The aim of the current study was to understand the relationship between core strength and core stability with dynamic balance and jumping performance; respectively, in young adults. It is an observational-correlation one time study. 30 young adults fulfilling the inclusion criteria were taken as subjects for the study by convenience sampling. Body mass index (BMI) was calculated by measuring the weight and height using the formula - kg/ m². Core strength was assessed using the Bent knee lowering test (BKLT) and core stability was assessed using the time to failure prone plank test. The assessment of dynamic balance was done by using Star excursion balance test (SEBT) and measuring the limb length to normalize excursion distances. Jumping performance was assessed by the Vertical jump test. Results show that no significant correlation was found between core strength and dynamic balance (Dominant leg; r= -0.2710, p=0.1474. Non dominant leg; r= -0.1658, p=0.3813), neither between core stability and dynamic balance (Dominant leg, r=0.1589, p=0.4015. Non dominant leg; r=0.1344, p=0.4789). However, significant correlation was seen between core strength and jumping performance(r= -0.4748, p=0.0080) and between core stability and jumping performance (r=0.5884, p=0.0006). Hence, we can infer that jumping performance can be significantly improved by improving the core strength and stability. Dynamic balance correlates poorly with core strength and stability and therefore, needs other factors to be evaluated.

Core strength and stability are also an important factor in execution of ADL which can be evaluated by many of the performance tests, one of them being vertical jump height; an outcome measure for jumping performance. Jumping performance is the maximum vertical height that can be achieved by an individual in a single jump and is required on a daily basis for young adults commuting by bus, train or metro and also for those participating in recreational sporting activities such as basketball, football, volleyball, etc. Poor jumping performance coupled with poor dynamic balance can lead to falls and injuries.

Few studies have investigated the relationship between core stability and athletic performance in professional players. It has been reported that core stability is moderately correlated to strength and performance in division I male football players.13 Thus, increase in core strength is not going to contribute significantly to strength and power and should not be the focus of training programs for footballers. Also Nesser et al (2009)14, reported in a separate study reported that there was no significant relationship between core stability and performance tests such as sprint, vertical jump, squat, and shuttle run in

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female soccer players. In contrast, Okada et al (2011) found significant relationship between core stability and sprinting, vertical jump, and agility in healthy individuals. Sharrock et al (2011), demonstrated in collegiate athletes that of the five tests, i.e., double leg lowering (core stability test), the forty yard dash, the T-test, vertical jump, and a medicine ball throw; only the Medicine ball throw test negatively correlated to the core stability. Thus, there appears to be a link between robust core stability and athletic performance tests; however, more research is needed to provide a definitive answer on the nature of this relationship.

The aim of the current study was therefore to assess the relationship of core strength and core stability with dynamic balance and jumping performance; respectively, in healthy young adults.

MATERIALS AND METHODS

Location and duration of study

This study was conducted at the department of physiotherapy, K.J. Somaiya College of Physiotherapy in Mumbai, which comes under the reputed Maharashtra University of Health Sciences (MUHS, Nashik), Maharashtra state, India. The study was approved by the Institutional Ethics committee. The preliminary synopsis, study design and the process of approval for the same; lasted for three months during the final year of my undergraduate course (BPTh.). The actual administration of the outcome measures on the subjects followed by statistical analysis and results took about 4 months during the period of my internship at the same institution.

Materials Used

- Coloured adhesive tape
- Weighing machine (SI unit- Kg)
- Pencil and Chalk as markers for readings
- Measuring tape
- Pressure biofeedback unit
- Stop watch

Study Design and Grouping

Prospective observational and correlational one-time study design was used. The recruitment of volunteers for the study was based on convenience sampling.

Participants

Thirty eight young healthy adults were identified to take part in the study. The following inclusion and exclusion criteria were applied:

Inclusion Criteria

1. Young adults between the age of 19 to 25 years.
2. Non-exercising subjects (not undergoing any structured athletic/fitness training programme).
3. Normal BMI (18-23 kg/m²).
4. Individuals willing to participate.

Exclusion Criteria

1. Musculoskeletal injury - low back pain, ankle sprain, recent fracture/dislocations, etc.

2. Neurological deficits such as sensory loss, motor deficits, visual loss, etc.
3. Vestibular dysfunctions - vertigo, dizziness.
4. Professional athletes, (undergoing a fixed strengthening and/or endurance training protocol)

Eight individuals had to be eliminated as they either could not fulfill the inclusion criteria or failed to complete the entire study. The remaining 30 individuals completed the study.

Intervention and Procedure

Each Participant underwent a set of measurements and outcome tests as outlined below

Body Mass Index (BMI) – Weight (in kilograms) was measured using a weighing machine and height (in centimeters) using a measuring tape against a wall.

\[ \text{BMI} = \frac{\text{weight (kg)}}{\text{height}^2 (\text{cm})} = \text{kg/m}^2. \]

Core Strength

Core strength was determined by Bent Knee Lowering Test (BKLT) using a pressure biofeedback device.\(^7,8\)

**Step I:** Volunteer lied supine with hips and knees at 90 degrees of flexion (checked with a Goniometer) and a pressure biofeedback cuff was inflated to 40 mmHg and placed under the L4-L5 vertebræ.

**Step II:** The volunteer was then asked to perform an abdominal hollowing (drawing-in) manoeuvre while maintaining the 40 mmHg pressure. During this step, participants were positioned supine with knees bent to 45 degrees.

**Step III** (Bent knee lowering phase): The participant lowered both the legs towards the plinth / bed until the therapist and the participant noted a visual change on the pressure cuff indicating a change in pelvic position. (Hip angle was measured at this point).

To arrive at the result, the participant undertook two practice trials and three attempts, and the best score out of the three attempts was taken. The strength scoring scale was used as described in Table 1.

**Table 1** Strength Scoring Scale for the Bent Knee Lowering Test

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Able to reach 0-15 degrees from the plinth before the pelvis tilts</td>
</tr>
<tr>
<td>4</td>
<td>Able to reach 16-45 degrees from the plinth before the pelvis tilts</td>
</tr>
<tr>
<td>3</td>
<td>Able to reach 46-75 degrees from the plinth before the pelvis tilts</td>
</tr>
<tr>
<td>2</td>
<td>Able to reach 76-90 degrees from the plinth before the pelvis tilts</td>
</tr>
<tr>
<td>1</td>
<td>Unable to hold the pelvis in neutral</td>
</tr>
</tbody>
</table>

Core Stability

Core stability was determined using the single time to failure prone plank holding test.\(^9\)

The plank test is a simple test to measure core muscle stability and measures the control and endurance of the core muscles. Participants lay down prone on a flat surface. They raised the upper body supported off the ground by the elbows and

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**Note:** The page number mentioned at the bottom of the document is 38855. The page number in the content is not relevant to the text. The page number in the document is 38.
forearms, with the legs straight and the weight taken by the toes. The hip was lifted off the floor creating a straight line from head to toe. As soon as the participant was in the correct position, the stopwatch was started. The test was over when the participant was unable to hold the back straight and the hip was lowered. The score was the total time taken by the participant to complete the test in the correct alignment. To arrive at the result, the participant undertook one practice trial and one attempt and the score of the attempt were recorded. The score grading of core stability was done according to Table 2 as shown below.

### Table 2 Score grading of core stability

<table>
<thead>
<tr>
<th>Rating</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>&gt; 6 minutes</td>
</tr>
<tr>
<td>Very Good</td>
<td>4-6 minutes</td>
</tr>
<tr>
<td>Above</td>
<td>2-4 minutes</td>
</tr>
<tr>
<td>Average</td>
<td>1-2 minutes</td>
</tr>
<tr>
<td>Below average</td>
<td>30-60 seconds</td>
</tr>
<tr>
<td>Poor</td>
<td>15-30 seconds</td>
</tr>
<tr>
<td>Very poor</td>
<td>&lt; 15 seconds</td>
</tr>
</tbody>
</table>

**Dynamic Balance**

The dynamic balance of participants was evaluated with the Star Excursion Balance Test (SEBT) [10,11,12]. Limb length was measured from the anterior superior iliac spine to the most prominent bony point of the ipsilateral medial malleolus with a standard measuring tape while subjects were lying supine on a bed.

The reach directions were determined by affixing coloured adhesive tape to the floor, one orientated anterior to the apex (A) and two aligned at 135° to this in the posteromedial (PM) and posterolateral (PL) directions. The length of the tape in each of the three directions was 122 cms.

Each subject was instructed to reach as far as possible with the non-dominant leg in each of the 3 directions while maintaining dominant-leg stance.

To arrive at the result, the participants undertook two practice trials and three attempts with each leg (both dominant and non-dominant).

**The trial was not counted and repeated if**

1. The participant was unable to maintain Single Leg Stance (SLS).
2. The heel of the stance foot does not remain in contact with the floor.
3. Weight was shifted onto reach foot.
4. The reach foot does not touch the line.
5. The participant does not maintain start and return positions for one full second.

The farthest reach distance in each direction was recorded in centimetres (cm). Reach distances were then normalized by limb length [13], as per the following formula:

\[
\text{Relative/normalised distance in each direction (\%)} = \frac{\text{Average distance in each direction}}{\text{limb length}} \times 100
\]

The average of all the 3 directions for both the dominant and non-dominant leg was also calculated for statistical convenience.

**Jumping Performance**

Jumping height of participants was measured by the vertical jump test [14]. Reach height was measured for all participants prior to Vertical jump testing. The participants were made to stand without shoes and reach as high as possible with one arm without jumping or toe standing and mark a point with a pencil / chalk (reach point). Participants were then instructed to bend slightly from the knees and then jump off with both feet and reach as high as possible with one arm (jump point). The highest point reached was marked by a pencil / chalk.

Then the difference between the reach point and jump point was measured and recorded. To arrive at the results, the participants undertook three attempts with a 30 second pause between each attempt and the best score out of the three attempts was taken.

**Statistical Analysis**

All Data was computed and analyzed using Graph Pad Instat software version 3.10.

Pearson’s correlation test was used for correlating those variables that passed the normalcy test.

Spearman’s correlation test was used for correlating those variables that did not pass the normalcy test.

**Table 3 Mean and standard deviation of variables**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Passed normalcy test?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (in years)</td>
<td>21</td>
<td>1.59</td>
<td>No</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>20.47</td>
<td>1.6</td>
<td>Yes</td>
</tr>
<tr>
<td>Core strength (hip angle in degrees)</td>
<td>84.7</td>
<td>4.49</td>
<td>No</td>
</tr>
<tr>
<td>Core stability (seconds)</td>
<td>40.866</td>
<td>25.52</td>
<td>Yes</td>
</tr>
<tr>
<td>SEBT COM (cm) Dominant leg</td>
<td>81.84</td>
<td>12.42</td>
<td>Yes</td>
</tr>
<tr>
<td>SEBT COM (cm) Non-dominant leg</td>
<td>83.72</td>
<td>13.45</td>
<td>No</td>
</tr>
<tr>
<td>Vertical jump (cm)</td>
<td>28.6</td>
<td>7.233</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**RESULTS**

**Flow of Participants through the study**

Thirty normal adults completed the study out of 38 individuals who were initially recruited. 8 subjects had to be excluded for inability to complete the protocols or for not fulfilling the inclusion criteria. Subjects were both males and females selected via random convenience sampling, with a mean age of 21 years (Range: 19 to 25). The mean BMI, core strength, core stability, SEBT and vertical jump are summarised in Table 3 as depicted above.

**Correlation**

There was no significant correlation between core strength and dynamic balance (dominant and non-dominant leg) as seen in Table 4 and illustrated in Figure 1.

Jumping performance correlated negatively with the hip angle, with a significant p-value as seen in Table 5 and illustrated in Figure 2. Since hip angle bears an inverse relation with core strength, it can be deduced that jumping performance improves with improvement in core strength.

There was no significant correlation between core stability and dynamic balance for dominant and non-dominant leg as seen in
Table 6 (a) & (b) and illustrated in Figure 3. Jumping performance correlated positively with core stability, with a significant p-value as seen in Table 7 and illustrated in Figure 4, thus suggesting that improving core stability improved the jumping performance. When we looked at core strength and core stability, we found a statistically significant correlation with a p-value of 0.002, suggesting that improvement in core strength improved core stability. (Table 8, Figure 5).

Although dynamic balance had a positive correlation with vertical jump performance, the result was not statistically significant for both the dominant and non-dominant leg. (Table 9, Figure 6)

Table 4 Correlation between core strength and dynamic balance (dominant leg and non-dominant leg) using Spearman’s (non-parametric) test.

<table>
<thead>
<tr>
<th>Core Strength (hip angle in degrees)</th>
<th>SEBT: dominant leg (cm)</th>
<th>r-value</th>
<th>p-value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean 84.7 SD 4.49</td>
<td>Mean 81.84 SD 12.42</td>
<td>-0.2710</td>
<td>0.1474</td>
<td>Not significant</td>
</tr>
</tbody>
</table>

Table 5 Correlation between core strength and jumping performance using Spearman’s (non-parametric) test.

<table>
<thead>
<tr>
<th>Core Strength (hip angle in degrees)</th>
<th>Vertical jump (cm)</th>
<th>r-value</th>
<th>p-value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean 84.7 SD 4.49</td>
<td>Mean 28.6 7.233</td>
<td>-0.4748</td>
<td>0.0080</td>
<td>Very significant</td>
</tr>
</tbody>
</table>

Table 6 (a) Correlation between core stability and dynamic balance (dominant leg) using Pearson’s (parametric) test.

<table>
<thead>
<tr>
<th>Core Stability: prone plank hold (sec)</th>
<th>SEBT: dominant leg (cm)</th>
<th>r-value</th>
<th>p-value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean 40.866 25.52</td>
<td>Mean 81.84 SD 12.42</td>
<td>0.1589</td>
<td>0.4015</td>
<td>Not significant</td>
</tr>
</tbody>
</table>

Table 6 (b) Correlation between core stability and dynamic balance (non-dominant leg) using Spearman’s (non-parametric) test.

<table>
<thead>
<tr>
<th>Core Stability: prone plank hold (sec)</th>
<th>SEBT: non-dominant leg (cm)</th>
<th>r-value</th>
<th>p-value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean 40.866 25.52</td>
<td>Mean 83.72 13.45</td>
<td>0.1344</td>
<td>0.4789</td>
<td>Not significant</td>
</tr>
</tbody>
</table>

Table 7 Correlation between core stability and jumping performance using Pearson’s (parametric) test.

<table>
<thead>
<tr>
<th>Core Stability: prone plank hold (sec)</th>
<th>Vertical jump (cm)</th>
<th>r-value</th>
<th>p-value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean 40.866 25.52</td>
<td>Mean 28.6 7.233</td>
<td>0.5884</td>
<td>0.0006</td>
<td>Extremely significant</td>
</tr>
</tbody>
</table>

Table 8 Correlation between core strength and core stability using Spearman’s (non-parametric) test.

<table>
<thead>
<tr>
<th>Core Strength (Hip angle)</th>
<th>Core stability: prone plank hold (sec)</th>
<th>r-value</th>
<th>p-value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean 84.7 SD 4.49</td>
<td>Mean 40.866 25.52</td>
<td>-0.5414</td>
<td>0.0020</td>
<td>Very significant</td>
</tr>
</tbody>
</table>

Table 9 Correlation between vertical jump and dynamic balance (dominant leg) using Pearson’s (parametric) test.

<table>
<thead>
<tr>
<th>Vertical jump (cm)</th>
<th>SEBT dominant leg (cm)</th>
<th>r-value</th>
<th>p-value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean 28.6 SD</td>
<td>Mean 81.84 SD 12.42</td>
<td>0.08682</td>
<td>0.6483</td>
<td>Not significant</td>
</tr>
</tbody>
</table>

Table 10 Correlation between jumping performance and dynamic balance (non-dominant leg) using Spearman’s (non-parametric) test.

<table>
<thead>
<tr>
<th>Vertical jump (cm)</th>
<th>SEBT non-dominant leg (cm)</th>
<th>r-value</th>
<th>p-value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean 28.6 SD</td>
<td>Mean 83.72 13.45</td>
<td>-0.03652</td>
<td>0.8481</td>
<td>Not significant</td>
</tr>
</tbody>
</table>

Figure 1 Graph showing negative correlation between core strength and dynamic balance (dominant leg – above and Non-dominant leg – below) which is not significant.

Figure 2 Graph showing significant negative correlation between hip angle and vertical jump.
Figure 3 Graph showing statistically insignificant positive correlation between core stability and dynamic balance for dominant leg.

Figure 4 Graph showing a significant positive correlation between core stability and jumping performance.

Figure 5 Graph showing a significant negative correlation between hip angle and core stability. (Since hip angle bears an inverse relation to core strength, core stability has positive correlation with core strength).

Figure 6 Graph showing statistically insignificant positive correlation between jumping performance and dynamic balance for dominant leg.

Graph showing statistically insignificant positive correlation between core stability and dynamic balance for non-dominant leg.

Graph showing statistically insignificant positive correlation between jumping performance and dynamic balance for non-dominant leg.
DISCUSSION

Core strength and Dynamic Balance

According to this study, no significant correlation was found between core strength (CS) and dynamic balance. The BKLT[8,15] includes the abdominal hollowing manoeuvre in order to measure the core strength (using Pressure biofeedback unit)[9] of the lower abdominal musculature. Specifically, and as utilized during the BKLT, the abdominal hollowing manoeuvre is the most typical manoeuvre used to activate the Transversus Abdominis (TA) muscle.[16] Further, abdominal hollowing has been shown to demonstrate the least amount of global muscle involvement, as compared to bracing and pelvic tilt where rectus abdominis and external oblique are used in conjunction with TA.[16,17]

However, as the muscle activation of all the core musculature was not measured or recorded, it is difficult to report that only the TA muscle was activated and not the other global core muscles (such as rectus abdominis, internal and external oblique) while performing BKLT. The average BKLT score of this study's participants was 84.7 degrees (classified as poor or grade 2/5 MMT of the lower abdominals).[16] While performing SEBT, if the global stabilizers were also activated (i.e., abdominal hollowing manoeuvre is not done correctly due to poor core strength), the readings of SEBT may not correlate with that of core strength. This can be one of the explanation for negative correlation between core strength and dynamic balance in our study. Further to these findings, Ozmen T et al (2016)[18] reported that 6 weeks of core strength training in badminton players resulted in significant gains in directions of SEBT and core endurance thus improving the dynamic balance.

Core stability and dynamic balance

This study found that there was no correlation between core stability and dynamic balance. The dynamic balance of participants was evaluated using SEBT with selected directions (namely, anterior, posterior-lateral and postero-medial). The SEBT is a quick and inexpensive method commonly used by many researchers to identify dynamic balance deficits and the responsiveness to training programs in young healthy adults with and without injuries to the lower extremity.[13] The SEBT performance may be affected by kinetic and kinematic factors such as the range of motion of the knee and hip joints, flexibility, the speed with which the movement is performed and strength of the lower extremity muscles.[12,15] In addition, postural control and maintenance of balance is a complex process for which different systems work collectively which includes the central nervous system comprising brain and spinal cord, peripheral nervous system comprising afferent and efferent pathways, musculoskeletal system, sensory system composed of a variety of sensory receptors, and visual system. In all, precise integration of nervous system function and musculoskeletal system will affect the performance during SEBT.[12] In consistence with the results of this study, Gordon et al (2013)[19] reported that core stability did not affect SEBT values in female lacrosse players. Shah et al (2014)[20] found that 6 weeks of core stability training significantly improved the dynamic balance as assessed by SEBT in normal healthy volunteers compared to a control group which did not undergo core stability training.

Core strength, stability and jumping performance

The jumping performance requires explosive power of lower extremity muscles including activation of the fast twitch muscle fibres. This study found a significant negative correlation between hip angle with jumping performance (i.e. a positive relationship between core strength and jumping performance) and a significant positive correlation between core stability and jumping performance.

The reason for this maybe that the act of jumping is a full body movement. The generation of power starts in the lower body before jumping. During this phase there is lowering of arms and bending of the knees. Then as the participant ascends, the power is transferred back up from the legs via the core and into the arms, to provide maximum upward momentum and lift. During both the descent and ascent phase, it is the core that is responsible for the efficient transfer of energy between the upper and lower body. If the core is unable to effectively handle this transfer of energy, i.e. if the core is weak, the participant would generate less momentum which would eventually result in lower heights being reached. This was in contrast to the findings of previous authors. Sharrock et al (2011)[6] demonstrated that there was no significant relationship between core stability and agility, vertical jump, sprint performance in basketball, volleyball, soccer, tennis players and swimmers.

Core strength and core stability

This study has additionally also found a direct negative correlation between the hip angle with the core stability i.e. there is positive relationship between core strength and core stability. This may be due to the same muscle groups being activated during BKLT (which is the measure of core strength) and the prone plank holding test (which is the measure of core stability).

Dynamic balance and jumping performance

As there was no significant correlation of core strength and stability with dynamic balance, thus, jumping performance also did not show any significant correlation with dynamic balance.
Limitations and Strength

Our study was limited by a small sample size (n=30). The order of outcome measures and the SEBT trials were not randomized and finally we did not specifically measure differential activation of global and local core muscles. We, however, feel that our study does contribute to improving the understanding of correlation between core strength and stability with dynamic balance and vertical jump performance in a healthy normal non-sporty population. Future study can be aimed at seeing the result of improved core strength and stability by exercise programs on dynamic balance and jump performance using a larger sample size.

CONCLUSION

Hence, we can infer that there is a significant correlation between both core strength and core stability with jumping performance; respectively, thus suggesting that improving the core stability & strength can improve jumping performance in young adults.

However, this study did not find a significant correlation between both core strength and core stability with dynamic balance and there needs to be evaluation of other factors to correlate with dynamic balance such as proprioception, lower limb strength and so forth.

References