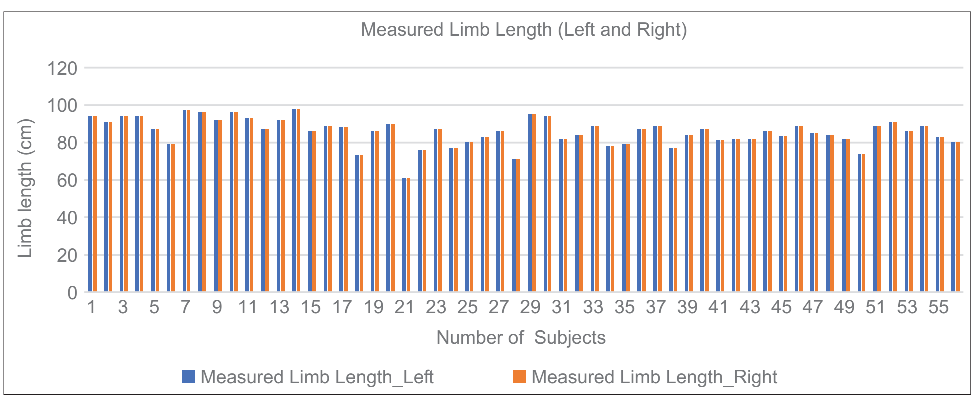

Figure 13: Equal leg length group

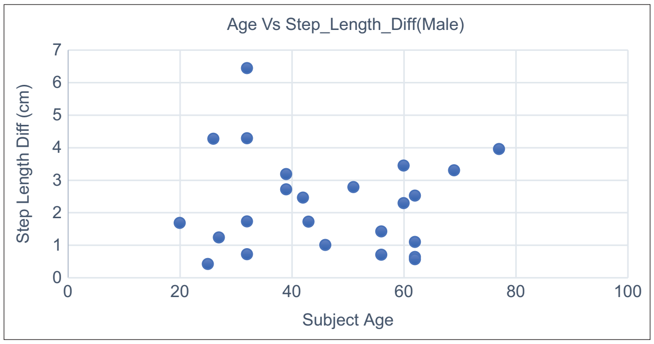

Figure 14: Step length difference as a function of age (Equal leg length group)

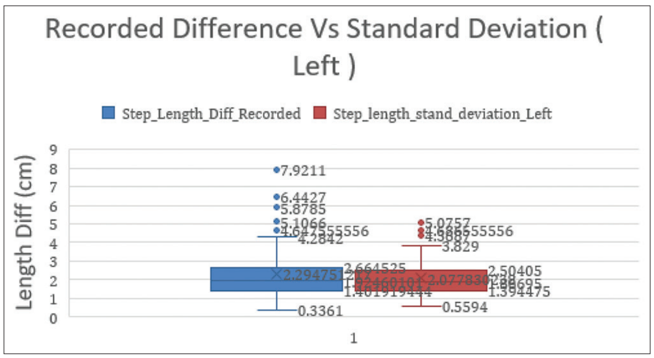

Fig 15: Box & Whisker plot of recorded step length difference and standard Deviation (Left)

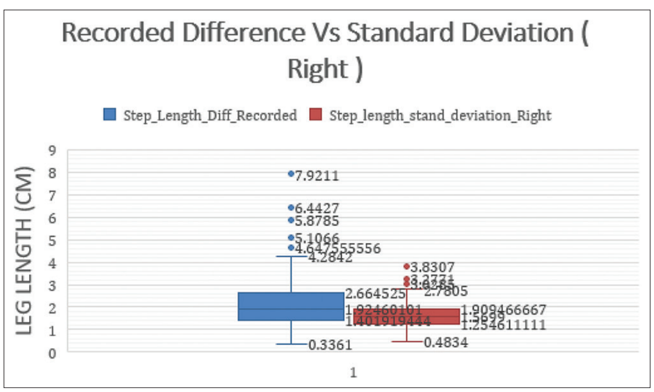

Fig 16: Box & Whisker plot of recorded step length difference and standard Deviation (Right)

As shown in figure the female group shows the step length difference up to 7 cm which is larger than the observed difference in male participant group.

Test Case-4

Considered participants are within age group 20–70 including male and female. While selecting the group the important point considered is unequal measured limb length between left and right. The variation in leg length is 0.5 cm–1.5 cm. The graphical view of the values is given in Figure 11 showing the leg length left and leg length right.

For the considered group of unequal leg length, the influence of step length difference is observed with reference to age and Figure 12 shows the maximum cases with variation of 4 cm, with few outliers.

Test Case-5

Considered participants are within age span of 20–70 years including male and female. The measured leg length is exactly equal. Figure 13 shows the equal value of measured limb length.

For the considered group of equal leg length the influence of step length difference is observed with reference to age and Figure 14 shows the maximum cases with variation of 7 cm.

After analyzing these test cases which are separated on the basis of gender and age, the comparative analysis is performed to understand the range of difference obtained in all case and the recorded values of standard deviation. The standard deviation could be treated as permissible value for the selected person or group. The comparison is done for the observed difference in the left and right step length and shown in Figures 15 and 16.

Figures 15 and 16 show the lower and upper bound of observed difference and standard deviation along with calculated median of the range and the extreme conditions of outliers.

Test Case-6

The considered group of subjects spans across 20–70 years including male and female. Measured limb length is not considered as a differentiating parameter. Figure 17 shows the step time left and right.

The observed difference is very less in terms of millisecond making it difficult to understand the exact behavior. The step time difference is plotted against the age and shown in Figure 18.

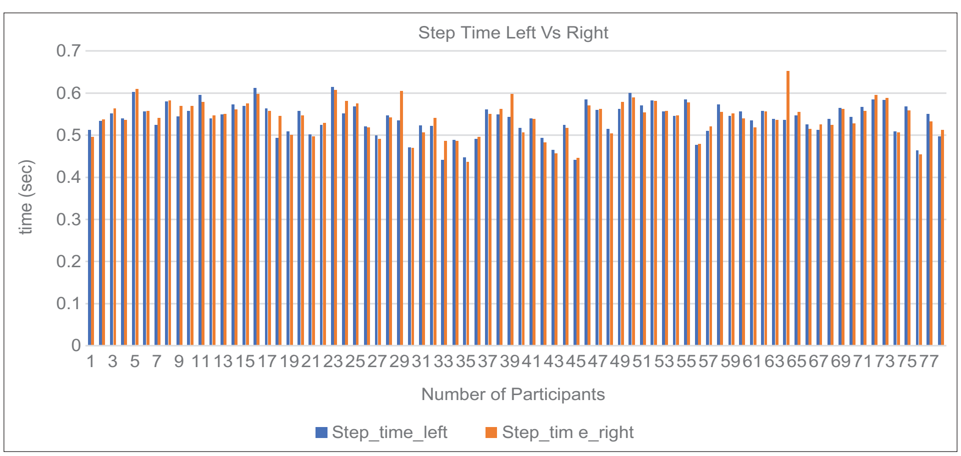

Figure 17: Step time difference left versus right

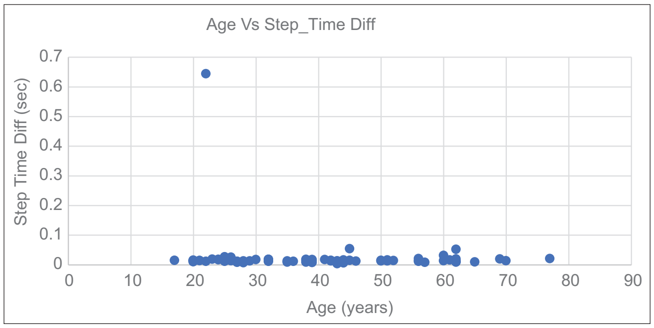

Figure 18: Step time difference as a function of age

As we can observe, the variation is too small in value in the part of 0.1 s duration, leading to difficulty in using it as a parameter for taking decision. To clarify on the time instances the other option verified is stance and swing cycle % as a part of gait cycle and the observation is shown in Figure 19.

Observed stance and swing % Cycle shows the ranges within Swing (34.76–40.84) and stance (57.9–65.52) for the selected normal ranges.

To get the clarification about the possibility of asymmetry measure using time, single support time left, single support time right and double support time is verified and Figure 20 shows the obtained result for it. While Figure 21 shows the single support left

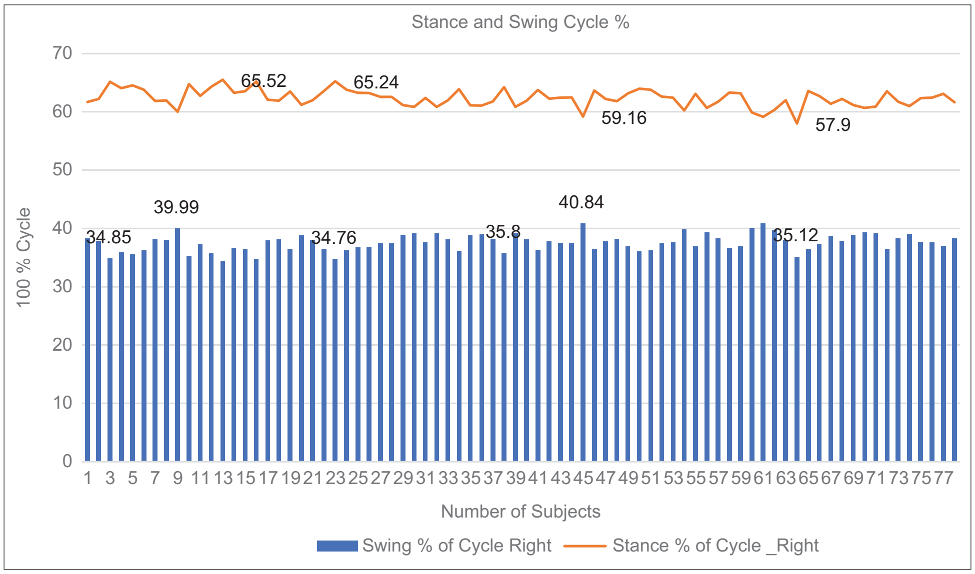

Figure 19: Stance and swing cycle %

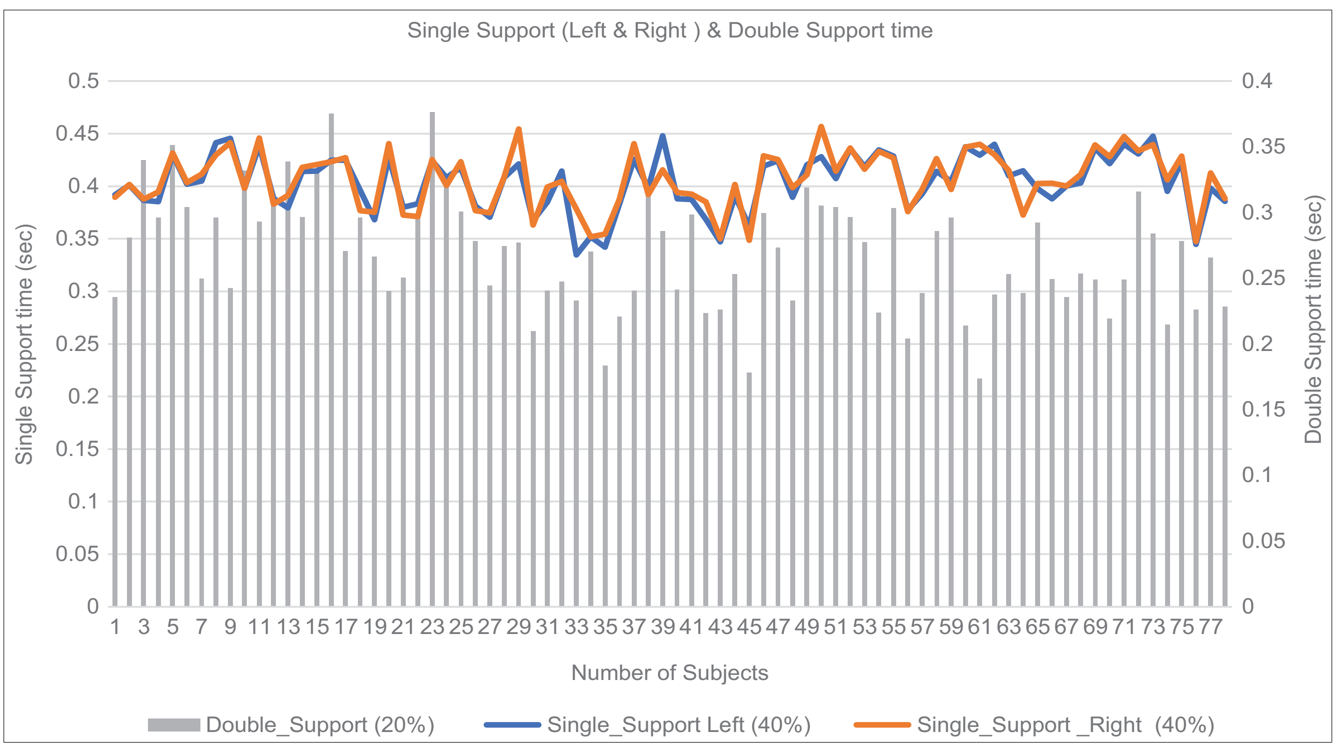

Figure 20: Single support (Left and Right) and double support time

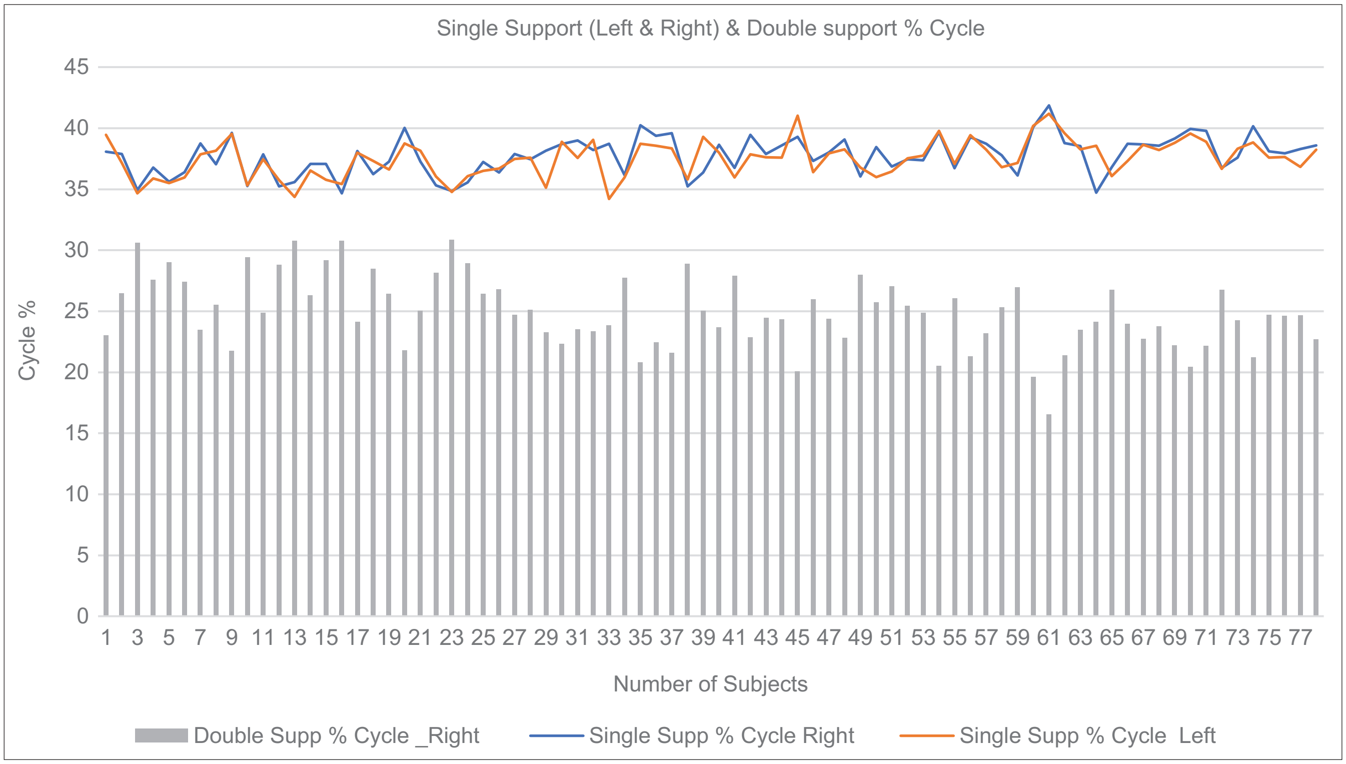

Figure 21: Single support (left and right) and double support % cycle

% cycle, single support right % cycle and double support % cycle for the selected group of the subjects.

Conclusion

Based on the recorded footfalls and calculated reference values for healthy subjects, it is possible to provide guidelines for gait assessment and spatiotemporal analysis for Indian Population for similar recording setup. According to the age groups of 20–29 years, 30–39 years, 40–49 years, 50–59 years, and 60–70 years mean, standard deviation, 95% confidence, and prediction intervals are obtained. Walking velocity is verified for each test case with its theoretical and practical value. Min-Max, Mean, and Standard deviation values for bilateral parameters such as step length, step time, stride length, swing time, and stance time are documented to be used for reference. Behavior and correlation among different spatiotemporal parameters are studied and its effect on age and sex is tested. Results obtained for influence of aging on step length shows variation up to 3 cm in club data and separated analysis it goes up to 6 cm for male and 7 cm for female group. To identify the possibility of walk asymmetry due to difference is limb length is tested. Results obtained for group with difference in measured limb length shows step length variation as per aging up to 4 cm and group with equal measured limb length shows the step length variation as an effect of aging up to 7 cm. Hence, we cannot specify that unequal limb length up to measured difference up to 1.5 cm cannot be treated as reason for asymmetry. Based on available result, it is possible to deploy and test proposed asymmetry algorithm for early identification of asymmetry.

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