Comparative Analysis of Functional Limb Length Discrepancy, Aerobic Fitness, Hip Muscle Imbalance, Balance, and Pelvic Tilt in Professional Versus Recreational Athletes.

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Abstract
Introduction: Functional limb length discrepancy (LLD) can negatively impact athletic performance by altering biomechanics and balance. This study aimed to compare hip muscle strength, flexibility, and balance between professional and recreational athletes with functional LLD.
Methodology: A comparative experimental study was conducted involving 30 athletes with functional LLD—15 professional athletes from Maharana Pratap Sports College, Raipur, Dehradun (mean age 15 ± 1.13 years), and 15 recreational athletes from Guru Nanak College hostel, Jhajra, Dehradun (mean age 19.73 ± 1.22 years). Purposive sampling was used to divide participants into two groups. Assessment tools included inch tape for limb length and reach, digital inclinometer for pelvic tilt, strain gauge for muscle strength, BESS and SEBT for balance, and a 20-meter shuttle test for VO_2 max.
Results: Preliminary findings indicated that professional athletes demonstrated greater hip muscle strength, better balance (as measured by BESS and SEBT), and superior flexibility compared to recreational athletes. Additionally, professional athletes showed better endurance on the 20-meter shuttle test.
Discussion: The results suggest that higher training intensity and routine in professional athletes may contribute to better neuromuscular control and muscle conditioning, thereby reducing the functional impact of LLD. The improved balance and strength may help compensate for biomechanical asymmetries associated with LLD.
Conclusion: Professional athletes with functional limb length discrepancy exhibit superior hip muscle strength, balance, and flexibility compared to recreational athletes. These findings emphasize the importance of targeted training in mitigating the effects of functional LLD in athletic populations.

Keywords: Functional limb length discrepancy, professional athletes, recreational athletes, VO_2 max, BESS, SEBT .

Introduction:

Recreational and competitive running is practiced by many individuals to improve cardio respiratory function and general fitness. The major negative aspect of running is a high rate of overuse injury, especially of the lower extremities. Many otherwise healthy runners are prevented from participating fully in their sport by injuries.[1] Epidemiological studies have demonstrated that 58% were injured during preparation for marathon.[7] Injury incidences of 2.5/1,000 h of marathon training[2,3] and of 89.4 injuries/1,000 h of marathon running has been reported. Injuries in long-distance runners are mainly overuse injuries to the lower extremities. Risk factors may be extrinsic or intrinsic. One of the potential risk factors for running injuries is LLD[1]. Limb length discrepancy, or anisomelia, is defined as a condition in which paired limbs are noticeably unequal. When the discrepancy is in the lower extremities, it is known as leg length discrepancy (LLD)[8]. LLD is a relatively common problem found in as many as 40[4] to 70%[5] of the population. LLD can be subdivided into two etiological groups: a structural LLD (SLLD) defined as those associated with a shortening of bony structures, and a functional LLD (FLLD) defined as those that are a result of altered mechanics of the lower extremities[6]. The etiology of SLLD may be congenital or acquired. Of the congenital causes, the most common include congenital dislocation of the hip and congenital hemiatrophy or hemihypertrophy with skeletal involvement. Acquired causes can be as a result of infections, paralysis, tumors, surgical procedures such as prosthetic hip replacement, and mechanical such as slipped capital femoral epiphysis[8]. Functional, or apparent LLD is a result of muscle (tightens/weakens) or joint tightness across any joint in the lower extremity or spine. Some of the more common causes can be pronation or supination of one foot in relation to the other, hip abduction/adduction tightness/contracture, knee hyperextension due to quadriceps femoris weakness, and lumbar scoliosis[8]. Because most running injuries are multifaceted in nature, areas secondary to the site of pain, such as hip muscle groups exhibiting strength imbalances, must also be considered to gain favorable outcomes for injured runners. There is an association between hip abductor, adductor, and flexor muscle group strength imbalance and lower extremity overuse injuries in runners[19]. When a muscle is tighter than it should be, it not only affects the opposing muscle but can have repercussions on the entire musculoskeletal system. If there is an imbalance in the length-tension relationships and improper dynamic posture during movement, the constant tug of war between muscles can prematurely lead to muscle, joint, tendon and ligament injuries[20].Athletic trainers often prescribe exercises in an attempt to enhance an athlete's postural control or balance and perhaps reduce the risk of injury[21]. Postural control or balance can be defined statically as the ability to maintain a base of support with minimal movement and dynamically as the ability to perform a task while maintaining a stable position[22]. Factors that influence balance include sensory information obtained from the somatosensory, visual, and vestibular systems and motor responses that affect coordination, joint range of motion (ROM), and strength[23-26]. Some evidence in the literature suggests that superior balance among experienced athletes is largely the result of repetitive training experiences that influence motor responses and not greater sensitivity of the vestibular system[27]. Others argue that superior balance is the result of training experiences that influence a person's ability to attend to relevant proprioceptive and visual cues[28]. Although experts may not agree on the mechanism, research suggests that changes in both sensory and motor systems influence balance performance[21].

A pelvic torsion is usually defined as an intrasegmental pelvic pattern in which one ilium is tilted more anterior in relation to the other. Another way to say it is that one ilium is tilted more anterior and one more posterior in comparison with each other. For reasons not totally understood by me most torsions are - according to several published studies - "right anterior" (i.e. right ilium anterior & left ilium posterior in comparison with each other). When the cilium tilts more forward this brings the anterior superior iliac spine (ASIS) more anterior & inferior (and in most cases also more lateral). The ischial tuberosity will go more posterior and superior (and in most cases more medial)[29] Cardio respiratory endurance is generally recognized as a major component of evaluating physical fitness and maximal oxygen consumption (vo2 max) and is consider most valid measure of cardiorspiratory fitness[10]. This measurement determines an athlete's ability to take in, transport and utilize oxygen and is probably the best assessment of the athlete's endurance capabilities[11]. The 20 MST is an appropriate field test of aerobic endurance[12].

Methodology

This section outlines the materials and methods employed in conducting the study, including details about the participants, procedures for data collection, and methods of analysis.

Population: The study involved a total of 120 athletes, selected from Maharana Pratap Sports College in Raipur, Dehradun, and the Guru Nanak College (GNC) hostel in Jhajra, Dehradun.

Source of Sample: Participants were screened from the aforementioned institutions—Maharana Pratap Sports College and the GNC hostel.

Sample: A total of 30 athletes with functional limb length discrepancy (LLD) were selected—15 from Maharana Pratap Sports College (mean age: 15 ± 1.13 years) and 15 from Guru Nanak College hostel (mean age: 19.73 ± 1.22 years).

Study Location: The study was conducted at two locations:

- The Physiotherapy Department of Maharana Pratap Sports College, Raipur, Dehradun
- The Exercise Laboratory of the Physiotherapy Department at Guru Nanak College of Paramedical Sciences and Hospital, Jhajra, Dehradun

Research Design: An experimental, comparative study design was adopted.

Selection Criteria

Inclusion Criteria:

- Age between 12 and 22 years
- Diagnosed with functional limb length discrepancy
- Capable of standing for at least 20 minutes
- Group A: Professional athletes from Maharana Pratap Sports College
- Group B: Recreational athletes from GNC hostel

Exclusion Criteria:

- Body Mass Index (BMI) above the normal range
- Structural limb length discrepancy
- Any musculoskeletal, neurological, systemic, or post-traumatic pain
- History of lower limb fractures, dislocations, or surgeries
- Neurological conditions affecting foot structure
- Vestibular or visual impairments
- Concussion within the last 12 weeks

Sampling Technique: Purposive sampling was utilized to form two groups, each consisting of 15 athletes.

Variables

Dependent Variables:

- Hip muscle strength and flexibility
- Balance Error Scoring System (BESS)
- Star Excursion Balance Test (SEBT)
- Inclinometry (for pelvic tilt)
- 20-meter shuttle run test (for VO_2 max)

Independent Variable:

- Type of athletic engagement: professional athletes vs. recreational athletes

Instrumentation

- **Inch Tape [36,21]:** Used to measure functional limb length (from ASIS to medial malleolus) and reach distances in balance tests
- **Ruler:** Used to assess tightness in hip adductors and flexors
- **Marker Pen:** For anatomical landmarks needed in limb length and pelvic tilt assessments
- **Digital Inclinometer [37]:** To evaluate pelvic tilt (innominate inclination)
- **Strain Gauge:** Measures muscle strength
- **Foam Surface [40]:** Introduced an unstable base for enhanced balance challenge, adjusted by body weight
- **Laptop with Speakers:** Played the 20-meter shuttle run test audio cues for VO_2 max estimation
- **Stopwatch:** Measured duration during static balance tests
- **Marking Cones:** Set up for the shuttle test
- **Digital Camera:** Recorded static balance performances for video analysis

PROTOCOL

Athletes with age ranging from 12 to 22 years were selected from Maharana Pratap Sports College in Raipur, Dehradun, and the Guru Nanak College (GNC) hostel in Jhajra, Dehradun.

Functional limb length discrepancy was measured by using tape measurement method[36]

30 athletes (mean age 15±1.13 and 19.63±1.22) with functional LLD were selected according to their inclusion and exclusion criteria and they were selected for further study

Consent of the subjects was obtained.

Purposive sampling (15 subjects in each group)

Group A (n=15) (Mean age = 15± 1.13)	Group B (n=15) (Mean age 19.73±1.22)

Professional athlete ⇓ Recreational athlete ⇓

⇓

Strength of his abductors and extensors was measured by using strain gauge

⇓

Length of hip adductor and hip flexor was measured

⇓

Balance was measured

- Static Balance – By using BEES[21]
- Dynamic balance – By using SEBT[21]

⇓

Pelvic tilt was measured by using digital inclinometer[37]

⇓

Aerobic fitness of both the group was measured by using 20 meter shuttle test[12]

⇓

To compare the hip muscle imbalance, balance, pelvic tilt and aerobic fitness between professional athletes & recreational athletes having functional limb length discrepancy and to find, is there any correlation between FLLD, hip muscle imbalance, balance, pelvic tilt and aerobic fitness in athlete.

Procedure

A total of 120 athletes aged between 12 and 22 years were initially selected from Maharana Pratap Sports College, Raipur, Dehradun and Guru Nanak College hostel, Jhajra, Dehradun, Dehradun. Functional limb length discrepancy (FLLD) was evaluated using a measuring tape, measuring from the anterior superior iliac spine (ASIS) to the medial malleolus in a standing, weight-bearing position³⁶. Of the screened athletes, 30 individuals with FLLD were identified and included in the study.

Participants were chosen based on defined inclusion and exclusion criteria, and informed consent was obtained from each participant .

The selected athletes were divided into two groups using purposive sampling, with 15 participants per group.

- **Group A** included professional athletes aged 12 to 16 years (mean age: 15 ± 1.13), selected from Maharana Pratap Sports College, Raipur, Dehradun .
- **Group B** consisted of recreational athletes aged 18 to 22 years (mean age: 19.73 ± 1.22), from Guru Nanak College hostel, Jhajra, Dehradun, .

Hip abductor strength was measured in a side-lying position and hip extensor strength in a prone position using a strain gauge. Muscle length for hip adductors was assessed in the supine position, while hip flexor length was evaluated using the Thomas test position. Measurements were performed three

times for both muscle strength and length, with the average of the three trials recorded. Balance was assessed using the Balance Error Scoring System (BESS) for static balance and the Star Excursion Balance Test (SEBT) for dynamic balance. Each test was repeated three times and the mean score was taken. Pelvic tilt was measured using a digital inclinometer. This assessment was also repeated three times and the average value was recorded.
To evaluate aerobic capacity, participants performed the 20-meter shuttle run test^{12, 41}, a standard field test to estimate VO_2 max⁴¹. Prior to testing, subjects completed a 10-minute warm-up and post-test cool-down. The shuttle test was administered twice, and the average VO_2 max was calculated using an online calculation.

Reliability and Validity
Instrument Reliability:

- **Inch Tape:** Measurement using a tape from ASIS to the medial malleolus is considered a valid and reliable method for identifying limb length discrepancies when the average of two readings is used³⁶.
- **Strain Gauge:** A standard ISI-certified strain gauge was used, ensuring reliable measurement of muscle strength.
- **Digital Inclinometer:** This tool has been shown to provide consistent and reproducible results, making it a practical and efficient instrument in clinical settings⁴².

Tester Reliability:
All measurements were taken three times by the same trained therapist under the supervision of a research guide. The mean of the three readings was used to ensure intra-rater reliability.

Procedure Reliability:

1. **Tape Measurement Method for Limb Length:** Research has demonstrated acceptable test-retest reliability and validity for the ASIS-to-medial malleolus tape method when using average values^{8, 17}.
2. **Balance Error Scoring System (BESS):** This test has shown high intra-tester reliability (Intraclass Correlation Coefficient = 0.78 to 0.96) and fair-to-good validity (r = 0.42 to 0.79)^{21, 39}.
3. **Star Excursion Balance Test (SEBT):** SEBT has also demonstrated high intra-tester reliability (Intraclass Correlation Coefficient = 0.78 to 0.96)^{21, 43}. While direct validity coefficients are not available, it is recognized as a sensitive screening tool for musculoskeletal injuries⁴⁴.
4. **20-Meter Shuttle Test (20 MST):** The 20 MST has been found to possess high intra-rater reliability ($r = 0.92$, $p < 0.01$) when administered to active adult athletes⁴¹.

Instrument

Measurement of static balance (tandem stance on foam)

zz**Measurement of dynamic balance**

Measurement of vo$_2$max by 20MST

RESULTS:

30 athletes are included, among which 15 subjects are taken in group A who are professional athletes, with mean age and other 15 athletes are taken in group B who are recreational athletes with mean age.

COMPARISON BETWEEN GROUPS A AND B FOR VARIABLES HIP MUSCLE IMBALANCE, BALANCE, PELVIC TILT AND AEROBIC FITNESS,

Independent t test was performed to compare the mean hip adductor length, hip flexor length, hip abductor strength, hip extensors strength, BESS score, SEBT, pelvic tilt and aerobic fitness, between group A and group B. The results are significant ($p < 0.05$) for aerobic fitness and for SEBT in Post Lat, Post, and Post Med direction and the mean values of these variables are 46.15± 5.38, for SEBT 100.72± 17.03,98.22± 18.65, 89.97 ± 16.58 respectively in group A and 39.62±4.72,85.63±17.36,78.95±16.35, 74.81±20.28 respectively in group B. (Refer table5.2 and 5.3)

The result are non significant($p>0.05$) for hip abductor strength, hip extensor strength, hip flexor and adductor length, Sati balance, pelvic tilt and SEBT in Ant, Ant Lat, Lat, Med and Ant Med directions and the mean values of these variables are 9.32 ± 2.81, 9.55 ± 3.52, 5.27 ±1.87, 18.61 ± 4.49, 15.60 ± 5.96, 8.22 ± 3.47 and SEBT in 89.99 ± 11.28, 97.05 ± 22.66, 95.43 ± 15.66, 80.39 ± 16.20, 88.73 ± 15.06 respectively in group A and 12.03 ± 2.68, 11.42 ± 2.15, 8.71 ± 4.56, 19.11 ± 5.40, 20.47 ± 10.02, 9.47 ± 2.41 and SEBT in 85.18 ± 15.26, 87.30 ± 15.99, 86.79 ± 14.77, 69.79 ± 15.94, 78.17 ± 14.41 respectively in group B.

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(Refer table5.2 and 5.3)
Result of correlation
PEARSON CORRELATIONMEASURE was used for correlation
The following results are obtained:-
The result shows the positive correlation between functional limb length discrepancy and the following variables: hip abductor strength (group A, r = 0.34), hip extensor strength (group A and group B, r =0.44, r = 0.22), hip adductor length (group B, r = 0.22), static balance (group B, r = 0.44) and dynamic balance (group A and group B). (Refer table 5.4, 5.5 & 5.6).
The result shows the negative correlation between functional limb length discrepancy and the following variables : hip abductor strength (group B, r = - 0.28), hip adductor length (group A , r = - 0.21) hip flexor length (group A and group B, r = - 0.29, r = - 0.17), static balance (group A, r = - 0.66), pelvic tilt (group A and group B, r = - 0.25, r = - 0.05) and aerobic fitness (group A and group B, r = - 0.01, r = - 0.27). (Refer table 5.4, 5.5, 5.7 & 5.8).

TABLE-5.1- Description of the subjects

S.NO.	GROUPS	MEAN AGE AND S.D.	NUMBER OF SUBJECTS
1.	A	15±1.13	15
2.	B	19.73±1.22	15

TABLE 5.2 COMPARISON OF MEAN AEROBIC FITNESS, HIP ABDUCTOR STRENGTH, HIP EXTENSOR STRENGTH, HIP ADDUCTOR LENGTH, AND HIP FLEXOR LENGTH BETWEEN GROUP A AND B (Independent t- test)

		AEROBIC FITNESS	HIP ABD STRENGTH	HIP EXT STRENGTH	HIP ADD LENGTH	HIP FLEXOR LENGTH
GROUP	A	46.15 ±5.38	9.32 ±2.81	9.55 ±3.52	18.61 ±4.49	5.27 ±1.87
	B	39.62 ±4.72	12.03 ±2.68	11.42 ±2.15	19.11 ±5.40	8.71 ±4.56
T value		3.59	-2.74	-1.78	-0.28	-2.75
P value		S	NS	NS	NS	NS

P>0.05 Not significant S - Significant
P<0.05 Significant NS - Non- significant

TABLE 5.3 COMPARISON OF MEAN BESS, SEBT AND PELVIC TILT BETWEEN GROUP A & B (INDEPENDENT T- TEST)

GRP	BESS	SEBT								Pelvic Tilt
		ANT	ANT LAT	LAT	POST LAT	POST	POST MED	MED	ANT MED	
A	15.60 ±	89.99 ±	97.05 ±	95.43 ±	100.72 ±	98.22 ±	89.97 ±	80.39 ±	88.73 ±	8.22 ±

	5.96	11.28	22.66	15.66	17.03	18.65	16.58	16.20	15.06	3.47
B	20.47 ± 10.02	85.18 ± 15.26	87.30 ± 15.99	86.79 ± 14.77	85.63 ± 17.36	78.95 ± 16.35	74.81 ± 20.28	69.79 ± 15.94	78.17 ± 14.41	9.47 ± 2.41
T - value	-1.62	0.98	1.851	1.57	2.40	3.01	2.24	1.82	1..96	-1.15
P - value	NS	NS	NS	NS	S	S	S	NS	NS	NS

P>0.05 Not significant S - Significant
P<0.05 Significant NS - Non- significant

TABLE 5.4: Correlation between Functional limb length discrepancy and Hip muscle strength and length

VARIABLE	GROUP	CORRELATION VALUE
HIP ABDUCTOR STRENGTH & FLLD	A	0.34
	B	-0.28
HIP EXTENSOR STRENGTH & FLLD	A	0.44
	B	0.22
HIP ADDUCTOR LENGTH & FLLD	A	- 0.21
	B	0.22
HIP FLEXOR LENGTH & FLLD	A	-0.29
	B	-0.17

TABLE 5.5: Correlation between Functional limb length discrepancy and Static balance

GROUP	CORRELATION VALUE
A	-0.66
B	0.44

TABLE 5.6: Correlation between Functional limb length discrepancy and Dyanamic balance

GROUP	ANT	ANT LAT	LAT	POST LAT	POST	POST MED	MED	ANT MED
A	0.31	0.30	-0.02	0.22	0.27	0.30	0.30	0.32
B	0.09	0.17	0.13	0.12	-0.005	0.03	0.17	0.28

TABLE 5.7: Correlation between Functional limb length discrepancy and PELVICT TILT

GROUP	CORRELATION VALUE
A	-0.25
B	-0.05

TABLE 5.8: Correlation between Functional limb length discrepancy and aerobic fitness.

GROUP	CORRELATION VALUE
A	-0.01
B	-027

Fig. 5.1 COMPARISION OF HIP ABDUCTOR STRENGTH AND HIP EXTENSORS STRENGTH BETWEEN GROUP A AND GROUP B

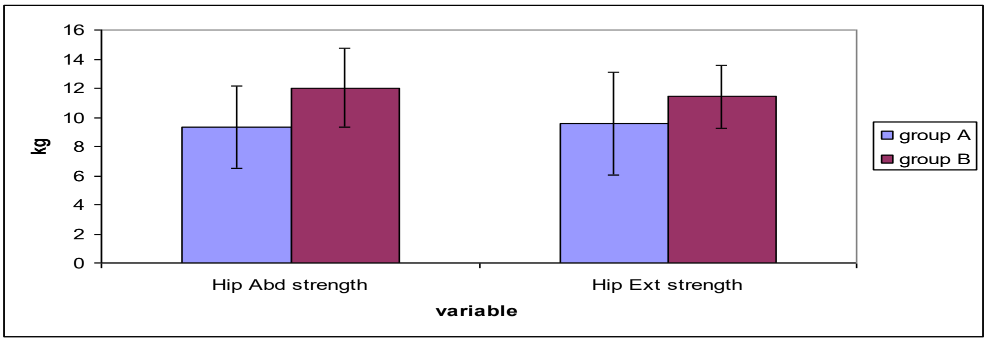


Fig. 5.2 COMPARISION OF HIP ADDUCTOR AND HIP FLEXOR LENGTH BETWEEN GROUP A AND GROUP B

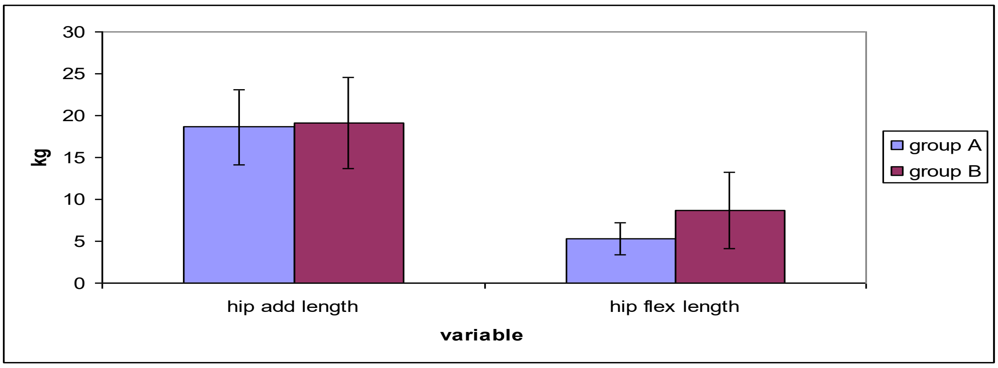


Fig. 5.3 COMPARISION OF BESS SCORE BETWEEN GROUP A AND GROUP B

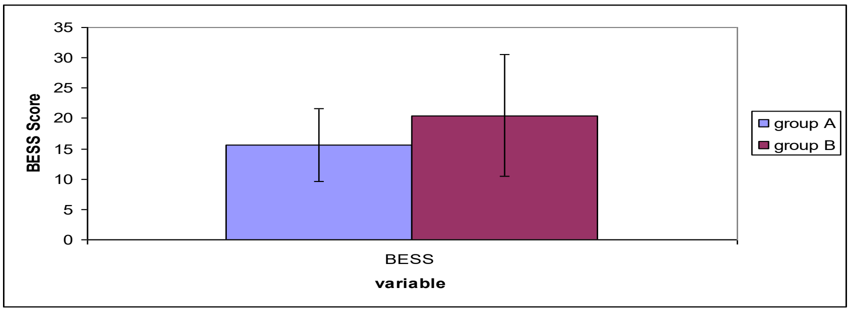


Fig. 5.4 COMPARISION OF SEBT IN DIFFERENT DIRECTIONS BETWEEN GROUP A AND GROUP B

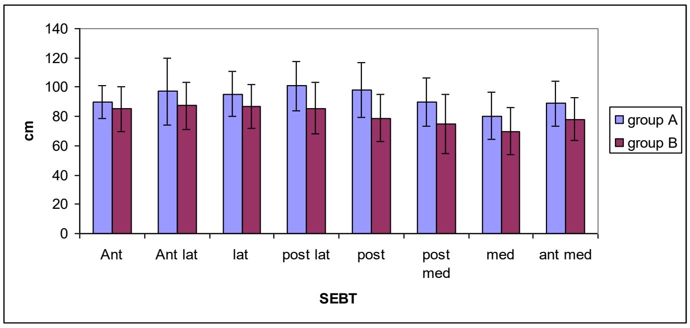


Fig. 5.5 COMPARISION OF PELVIC TILT BETWEEN GROUP A AND GROUP B

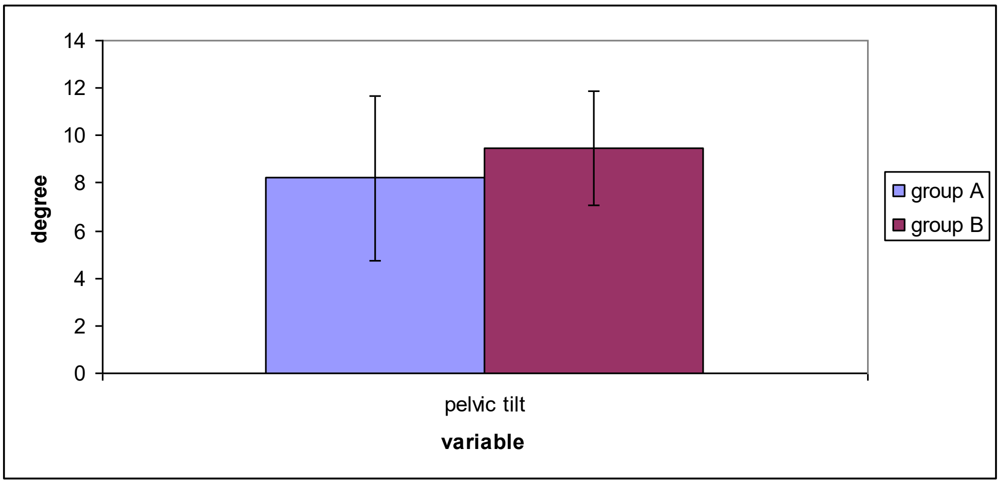


Fig. 5.6 COMPARISION OF AEROBIC FITNESS BETWEEN GROUP A AND GROUP B

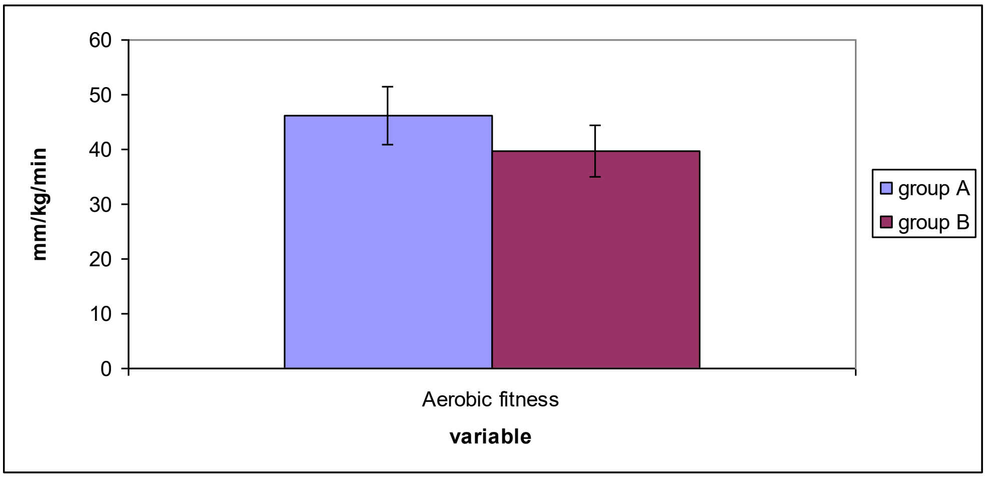


Fig. 5.7 Correlation between FLLD and Hip ABDUCTOR AND HIP EXTENSORS strength IN GROUP A

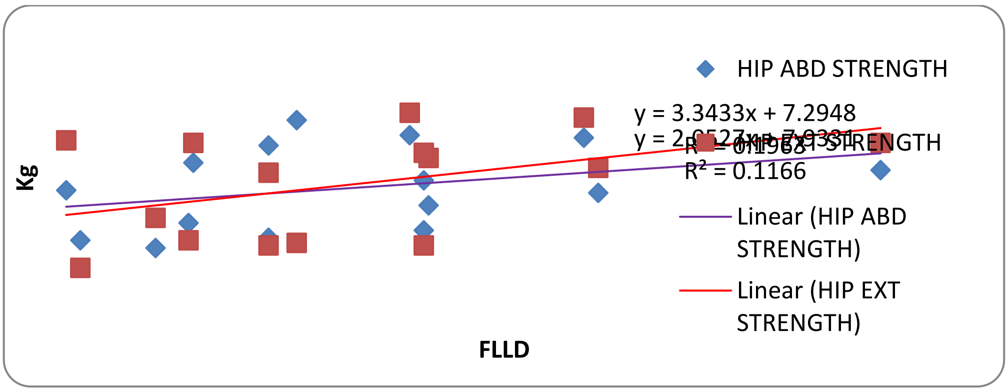


Fig. 5.8 Correlation between FLLD and Hip ADDUCTOR AND HIP FLEXOR LENGTH IN GROUP A

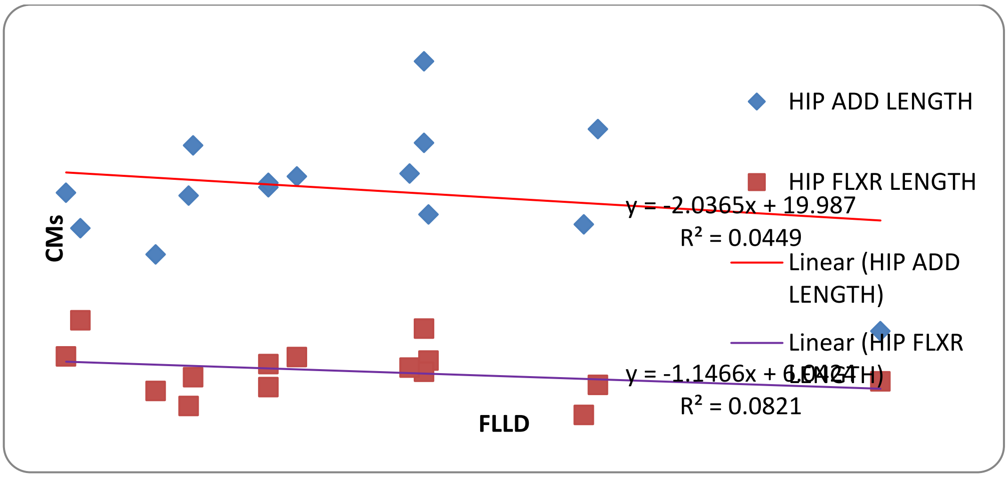


Fig. 5.9 Correlation between FLLD and STATIC BALANCE IN GROUP A

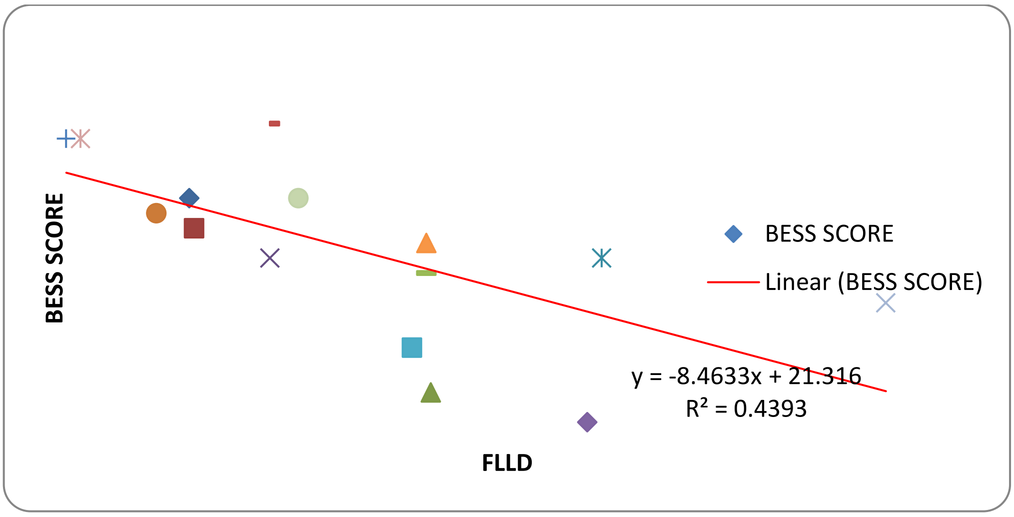


Fig. 5.10 Correlation between FLLD and SEBT (ANT, ANT-LAT DIERECTIONS) IN GROUP A

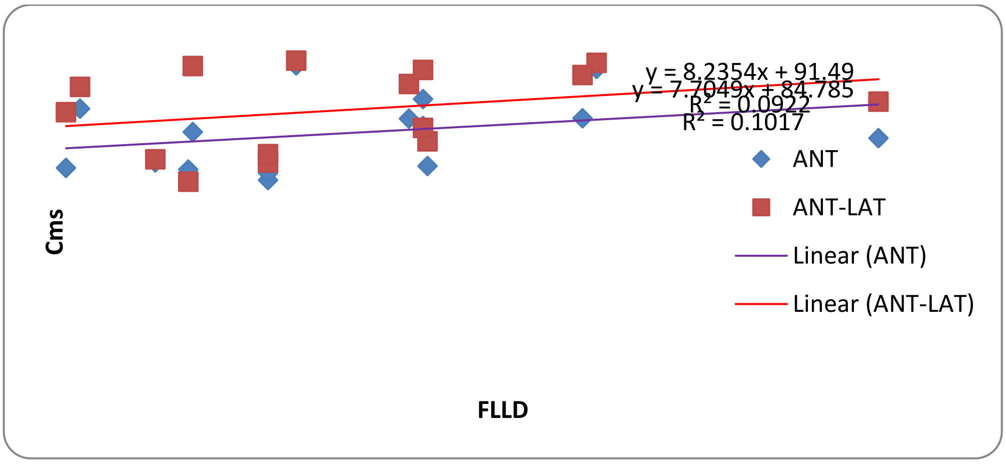


Fig. 5.11 Correlation between FLLD and SEBT (LAT, POST-LAT DIERECTIONS) IN GROUP A

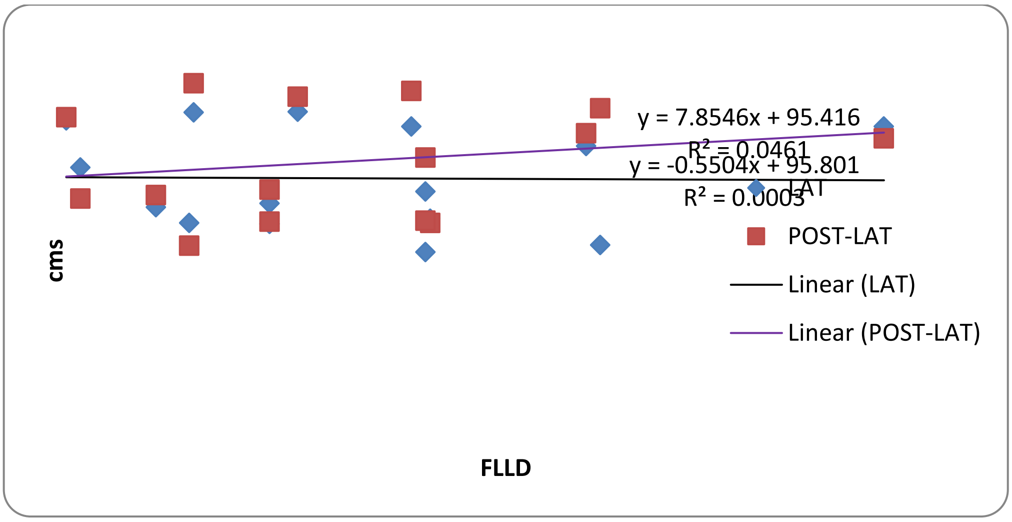


Fig. 5.12 Correlation between FLLD and SEBT (POST, POST-MED DIERECTIONS) IN GROUP A

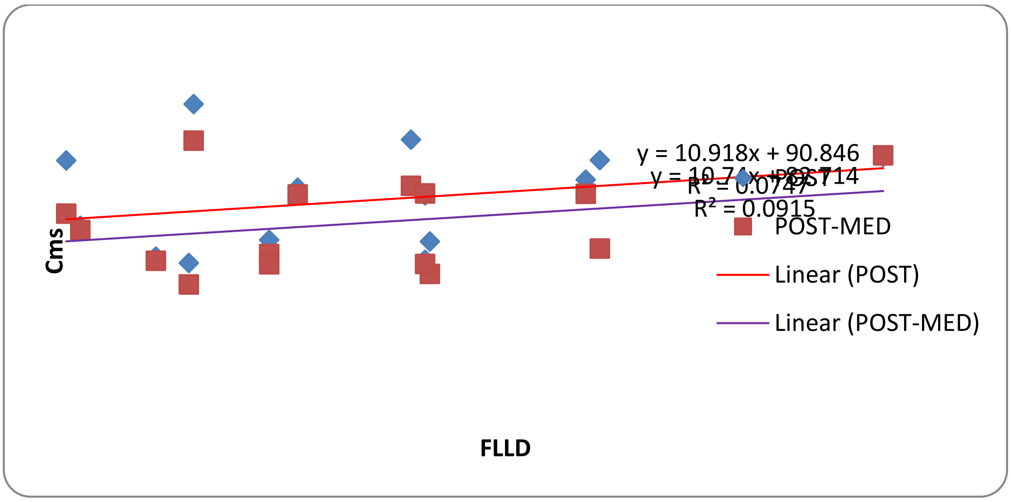


Fig. 5.13 Correlation between FLLD and SEBT (MED, ANT-MED DIERECTIONS) IN GROUP A

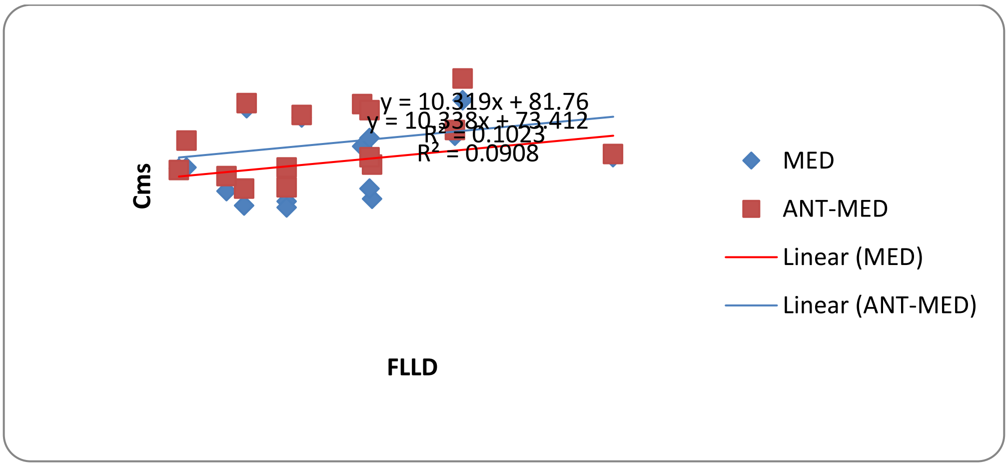


Fig. 5.14 Correlation between FLLD AND PELVIC TILT IN GROUP A

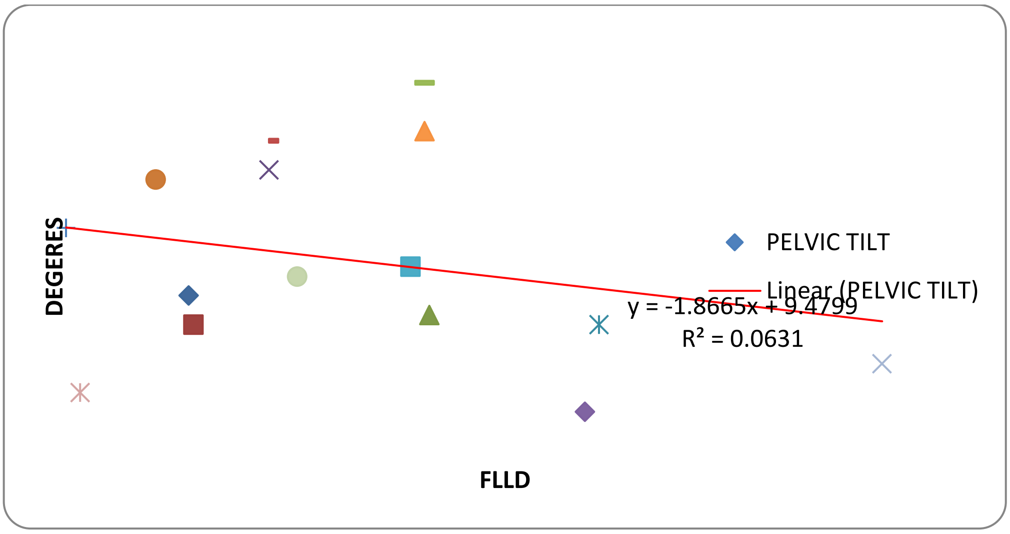


Fig. 5.15 Correlation between FLLD and aerobic fitness IN GROUP A

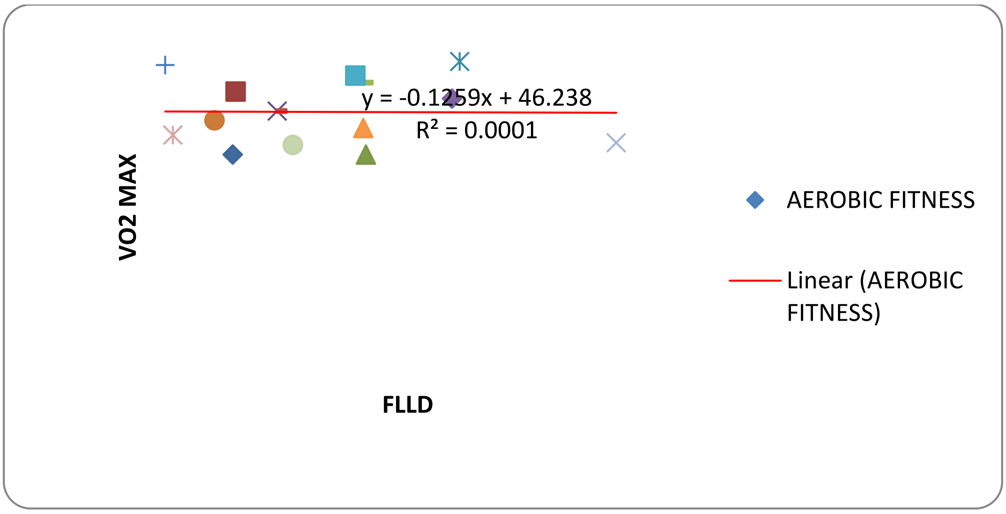


Fig. 5.16 Correlation between FLLD and Hip ABDUCTOR AND HIP EXTENSORS strength IN GROUP B

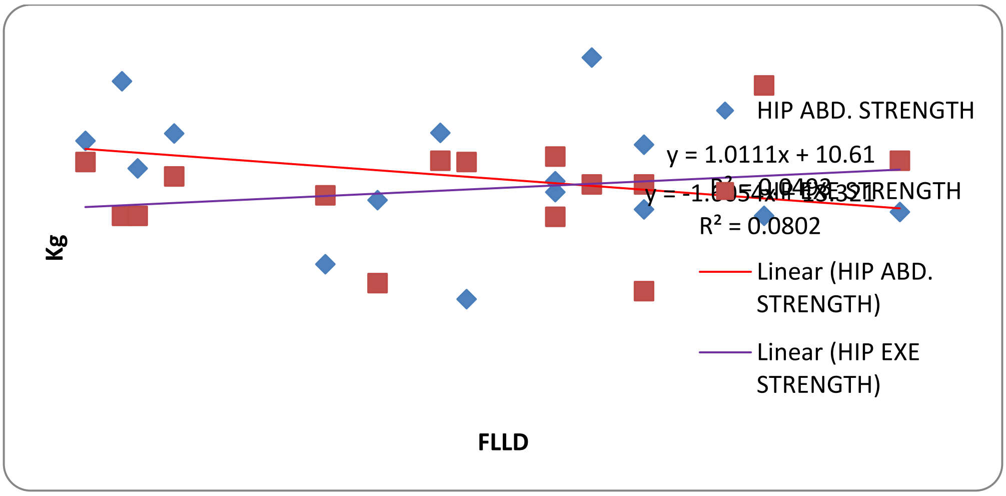


Fig. 5.17 Correlation between FLLD and Hip ADDUCTOR AND HIP FLEXOR LENGTH IN GROUP B

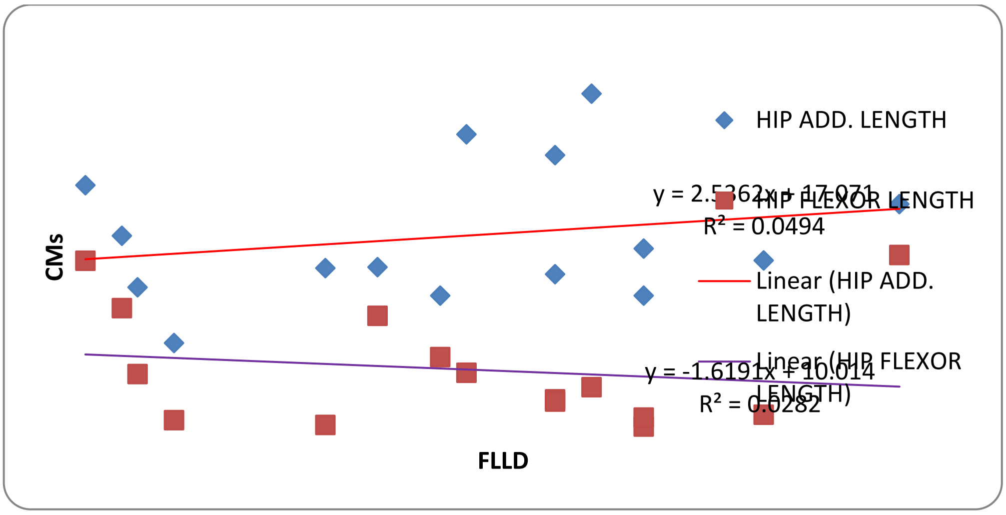


Fig. 5.18 Correlation between FLLD and STATIC BALANCE IN GROUP B

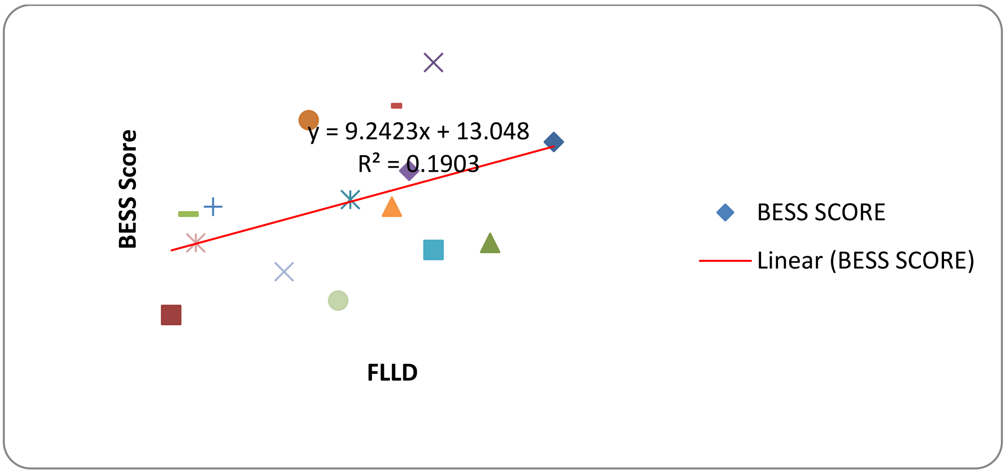


Fig. 5.19 Correlation between FLLD and SEBT (ANT, ANT-LAT DIERECTIONS) IN GROUP B

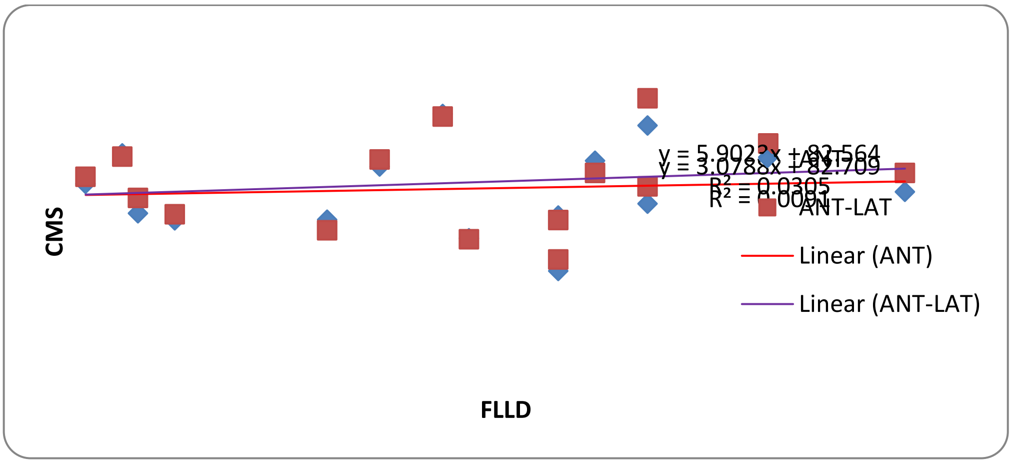


Fig. 5.20 Correlation between FLLD and SEBT (LAT, POST-LAT DIERECTIONS) IN GROUP B

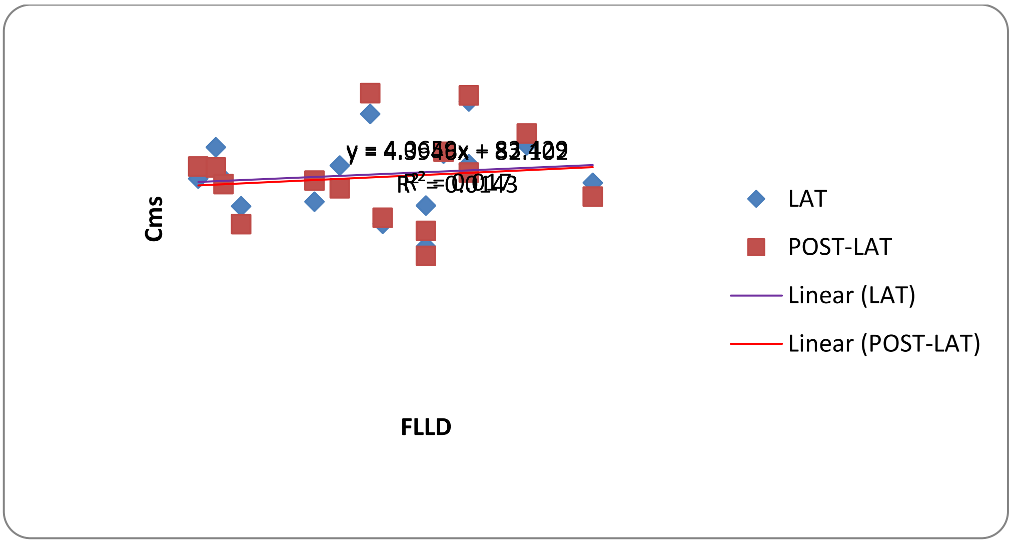


Fig. 5.21 Correlation between FLLD and SEBT (POST, POST-MED DIERECTIONS) IN GROUP B

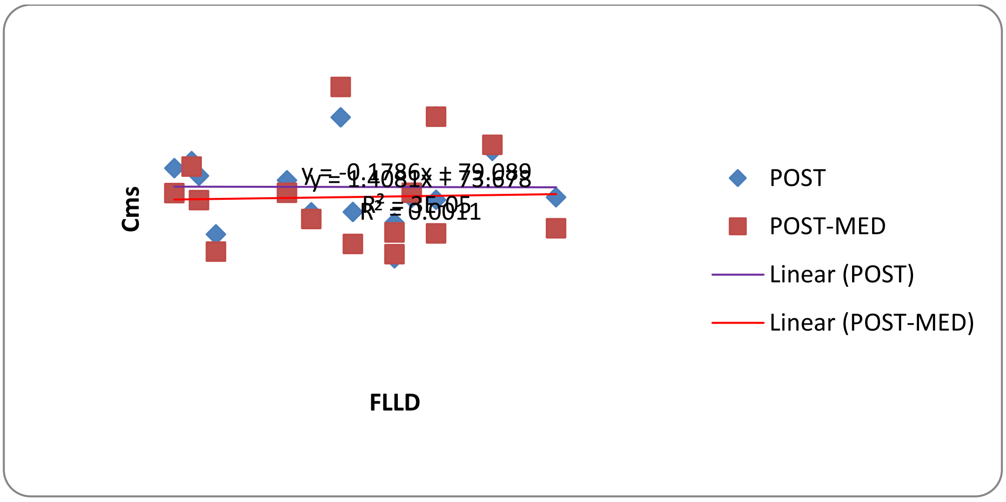


Fig. 5.22 Correlation between FLLD and SEBT (MED, ANT-MED DIERECTIONS) IN GROUP B

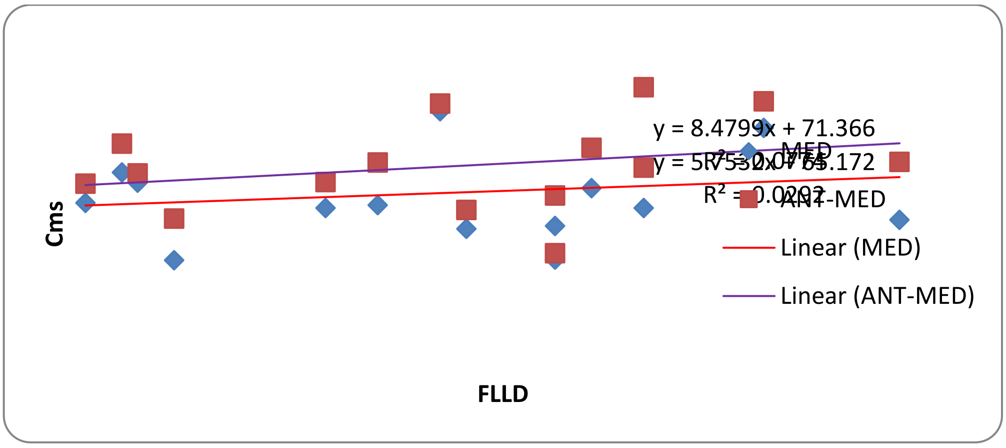


Fig. 5.23 Correlation between FLLD AND PELVIC TILT IN GROUP B

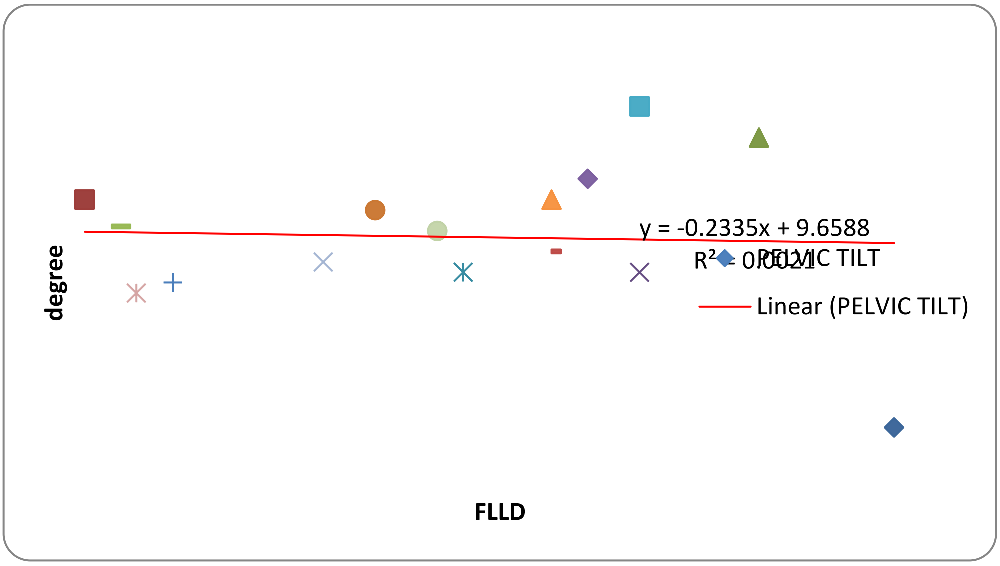
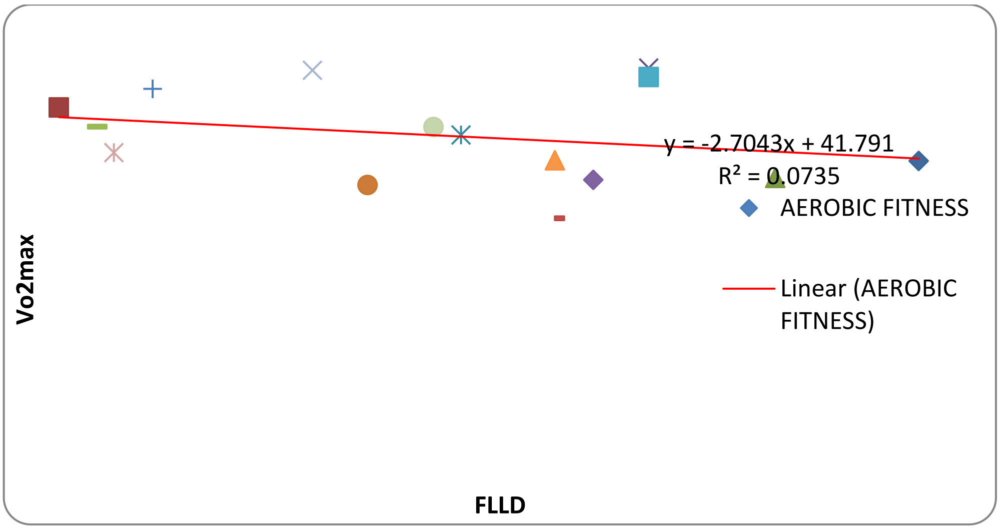


Fig. 5.24 Correlation between FLLD and aerobic fitness IN GROUP B



DISCUSSION

This study employed an experimental design with two groups: Group A (professional athletes) and Group B (recreational athletes). The primary aim was to compare hip muscle imbalance, balance, pelvic tilt, and aerobic fitness between these groups.

Hip Muscle Imbalance

The results indicated **no significant difference** in hip muscle imbalance between professional and recreational athletes with functional limb length discrepancy (FLLD). Pelvic tilt, resulting from an asymmetrical pressure gradient, is a known cause of FLLD. Tight hip flexors exaggerate anterior pelvic tilt, which, according to **Sherrington's law of reciprocal inhibition**, leads to weakness and lengthening of the primary hip extensors. This altered pelvic positioning also affects adjacent muscle groups, often tightening the hip adductors. In turn, these tight adductors inhibit the hip abductors, resulting in further muscular imbalance.

Balance

No significant differences were observed in static and dynamic balance between the two groups. However, FLLD appears to influence balance by creating muscular imbalances. Muscle tightness in one group tends to inhibit the antagonist muscle group (as per Sherrington's law), disrupting stabilization and reducing core strength (as noted by John D. Willson). This can lead to compromised proprioception (Lephart, 1992; Gurney, 2000), disturbed coordination, and impaired muscle-joint function, ultimately affecting balance.

Pelvic Tilt

Similar to balance, **pelvic tilt** did not differ significantly between groups. LLD typically shifts the center of gravity toward the shorter limb, causing compensatory mechanisms such as pelvic tilt to the shorter side. Studies (e.g., Young et al.) have shown that in response to lift-induced discrepancies, the contralateral innominate bone rotates anteriorly and lateral trunk flexion increases toward the lifted side.

Aerobic Fitness

A **significant difference** was found in aerobic fitness between professional and recreational athletes with FLLD. Professional athletes likely benefited from regular, long-term aerobic training, which enhances cardiac volume, heart mass, and overall aerobic capacity. In contrast, recreational athletes typically do not engage in consistent endurance training. Although some studies (e.g., Kern, 1995; Reid et al., 1982) reported no differences in oxygen consumption with or without corrective lifts, others, such as Delacerda and McCrory, observed increased oxygen consumption in individuals with LLD, suggesting greater energy expenditure.

Correlations

In **Group A (professional athletes)**, FLLD showed a **positive correlation** with hip abductor and extensor strength, and a **negative correlation** with hip adductor and flexor length.

In **Group B (recreational athletes)**, FLLD was positively correlated with hip extensor strength and hip adductor length, and negatively correlated with hip abductor strength and hip flexor length.

The probable explanation is that while FLLD and pelvic tilt contribute to muscle imbalance, professional athletes' regular stretching routines may mitigate these effects on muscle length.

Balance and FLLD Correlation

A positive correlation was found between FLLD and both static and dynamic balance in both groups. This aligns with Mahar et al.'s study, which demonstrated that artificially induced LLD increases postural sway. However, Murrell et al. reported contrasting results, attributing the difference to long-term neuromuscular adaptation.

Pelvic Tilt and FLLD Correlation

A **negative correlation** between pelvic tilt and FLLD was found in both groups. Previous literature supports this, indicating that pelvic tilt is both a cause and result of FLLD (Casselli, Roothbart, Young et al.).

Aerobic Fitness and FLLD Correlation

No correlation was found in Group A, while a **negative correlation** was seen in Group B between FLLD and aerobic fitness. These findings are in line with studies suggesting that FLLD may not significantly impact oxygen consumption in trained individuals, whereas untrained individuals might exhibit decreased aerobic efficiency.

LIMITATIONS

Small sample size (n = 30)

Inability to use force plate for balance assessment
Muscle strength could not be measured with a dynamometer
Participants were mostly junior-level players, not elite athletes
No radiographic evaluation was performed

FUTURE SCOPE

Further research can explore:
FLLD correlations in elite and older athletes, female athletes, and specific sports like soccer.
Relationship between FLLD and EMG activity in lower extremity muscles, especially quadriceps and plantar flexors.

CLINICAL IMPLICATIONS

Despite available research, comprehensive assessment and treatment protocols for FLLD are underutilized in clinical settings. This study aims to bridge that gap by connecting risk factors to functional outcomes, helping physiotherapists, athletic trainers, and coaches better understand the cascade of biomechanical consequences due to FLLD. Ultimately, this could lead to more effective assessments, improved treatment strategies, and enhanced athletic performance.

CONCLUSION

This study found that functional limb length discrepancy (FLLD) affects professional and recreational athletes differently. Professional athletes showed better muscle balance and aerobic fitness, likely due to consistent training. FLLD was linked to variations in hip muscle strength, pelvic tilt, balance, and aerobic fitness in both groups. However, professional athletes demonstrated better adaptation to FLLD-related changes than recreational athletes.

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