Correlation between Gait Parameters and Physiological Cost Index in healthy Indian females

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Abstract:

Objective: To analyze the correlation between Physiological Cost Index and the Gait Parameters and demographics. **Participants:** A convenience sample of 24 healthy females, age 25 to 50 years. **Intervention**: For the purpose of arriving at the Physiological Cost Index, after measuring the resting vitals, subject was instructed to walk to and fro the walkway at self-selected speed, wearing an ambulatory heart rate meter for measuring the heart rate at regular intervals. For gait parameters, the patient was asked to first dip her foot in hypoallergenic colour solution and then walk on a paper walk way to arrive at main outcome measures values such as step length, stride length, and base of support. **Result**: Mean age was 33.9±8.248 years. Mean height of the subjects was 155.2 ± 5.414 cm. Mean weight was 58.3 ±12.855 kg, mean BMI was 23.86±4.996 kg/m^2, mean stride length, was 94.7 ±10 cm, mean antero-posterior length was 23.29 ± 1.552 cm, mean lateral width of base was 21.86 ± 1.876 cm, toe out was 14.71 ± 2.594 degrees, and mean PCI was 0.4435 beats per meter. A Pearson correlation between the studied variables and PCI was found to be strongly correlated with the anteroposterior length, moderately positively correlated with weight, height, BMI, step length, stride length, toe out angle, and lateral width of base of the individual. There was a mild negative correlation between PCI and age. **Conclusion:** Physiological cost of walking in normal Indian females is directly associated with the weight, height, BMI, and gait parameters of the individual.

Keywords: Physiological Cost Index, 6 Minute Walk Test, 6 Minute Walk Distance, BMI, VO2

1. Introduction

Health and fitness of the women is a prerequisite to the progression of a civilized society. Even though we claim of technological advancement and women empowerment; women in India, whether urban or rural, face numerous health issues. Indian women have high mortality rates, particularly during childhood and in their reproductive years. The health of Indian women is intrinsically linked to their status in society. Multiple factors exert a negative impact on the health status of Indian women. Poor health has repercussions not only for women but also their families. Women in poor health are more likely to give birth to low weight infants. Research has shown that numerous pregnancies and closely spaced births erode a mother's nutritional status, which can negatively affect the pregnancy outcome (e.g., premature births, low birth-weight babies) and also increase the health risk for mothers (Jejeebhoy, 1995). In fact, India has a high maternal mortality ratio—approximately 453 deaths per 100,000 births in 1993. (U.S. Department of Commerce Economics and Statistics Administration, 1998). Given such a grim picture, it is imperative to analyze the health and fitness levels of women in India, and draw out normative figures regarding the basic markers of fitness and endurance, which one can then apply to the population in question. Some of the basic measures of fitness and energy expenditure include BMI, PCI, Vo2 Max, and 6MWD.Increase in BMI is related with a lot of chronic diseases [Reaven PD.,1991,Fletcher G.F.,1992, Heinonen A., 1998, Hatemi R.,2003)

Talking of fitness and expenditure, its association with gait cannot be undermined. In human locomotion too, there is a cost of transport, or metabolic energy that must be spent by the body (Ralston, H.J., 1958). Healthy human at self-selected walking speeds have a cost of transport approximately 0.8 calorie/meter/kg.(Zarrugh et al, 1974). Depending on speed, stability conditions, internal other and external factors, (Voloshina et al, 2013, Ijmker,et al,2013,Detrembleur2003),the cost of transport can change. Conventionally, the tracking of metabolic activity is done by VO2 measurement during treadmill walking. Furthermore, decrease in stride length by 15 percent significantly increased the metabolic cost by 4.6 percent (Russel et al, 2010).

The traditional parameter of measuring energy expenditure has been the oxygen uptake(Blessey, R., 1976, Booyens, J., 1957). Authors developed the Physiological Cost Index (PCI) for measuring the energy expenditure of walking (MacGregor, J., 1981). It is easy to apply in clinics, no heavy equipment required, and influence of emotional stress, fitness, medication, illness and ambient temperature are very small. For these advantages, there have been many studies using the PCI to measure energy expenditure of ambulation in normal children and children with ambulation disabilities (Chin, T., 1999, Loder, R.T., 1987, Mossberg, K.A., 1990, Mukherjee, G, 2000, Mukherjee, G, 2001, Mukherjee, G, 2004, Popovi, D., 2003, Rose, J., 1990, Suzuki, T., 2005). The PCI enables the therapist to carry out energy cost assessment in the clinical setting.The heart rate is the simplest and the most direct measure of physical effort.For normal people and people with lower extremity handicaps, heart rate has been shown to be a reliable monitor of energy expenditure because it is linearly related to the rate of oxygen uptake under submaximal workloads.Therefore,heart rate has been recommended as a method of measuring energy cost (Graham, R.C., 2005, MacArthur, C.,1991).

The Physiological Cost Index (PCI) proposed by MacGregor (MacGregor, J., 1981) is calculated as the quotient of the difference in working and resting heart rates and walking speed. The PCI value reflects the increased heart rate required for walking and is expressed as heartbeats per meter. PCI may provide a measure of overall walking performance, inasmuch as it includes both a physiologic measurement and velocity. The correlation between PCI and $\dot{V}O_2$ has been studied in healthy adults (Chin, T., 1999). The retest reliability of PCI has been investigated in healthy subjects (Chin, T., 1999, Loder, R.T., 1987, Mossberg, K.A., 1990, Mukherjee, G, 2000), children with cerebral palsy (Mukherjee, G., 2004) and adults with spinal cord (Mukherjee, G, 2000) and brain injuries. PCI has been used as an outcome measure after interventions in persons with cerebral palsy (Rose, J., 1990) spinal cord injury (Suzuki, T., 2005, Graham, R.C., 1991) and stroke (Fisher, S.V., 1978, Butler, P., 1984).

Metabolic cost is naturally optimized by natural selection of an optimal gait pattern by the individual. While external factors such as instability and perceived dangers may temporarily alter the body's priorities (Voloshina et al, 2013),the primary goal of minimizing a task dependent energy expenditure ultimately reigns in the self selection of a preferred walking pattern by the individual (Mcneil A, 2002).

While multiple proportional combinations of step length and cadence can be used to achieve the same walking speed, taking faster and shorter steps or slower and longer steps than the optimal combination leads to increased cost of transport.(Zarrughet al,1978). Gait parameters therefore exhibit a relationship with the energy cost of walking, and the source of this relationship stems from the deviation of these gait parameters from metabolically optimal values, with deviations also due to environmental, pathological and other factors.

The main aim of this study was to investigate the correlation of PCI with the gait parameters in healthy Indian females.

2. Methods/ Approach

Twenty four healthy normal females volunteers aged between 25 to 50 years were selected. None of the participants had been engaged in any exercise training. Also, none of them had a history of respiratory or cardiac diseases, any airway disorder, or thoracic, abdominal, ENT or ophthalmic surgery. None of them had any sign or symptom of medical instability including postpartum problems like perineal pain, backache, diastasis recti, mastitis, breast abscess, stress incontinence, or diastasis symphysis pubis.

2.1 Subject Preparation:

The subject's usual medical regimen, if any, was to be continued. A light meal was acceptable before early morning or early afternoon tests. Subjects would not have exercised vigorously within 2 hours of beginning the test. The subject was then instructed /helped to fill the questionnaire regarding herself. All the participants received a full explanation of the study's purposes and a consent form was read and signed by the subjects before the study. Information regarding the subjects demographic data, age, height, weight, medical and obstetric history and current medical status was obtained from subjects.

2.2 Equipment Required:

A couch, sphygmomanometer, weighing machine, a stop watch, work sheets, POLAR® Heart Rate monitor consisting of a chest band, and a wrist monitor to measure the immediate accurate heart rate, alcohol swabs, a 25 meter walking pathway, two small cones to mark the turnaround points, and a chair to be kept along the walking course. paper walk way 1.5 ft x8 ft long, tray with wet hypoallergenic colour to colour the feet for making impressions on paper walkway, measuring tape to measure gait parameters, pencils, scale and a goniometer.

2.3 Measurements:

2.3.1 Physiological Cost Index:

An ambulatory pulse rate meter was placed on the chest of the subject, and she was made to rest comfortably to first obtain the resting heart rate. Two such readings were taken in an interval of ten minutes and the lower one was selected. The subject was instructed to walk to and fro the walkway at a comfortable walking speed that one normally uses to walk. Heart rate and time was recorded at the end of each excursion of 25 meters, repeated eight times. Average walking heart and Physiological Cost Index was calculated as following:

PCI= {HR (w)-HR(r)} x total time walked/ total distance walked

Where: HR (w) = Average Walking Heart Rate; HR(r) = Resting Heart rate

2.3.2 Gait Parameters:

Gait parameters study was facilitated in a clinical setting by asking the patient to first dip her foot in hypoallergenic colour solution and then asking her to walk on a paper walk way.Following gait parameters were measured:

a) Step length
b) Stride length
c) Anteroposterior length

d) Lateral width of walking base

e) Toe out angle

3. Statistical Analysis /Results

The independent variables such as Age, Height, Weight, Step length, Stride length, Anteroposterior length, Lateral width of walking base, Toe out angle and dependent variable PCI was first expressed as mean ± standard deviation and variance was also calculated. Pearson correlation coefficient was calculated between the above parameters and PCI values respectively.

Mean age was 33.9±8.248 years. Mean height of the subjects was 155.2 ± 5.414 cm. Mean weight was 58.3 ±12.855 kg, mean BMI was 23.86±4.996 kg/m^2, mean step length was 46.89 ± 6.121 cm, mean stride length, was 94.7 ±10 cm, mean antero-posterior length was 23.29 ± 1.552 cm, mean lateral width of base was 21.86 ± 1.876 cm, toe out was 14.71 ± 2.594 degrees, and mean PCI was 0.4435 beats per meter.

Table1: Demographic data of the subjects.

N=24	Age In years	Height in cm	Weight in KG	BMI IN kg/m^2
Mean	33.9	155.2	58.33	23.86
Standard deviation	8.248	5.404	12.855	4.9964
Variance	68.04	29.19	165.25	24.964
Pearson Correlation Coefficient	**-0.23**	**-0.47**	**0.386**	**0.473**

Table 2: Correlation of PCI with Step length, Stride length, A-P length, Lateral width of base, and Out toe angle.

N=24	Step length in cm	Stride length in cm	A-P length in cm,	Lateral WOB	Out toe angle
Mean	46.89	94.7	23.29	21.86	14.71
Standard	6.121	10.007	1.552	1.876	2.597

deviation					
Variance	37.459	100.142	2.408	3.520	6.727
Pearson Correlation Coefficient	**0.517**	**0.344**	**0.703**	**0.167**	**0.138**

4.1 Figures:

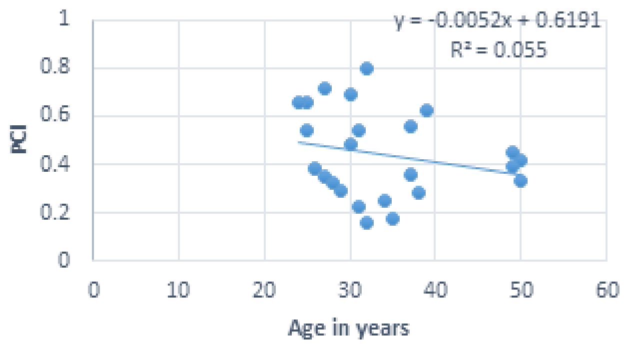

Figure 1: Correlation of Age (x1) with Physiological cost Index

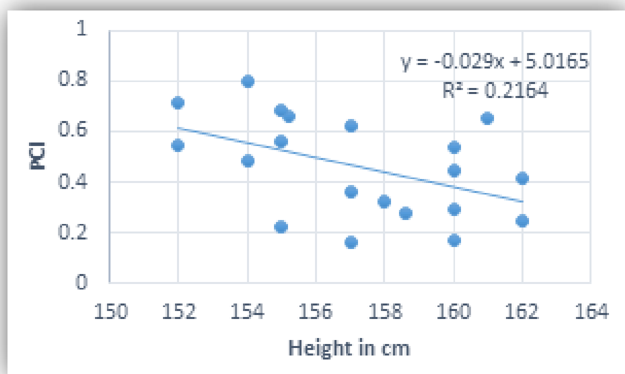

Figure 2: Correlation of Height (x2) with Physiological cost Index

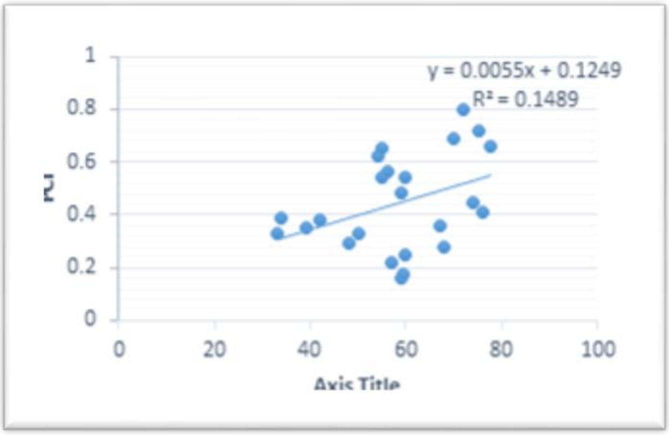

Figure 3: Correlation of Weight (x3) with Physiological cost Index

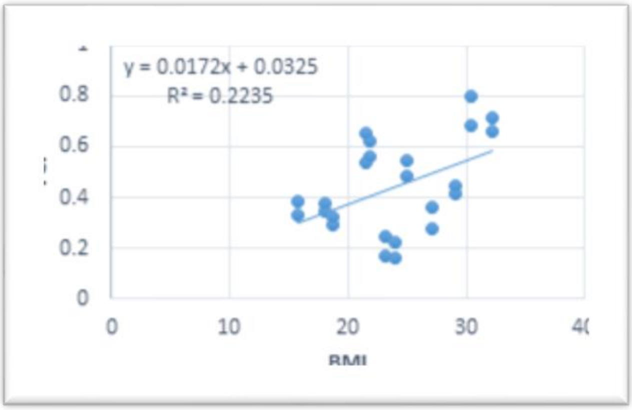

Figure 4: Correlation of Body Mass Index (BMI) (x4) with Physiological cost Index

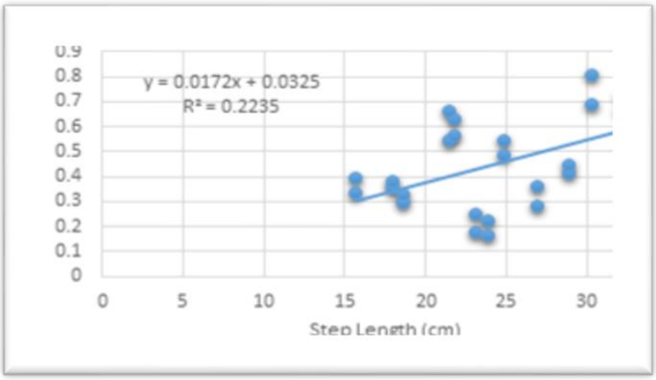

Figure 5: Correlation of Step Length (x5) with Physiological cost Index

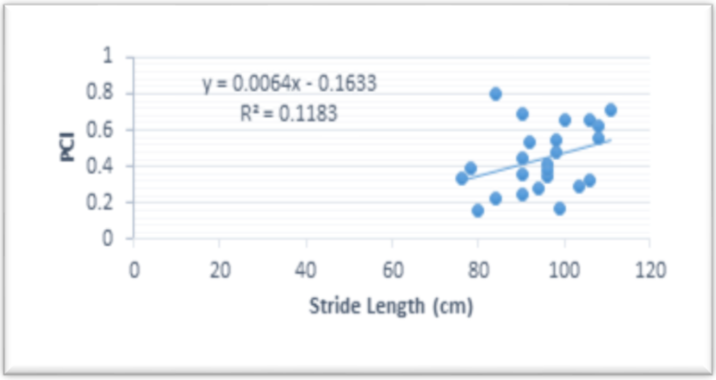

Figure 6: Correlation of Stride Length (x6) with Physiological cost Index

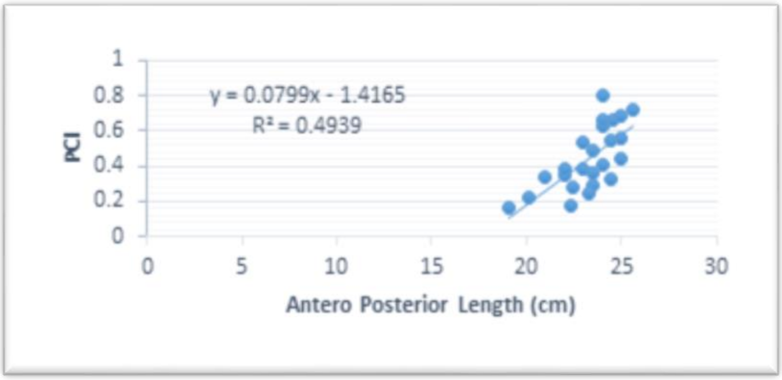

Figure 7: Correlation of Anteroposterior length (x7) with Physiological cost Index

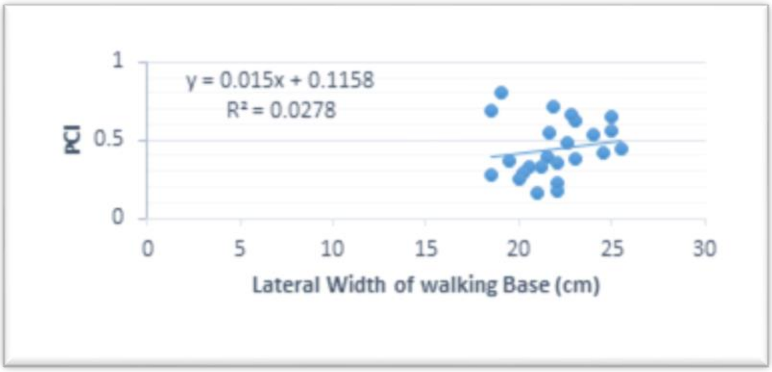

Figure 8: Correlation of Lateral Width of walking base (x8) with Physiological cost Index

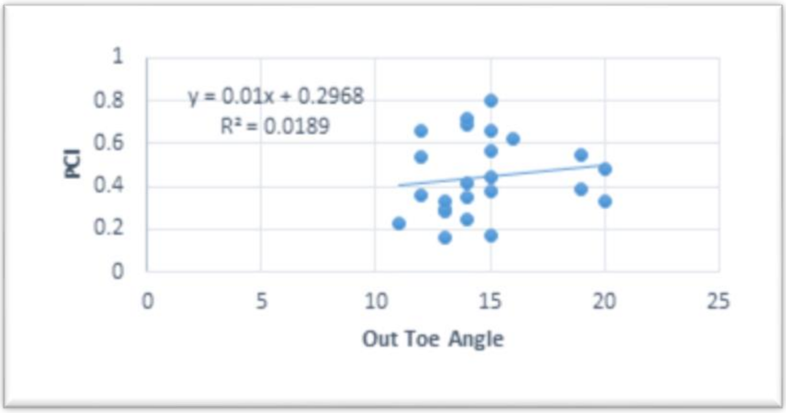

Figure 9: Correlation of Out toe angle (x8) with Physiological cost Index

When Pearson Product Moment Correlation was applied to ascertain the correlation between the dependent variable PCI with the independent variables such as age, height, weight, BMI, Step length, Stride length, Anteroposterior length, Lateral width of walking base, Toe out angle; the following observations came up:

The Physiological cost Index was shown to have mild negative correlation with increasing age in normal healthy Indian women(r value=-0.23). Initially, height did not seem to have much of a correlation with PCI in the studied sample, but after removing four outlier points of least height, the correlation became significant (r value=-0.47). In the given sample of non obese and non overweight Indian females, weight and BMI seemed to be positively correlated with the PCI, (r value0.386 and 0.473 respectively).

In this study, VO2 max calculated during the 6MWT did not correlate with PCI of the individual (r value=-0.0428). **Anteroposterior length** showed a strong positive correlation with the PCI. (r value= **0.7166). Step length** showed a moderate positive correlation with the PCI. (r value= **0.4986).**

The increase in **stride length** was also mild positively correlated with the increase in PCI. (r value= **0.205). Lateral width of walking base** as well as **toe out** angle showed a mild positive correlation with the PCI. (r value= **0.1547 and 0.1509 respectively)**

4. Discussion

The Physiological cost Index was shown to have mild negative correlation with increasing age in normal healthy Indian women. Initially, height did not seem to have much of a correlation with PCI in the studied sample. This finding is in line with Mac Donald (MacDonald, I.,1961), who reviewed literatures from 1912 to 1958. He found no significant correlation between age or height and the energy expenditure of walking. However, after removing outliers subjects from the graph the height showed a mild positive correlation with PCI. This association therefore needs further exploration. As per authors (MacDonald, I., 1961), walking speed, sex, and weight significantly influenced the energy expenditure of walking.

In the given sample of non obese and non overweight Indian females, weight and BMI seemed to be positively correlated with the PCI, thereby indicating that with increase in body weight, the physiological cost of walking tends to increase as well. There were conflicts regarding the effect of sex, weight and leg length on the energy expenditure (Mukherjee, G., 2001, Loder, R.T., 1987, Mahadeva, K., 1953). In a study involving fifty people of variation in only weight(48-110 kg) age (13-79 yrs), sex, height (150-188 cm) and race European and Asiatic, authors [Mahadeva, K., 1953] measured the Oxygen uptake during stepping and walking. Stepping was carried out on a 10 inch stool at a rate of 15 steps per minute for ten minutes. Walking took place on an indoor track the subjects walked for ten minutes at 80 m/min(3 mph).They found that in stepping, the energy expenditure was directly proportional to body weight; in walking, the regression line was also linear but did not pass through the origin. Statistical analysis showed that no significant difference in PCI was obtained by taking into account the height, sex, age and race for the individual. The authors concluded that in any physical activity, a large proportion of the energy was used to move the body weight and the metabolic cost was directly proportional to the body weight.

The observations are supported by the results of a study by Oberg et al,1993, who studied basic gait parameters in normal subjects aged 10-79 years, and found statistically significant age related change in gait speed as well as significant interaction effects of age and sex in the step length parameter.

According to Donelan et al, 2002, larger step length requires additional hip torque during the swing phase to travel a wider angle, which contributes to the rate of metabolic cost by a factor of leg length squared. However, in our study, we did find only a moderate correlation between the step length and PCI, which is also a measure of energy cost at accustomed walking speeds. This therefore needs further exploration.

As for the lateral width of walking base, we found a moderate correlation between the width and PCI. In another study by (Donelan et al 2001) they have suggested that a narrower stance with a reduced step width, the metabolic cost may increase, with a rationale that to compensate for insufficient leg clearance, the hip torque may increase to project the swinging leg out laterally.

In general, the relationship between walking and cost of transport is like a parabola with the preferred walking speed at the minimum, meaning walking at a slower of faster speed can incur an increase in energy cost. (Ralston, 1958).

The strong correlation between foot antero-posterior length and PCI suggests probably an interesting association between the energy consumption and the mechanical advantage and leverage length at toe off, which is less studied till date and would unfold greater information when explored further.

The out toe angle, in the sample studied, had a less variability, and therefore even though mildly correlated with PCI, a greater variability in the angle in a larger sample may help clarify the association in a clearer manner.

5. Conclusion

Physiological cost of walking in normal Indian females is directly associated with the height, weight, BMI, and gait parameters. This association needs to be investigated further to explain the interplay of extraneous factors as well.

6. Future Scope

This study opens doors to further exploration on the studied parameters, and suggests inclusion of these parameters in assessment protocols of women health, to give a better picture of functional status, as opposed to the clinical status which is stressed upon in current health scenario.

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