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OPTIMIZING UTKATASANA POSTURE STABILITY FOR MENTAL STRESSED STUDENTS: A MATHEMATICAL INTERPRETATION OF ACADEMIC STRESS MANAGEMENT APPROACH

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Objective:
The objective of this study is to develop and evaluate a mathematical model for Utkatasana, focusing on the interactions between muscles and joints during the pose. The study aims to assess the accuracy of a real-time pose recognition simulation system by comparing its joint angle measurements to those obtained through traditional goniometer methods. Additionally, the research seeks to analyse the impact of Utkatasana on stress reduction by evaluating changes in systolic blood pressure and respiration rates in both an experimental group practicing Utkatasana and a control group. Through these assessments, the study aims to determine the effectiveness of Utkatasana in improving balance, posture stability, and stress management.

Design/Methodology/Approach
The study emphasizes maintaining correct posture during Utkatasana, which is controlled by the body's center of gravity. A mathematical model of human kinetic movement was developed and analysed using both simulation software and traditional goniometer measurements. The proposed simulation system was designed to monitor body movements in real-time, calculating joint angles to ensure pose accuracy. An independent samples t-test was conducted to compare the accuracy of the simulation system with traditional goniometer measurements. Additionally, the study examined Utkatasana impact on stress reduction by evaluating changes in systolic blood pressure and respiration rates. The initial sample of 15 participants was expanded in a second experiment by adding 15 participants to create a control group, resulting in a total of 30 participants. A Mann-Whitney U test was used to assess pre- and post-test systolic blood pressure and respiration rates in both the experimental group practicing Utkatasana and the control group, providing insights into the pose's effectiveness in stress management

Result/Findings
The study demonstrated that the human simulation system effectively detects joint points and measures angles in real-time, providing reliable assessments of Utkatasana poses. The independent samples t-test showed no statistically significant differences between the simulation system and traditional goniometer measurements for various joints, such as dorsiflexion ($F(1, 28) = 0.242$, $p = 0.627$) and knee ($F = 0.007$, $p = 0.934$). Similarly, hip and shoulder measurements also indicated no significant differences, validating the accuracy of the simulation system. The Mann-Whitney U test revealed no significant difference between the experimental and control groups at the pre-test phase for systolic blood pressure ($U = 100.000$, $p = 0.602$) and respiration rate ($U = 111.500$, $p = 0.967$). However, post-test results showed significant reductions in systolic blood pressure ($U = 33.000$, $p = 0.001$) and respiration rate ($U = 34.000$, $p = 0.001$) for the experimental group practicing Utkatasana, while no significant changes were observed in the control group. These findings highlight Utkatasana's effectiveness in reducing stress-related physiological parameters and its potential benefits for neuromuscular health. The simulation system’s accurate real-time pose recognition further supports its application in both online and offline practice settings

Research Limitations/Implications:
The initial sample size of participants limits the generalizability of the findings. Future studies should include larger, more diverse groups and explore other yoga poses to enhance understanding of yoga's effects on physiological and psychological health. Although the simulation system demonstrated accuracy, further research is needed to assess its applicability in different settings. The second experiment with 30 participants revealed significant reductions in post-test systolic blood pressure and respiration rates for the Utkatasana group.

1.INTRODUCTION

Yoga, originating over 5,000 years ago in the Indian subcontinent, has evolved into a significant mind-body practice recognized for its therapeutic benefits. Its name, derived from the Sanskrit "yuj," meaning "union," embodies the practice's aim to unite individual consciousness with the universal spirit. Maharishi Patanjali and Sidthar Thirumoolar both of as known the "Father of Yoga," organized and systematized these practices in his "Yoga Sutras" and "Thirumanthiram" where their introduced Ashtanga Yoga [1][2][3], an eight-fold path for holistic personal growth. In recent years, yoga has gained attention as a complementary and alternative therapy, particularly following endorsement by the World Health Organization in developing countries [4][5]. Scientific interest has spurred rigorous studies and clinical trials exploring yoga's efficacy in enhancing overall health, preventing diseases, and managing chronic conditions. Notably, yoga has shown effectiveness in reducing non-motor symptoms, improving physiological health, and managing stress[6][7][8]. Utkatasana, or Chair Pose, is a key "Standing Asana" that strengthens the Shoulder, hips, and thighs while improving balance by engaging the core muscles. This underscores yoga's role as a valuable intervention for improving motor skills, balance, strength, and flexibility, ultimately contributing to overall well-being Figure 1 illustrates a tree map of Utkatasana, placing it within the category of "Standing Asanas," which encompasses all upright postures. In this classification, Utkatasana, also known as Chair Pose, is included.

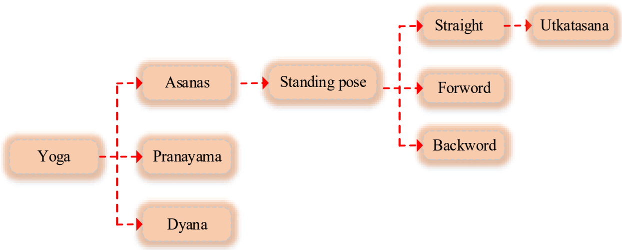


Fig. 1. Tree map of Utkatasana[17]

Lower and upper limb joint moments in the sagittal plane have been the focus of numerous studies, and this research aimed to analyse the movements involved in Utkatasana. Given the connection of these movements to stress and physiological disorders, they were deemed appropriate for assessing segmented trunk models. Utkatasana, also known as Chair Pose , is widely recognized for strengthening the muscles in the lower legs. The pose, which translates to "powerful pose" in Sanskrit, is a demanding asana that requires a balance of effort between the upper and lower body. It promotes mental focus and perseverance. The pose is performed by bending the knees and hips as though sitting in an invisible chair, and then returning to the initial standing position. This asana primarily engages the quadriceps, hamstrings, gluteus maximus, gastrocnemius, tibialis anterior, soleus, and other muscles in the lower body. Throughout a full cycle of Utkatasana, movements involve a vertical descent, holding the lowered position, rising back up, and returning to a neutral stance[9][10][11][12].

The "Sun Salutation" is a sequence of twelve yoga postures that balance flexion and extension, synchronized with breathing and aerobic activity, often recommended for its clinical benefits. Similarly, Utkatasana, or Chair Pose, is a dynamic standing posture that engages multiple muscle groups to enhance strength, stability, and balance. Both sequences involve precise alignment and controlled movements, highlighting the need to understand the biomechanical forces at play. Developing a mathematical model, similar to that for Sun Salutation, could help analyse Utkatasana's impact on joint health and overall conditioning, ensuring submaximal joint loading for optimal musculoskeletal health[13][14][15]. Understanding the biomechanics of the center of gravity (COG) and base of support (BOS) is crucial for stability in physical activities like yoga. In Utkatasana (Chair Pose), the body's weight must be evenly distributed across both feet to maintain balance, as shifting the center of gravity outside the base of support can lead to instability. Proper alignment ensures safety and minimizes the risk of falls. Therefore, awareness of COG and BOS is essential for performing Utkatasana and other exercises effectively[16][17][18]. AI software, leveraging computer vision and data science techniques, acts as a virtual yoga trainer by providing feedback on pose accuracy and benefits. It utilizes machine learning and deep learning models, trained on extensive image datasets of yoga poses. Using the tf-pose algorithm, the software creates a skeletal representation of the body by marking and connecting joints, allowing for precise angle measurements. These angles are then used as features in various machine learning models to assess the accuracy of the pose, enabling users to practice yoga effectively without needing a physical trainer[19][20][21][22]. Our research Similarly, Utkatasana can benefit from mathematical modelling and simulation methods. By applying AI and machine learning techniques, the pose can be analyzed with precision, allowing the creation of a detailed mathematical model. This model can simulate the posture, balance, and alignment needed for Utkatasana, helping practitioners understand the correct form. The simulation method, combined with AI feedback, can guide users in real-time, ensuring accurate practice and reducing the risk of injury. Practicing Utkatasana is expected to lead to noticeable reductions in systolic blood pressure and respiratory rate, indicating positive effects on physiological health[23][24][25].

2. METHOD & MATERIALS

Gravitational forces impact all objects, and biomechanics explore how these forces influence the body's structure and movement. In Utkatasana, joint positioning is crucial, as effective movement relies on the coordination of the musculoskeletal system, including bones, muscles, and joints. Stability is primarily determined by the body's center of gravity (COG), which is influenced by factors such as the horizontal distance from the edge of support, base of support size, body weight, COG height, and base orientation relative to force. This research developed a mathematical model to represent each phase of Utkatasana, applying mechanical principles to calculate forces and joint moments.

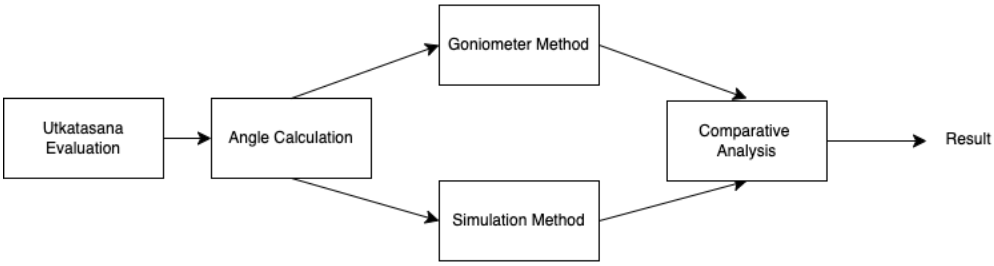


Fig.2.Posture Evaluation Technique: Flow Diagram

Figure 2 illustrates the primary goal of this study, which is to demonstrate the effectiveness of teaching yoga, specifically Utkatasana, through offline and online methods. To evaluate Utkatasana performance, we measured the angles of the musculoskeletal system using both the traditional Goniometer method and a simulation method. A comparative analysis was then conducted to assess the accuracy and reliability of the results obtained from each approach[26][27].

2.1 Position of Utkatasana Human Rigid Body

Figure 3 illustrates that with proper training and technique, individuals can perform Utkatasana (Chair Pose) safely and at full depth without risking joint injury. Start in Tadasana (Mountain Pose), then bend your knees and, while inhaling, shift your hips back as if sitting in a chair, engaging your core to protect your lower back. Focus on moving the hips back so your knees don’t extend past your toes. Extend your arms alongside your ears, inhale, and relax your shoulders. Hold the pose for 15–20 breaths, then straighten your legs while inhaling, returning your hands to your sides to complete the pose. This method promotes correct alignment and prevents injury, ensuring the benefits of Utkatasana[28][29].

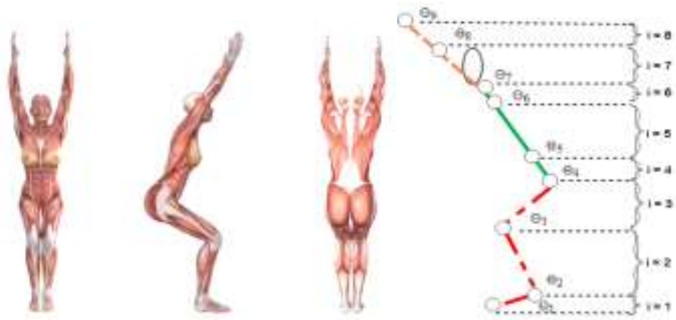


Fig. 3 Position of Utkatasana Human Rigid Body

2.2 Measurement for Utkatasana pose using Goniometer

Goniometers are commonly used in therapy and rehabilitation to measure the angles of the musculoskeletal system. This technique requires a clear understanding of the forces and moments at the various joints, which allows for the determination of joint coordinates. Figure 4 illustrates the goniometer is used to measure the musculoskeletal angles for the Utkatasana pose. The goniometer is a cost-effective, portable, and user-friendly tool, making it easy to measure angles with a single degree of freedom, such as knee flexion. However, for more complex movements involving multiple degrees of freedom, such as those at the shoulders, wrists, hips, knees, and ankles, additional precision is required. Using the goniometer, practitioners can accurately measure key angles in Utkatasana, including knee flexion (the angle between the thigh and lower leg), hip flexion (the angle between the torso and thigh), and shoulder flexion (the angle between the arm and torso). Monitoring these angles ensures proper technique, helping practitioners make necessary adjustments to perform the pose safely and effectively.

Fig.4 Utkatasana pose using Goniometer

2.2 Measurement for Utkatasana pose Using Simulation Tool

Figure 5 illustrates the musculoskeletal angle measurement for the Utkatasana pose using a simulation tool. This simulation tool is a video analysis software specifically designed for motion analysis and biomechanical studies. It provides detailed tracking and measurement of body movements, making it highly effective for evaluating yoga poses such as Utkatasana. In the case of Utkatasana, tools like the Kinovea simulation software can capture video footage of the practitioner and analyse the joint angles involved. By doing so, it assesses the accuracy of the pose in real time, offering immediate feedback on alignment and posture. This method allows for precise evaluation, helping practitioners make necessary adjustments to improve technique. The simulation tool is especially useful for capturing complex movements and joint angles that may not be easily measurable with traditional instruments, thereby enhancing the overall effectiveness of the analysis.

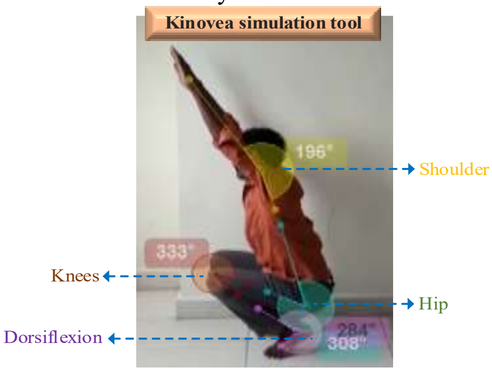


Fig. 5. Utkatasana pose using Simulation Tool

2.3 Detecting and Measuring Human Rigid Musculoskeletal Motion

In modern vision, human pose estimation focuses on locating joint positions[30]. We propose a posture detection system to monitor joint movements and evaluate the accuracy of utkatasana yoga poses, simplifying the practice for users. In our research[31], we highlighted that traditional goniometer methods do not attach sensors to limbs but require technical expertise and equipment. However, these methods often face challenges in obtaining accurate angle measurements without a proper reference system[32][33][34]. On the other hand, the kinovea simulation tool is user-friendly, eliminates the need for sensors. Making it a valuable option for recovery monitoring. The kinovea simulation tool offers ease of use, eliminates the need for sensors, and is free, making it ideal for recovery monitoring. This study assesses kinovea's effectiveness in movement analysis, specifically in Stress and neuromuscular rehabilitation. To use kinovea for utkatasana analysis, set up a camera to capture the full body in high resolution, apply reflective markers to key joints, and calibrate the tool. After recording, import the video, track joint markers, and measure key angles like knee and hip flexion. Results are then compared with goniometer data to ensure accuracy and refine yoga techniques[35][36].

3.Mathematical Modelling

3.1 Mathematical Model for Utkatasana (Chair Pose) Position

Mathematical models are essential for generating pathways and enabling computer simulations, though accurately modelling metabolic responses to asana exercises can be challenging due to factors like exercise intensity, duration, and individual traits such as age, gender, and fitness level. Measuring forces and moments directly is difficult, so mathematical models are used to estimate these loads by defining parameters like structural loads, geometry, and support conditions[37][38]. In Utkatasana, precise joint measurements for Knee Flexion, Hip Flexion, and Shoulder Flexion are necessary for effective diagnostics. Tailored joint coordinate systems that consider each joint's structure and function enhance kinematic analysis. These models enable accurate simulations, aiding in Stress management ,rehabilitation and individualized exercise plans. To develop a mathematical model for Utkatasana, we need to consider the biomechanics of the human body in this specific yoga posture. The model can be created using the principles of mechanics and the properties of human joints and muscles. Here's an outline of a basic mathematical model for Utkatasana:

3.2. Posture Geometry

Body Segments: Represented as cylinders or rods.
Joints: Treated as pin joints (e.g., hip, knee).
Angles:

- Knee Flexion (θ_k): Angle between the thigh and calf.
- Hip Flexion (θ_h): Angle between the torso and thigh.
- Torso Angle (θ_t): Angle between the torso and vertical.
- Shoulder Flexion Angle (θ_s): Angle between the upper arm and the torso.

Force and Moments :

- Gravity (g): Acts downward through the center of mass (m).
- Support Reaction Force (R): Acts upward from the ground at the base of support.
- Joint Forces (F_j): Forces acting at the joints to maintain posture.

3.3 Kinematic Equations

The kinematic equations describe the motion of joints and limbs. For Utkatasana, we can use the following:

$$\text{Position ankle} = (x_{ankle}, y_{ankle})$$
$$\text{Position knee} = (x_{knee}, y_{knee})$$
$$\text{Position hip} = (x_{hip}, y_{hip})$$
$$\text{Position shoulder} = (x_{shoulder}, y_{shoulder})$$
$$\text{Position hand} = (x_{hand}, y_{hand})$$

Using trigonometric relations:

- Position of the Ankle (x_{ankle}, y_{ankle}):

$$x_{ankle} = x_{knee} - L_{calf} \cdot \cos(\theta_k)$$
$$y_{ankle} = y_{knee} - L_{calf} \cdot \sin(\theta k)$$

- Position of the Knee (x_{knee}, y_{knee}):

$$x_{knee} = x_{hip} - L_{thigh} \cdot \cos(\theta h)$$
$$y_{knee} = yhip - L_{thigh} \cdot \sin(\theta h)$$

- Position of the Shoulder ($x_{shoulder}$, $y_{shoulder}$):

$$x_{shoulder} = x_{hip} + L_{torso} \cdot \cos(\theta h)$$
$$y_{shoulder} = y_{hip} + L_{torso} \cdot \sin(\theta h)$$

- Position of the Hand (x_{hand},y_{hand}):

$$x_{hand} = x_{shoulde}r + L_{arm} \cdot \cos(\theta s)$$
$$y_{hand} = y_{shoulde}r + L_{arm} \cdot \sin(\theta s)$$

where
L_{thigh},L_{calf},L_{torso},L_{arm} are the lengths of the respective body segments.

3. Dynamic Equations

The forces and moments acting on the body can be described as follows:

- Force Balance:

$$\sum F = m \cdot a$$

- Moment Balance:

$$\sum M = I \cdot \alpha$$

Where

- F is the force, m is mass, a is acceleration.
- M is the moment, I is the moment of inertia, α is angular acceleration.

3.4 Balance and Stability

To ensure a stable posture, the sum of forces and moments must equal zero:

$$\sum Fx = 0, \sum Fy = 0, \sum M = 0$$

3.5 Muscle Forces

Muscle forces can be estimated using inverse dynamics:

$$F_{muscle} = M_{joint} / r_{muscle}$$

Where

- M_{joint} is the moment at the joint.
- r_{muscle} is the moment arm of the muscle.

To apply the formulas given, let's calculate the position of the knee and ankle, and determine the force exerted by the quadriceps. We'll use the following values:

- $x_{hip} = 1$ m
- $y_{hip} = 1.2$ m
- $L_{thigh} = 0.5$ m
- $\theta h = 60$
- $L_{calf} = 0.4$ m
- $\theta k = 45\circ$
- $M_{knee} = 50$ Nm
- $r_{quad} = 0.05$ m

I. Calculate the position of the knee:

$$\text{Given: } \theta_h = 60^\circ$$
$$L_{thigh} = 0.5 \text{ m}$$

The position of the knee is:

$$x_{knee} = x_{hip} - L_{thigh} \cdot \cos(\theta h)$$
$$y_{knee} = yhip - L_{thigh} \cdot \sin(\theta h)$$

II. Calculate the position of the ankle:

$$\text{Given: } \theta k = 45^\circ$$
$$L_{calf} = 0.4 \text{ m}$$

The position of the ankle is:

$$x_{ankle} = x_{knee} - L_{calf} \cdot \cos(\theta k)$$
$$y_{ankle} = y_{knee} - L_{calf} \cdot \sin(\theta k)$$

III. Determine the force exerted by the quadriceps:

$$\text{Given: } M_{knee} = 50 \text{ Nm}$$
$$r_{quad} = 0.05 \text{ m}$$

The force exerted by the quadriceps is

$$F_{quad} = M_{knee} / r_{quad}$$

Here are the calculated results:

Position of the knee:

$$x_{knee} = 0.75 \text{ m and } y_{knee} = 0.767 \text{ m}$$

Position of the ankle:

$$x_{ankle} = 0.467 \text{ m and } y_{ankle} = 0.484 \text{ m}$$

Force exerted by the quadriceps:

$$F_{quad} = 1000 \text{ N}$$

Graphical representation of the Utkatasana

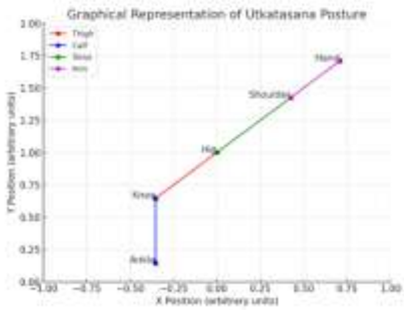


Fig.6 Graphical representation of the Utkatasana

Figure 6 illustrates the graphical representation of the Utkatasana (Chair Pose) posture based on the mathematical model. The diagram shows the positions of the hip, knee, ankle, shoulder, and hand joints, with the corresponding body segments (thigh, calf, torso, and arm) illustrated. This visual can help understand the biomechanical aspects of the Utkatasana pose, showing the angles and positions of the joints involved.

4. RESULTS AND DISCUSSIONS

4.1 Sampling and Data Analysis

The sample data were collected from 15 research scholars who volunteered to participate in this study. Participants were selected based on specific eligibility criteria, including an age range between 18 and 35 years. The model evaluates balance stability and posture steadiness in Utkatasana, which is used to address psychological stress in students and individuals with neuromuscular disorders. Each participant provided informed written consent. Participants completed one tier of a two-part study. Goniometer measurements of ankle dorsiflexion, knee, hip, and shoulder angles were compared with data from the Kinovea human motion model. A mathematical model was applied for further analysis and conclusions.

4.2 Statistical Analysis and Calculations

In the research aimed at optimizing Utkatasana posture stability for stressed students, statistical analysis was conducted using SPSS 19.0. The data, including posture performance and balance metrics, were evaluated using percentages, averages, and standard deviations. SPSS, initially developed for statistical analysis, independent Samples T-Test has become a versatile tool for academic research across various disciplines. By leveraging SPSS for this study, the analysis provided insights into how factors like body alignment, joint angles, and center of gravity contribute to maintaining stability in Utkatasana, offering a scientific approach to improving posture for stressed individuals[39][40] [41][42] [43].

4.3 Analysis of Results

If the calculated t-value (t-cal) is less than the tabulated t-value (t-tab), we accept the null hypothesis (Ho), indicating that there is a relationship between the Goniometer measurements and the Simulation tool measurement data. Conversely, if the calculated t-value is greater than the tabulated t-value, we reject the null hypothesis, suggesting no significant relationship between the Goniometer measurements, Simulation tool measurements, and the yoga practice. The degree of freedom (df) is calculated as n-1, so with 15 participants, df = 14.

Table.1 T-Test for Group Statistics of Goniometer and Simulation Tool Measurements of Utkatasana

Group Statistics					
Group		N	Mean	Std. Deviation	Std. Error Mean
Dorsiflexion	Goniometer	15	268.2000	12.46825	3.21929
	Simulation tool	15	269.0000	13.34702	3.44618
Knees	Goniometer	15	264.2000	23.40696	6.04365
	Simulation tool	15	264.1333	24.03529	6.20589
Hip	Goniometer	15	250.6000	18.20440	4.70035
	Simulation tool	15	250.5333	17.97167	4.64027
Shoulder	Goniometer	15	229.7333	12.46977	3.21968
	Simulation tool	15	228.6667	13.24854	3.42076

Table.1 evaluate whether the differences in measurements between the Goniometer and the Simulation Tool are statistically significant, we can interpret the data for each joint separately and then apply a T-Test. For Dorsiflexion, the Goniometer has a mean of 268.2 (SD = 12.47) and the Simulation Tool has a mean of 269.0 (SD = 13.35). The means are very close, with similar variability. For Knees, the Goniometer's mean is 264.2 (SD = 23.41), while the Simulation Tool's mean is 264.13 (SD = 24.04), showing a slight increase in variability with the Simulation Tool. The Hip measurements are also close: Goniometer mean is 250.6 (SD = 18.20) and Simulation Tool mean is 250.53 (SD = 17.97), indicating consistency between tools. For the Shoulder, the Goniometer mean is 229.73 (SD = 12.47) and the Simulation Tool mean is 228.67 (SD = 13.25), with a small difference in means but similar variability. To determine if these differences are statistically significant, a T-Test is performed where the null hypothesis (H0) posits no significant difference between tools, and the alternative hypothesis (H1) suggests a significant difference. If the P-value is less than 0.05, the null hypothesis is rejected, indicating a significant difference; otherwise, no significant difference is concluded.

Table.2 Independent Sample T-Test for Group Statistics of Goniometer and Simulation Tool Measurements of Utkatasana

Independent Samples Test									
	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Diff.	Std. Error Diff.	Lower	Upper

Dorsiflexion	Equal variances	0.242	0.627	-0.17	28	0.867	-0.800	4.715	-10.460	8.860
	Un equal variances			-0.17	27.87	0.867	-0.800	4.715	-10.462	8.862
Knees	Equal variances	0.007	0.934	0.008	28	0.994	0.066	8.662	-17.677	17.810
	Un equal variances			0.008	27.98	0.994	0.066	8.662	-17.678	17.811
Hip	Equal variances	0.001	0.970	0.010	28	0.992	0.066	6.604	-13.462	13.596
	Un equal variances			0.010	27.99	0.992	0.066	6.604	-13.463	13.596
Shoulder	Equal variances	0.055	0.816	0.227	28	0.822	1.066	4.697	-8.556	10.689
	Un equal variances			0.227	27.89	0.822	1.066	4.697	-8.557	10.690

Table.2 illustrates the independent samples t-test was conducted to compare the accuracy of joint measurements between two groups using different methods: a simulation system and traditional goniometer measurements. The results for each joint measurement are summarized below:

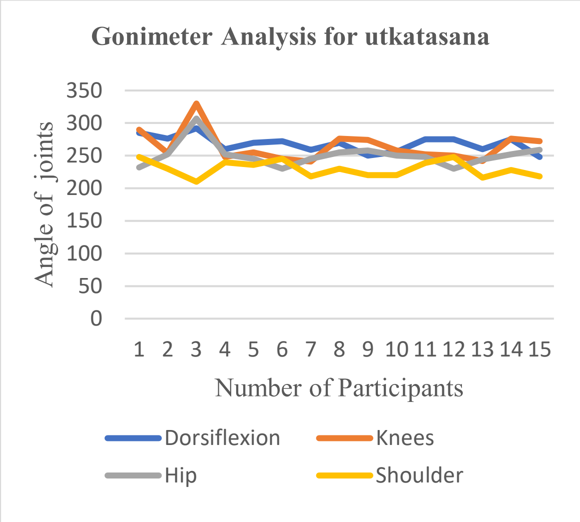
Dorsiflexion: Levene's Test for Equality of Variances for dorsiflexion yielded an F-value of 0.242 with a p-value of 0.627, indicating that the assumption of equal variances was met. The t-test revealed a t-value of -0.17 with 28 degrees of freedom and a p-value of 0.867. This result suggests no statistically significant difference in dorsiflexion measurements between the groups. The mean difference was -0.800 with a standard error of 4.715. The 95% confidence interval ranged from -10.460 to 8.860, supporting the conclusion that the accuracy of dorsiflexion measurements did not differ significantly between the simulation system and traditional goniometer measurements.

Knees: For knee measurements, Levene's Test showed an F-value of 0.007 and a p-value of 0.934, indicating equal variances. The t-test produced a t-value of 0.008 with 28 degrees of freedom and a p-value of 0.994. This result indicates no significant difference in knee measurements between the groups. The mean difference was 0.066 with a standard error of 8.662. The 95% confidence interval ranged from -17.677 to 17.810, reflecting a broad range that includes zero, reinforcing the lack of significant difference in knee measurements between the simulation system and traditional goniometer.

Hip: Levene's Test for hip measurements reported an F-value of 0.001 with a p-value of 0.970, suggesting equal variances. The t-test yielded a t-value of 0.010 with 28 degrees of freedom and a p-value of 0.992, indicating no significant difference in hip measurements between the groups. The mean difference was 0.066 with a standard error of 6.604. The 95% confidence interval for the mean difference ranged from -13.462 to 13.596, including zero, and supports the finding that there is no significant difference in hip measurements between the simulation system and traditional goniometer.

Shoulder: Levene's Test for shoulder measurements showed an F-value of 0.055 and a p-value of 0.816, indicating that the assumption of equal variances was reasonable. The t-test produced a t-value of 0.227 with 28 degrees of freedom and a p-value of 0.822. This result shows no significant difference in shoulder measurements between the groups. The mean difference was 1.066 with a standard error of 4.697. The 95% confidence interval for the mean difference ranged from -8.556 to 10.689, which includes zero, confirming the lack of a significant difference in shoulder measurements. Overall, the results from the independent samples t-tests for dorsiflexion, knees, hip, and shoulder measurements indicate no significant differences between the simulation system and traditional goniometer measurements. The non-significant p-values and confidence intervals that include zero suggest that both measurement methods provide similar accuracy for these joint angles. These findings are consistent with the research emphasizing the importance of maintaining proper posture during Utkatasana, as controlled by the body's center of gravity. The development and analysis of a mathematical model of human kinetic movement using simulation software, combined with goniometer measurements, supported the accuracy of real-time monitoring of body movements. The simulation system was proposed to ensure accurate Utkatasana poses by calculating various joint angles, and the statistical analysis confirmed that this system provides comparable accuracy to traditional goniometer measurements.

4.4 Graphical representation of Goniometer and Simulation Techniques



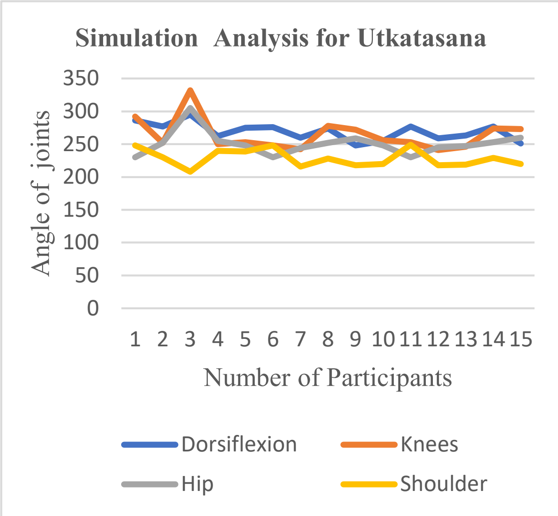


Fig. 7 Graphical representation of Goniometer and Simulation Techniques

The figure 7 displays the measured angles for dorsiflexion, knees, hips, and shoulders for 15 participants using both goniometer and simulation methods. In the graph, dorsiflexion is depicted in blue, knees in orange, hips in ash, and shoulders in yellow. The dorsiflexion angles ranged from 248 to 292 degrees for the goniometer and 248 to 295 degrees for the simulation, indicating only slight variations between the two methods. Knee angles ranged from 241 to 330 degrees with the goniometer and 241 to 332 degrees with the simulation, reflecting minimal differences. Hip measurements were between 230 and 307 degrees for the goniometer, while the simulation showed a similar range of 230 to 305 degrees. Shoulder angles were also closely matched, ranging from 210 to 248 degrees with the goniometer and 208 to 249 degrees with the simulation. Overall, the data suggest that both the goniometer and simulation methods provided measurements of similar accuracy, demonstrating the reliability and precision of the simulation method in replicating traditional goniometric assessments.

4.5 Mann-Whitney U Test Results for Pre- and Post-Test Systolic and Respiration Rat

	Pre Systolic	Pre Respiration Rate	Post Systolic	Post Respiration Rate
Mann-Whitney U	100.000	111.500	33.000	34.000
Wilcoxon W	220.000	231.500	153.000	154.000
Z	-.521	-.042	-3.303	-3.272
Asymp. Sig. (2-tailed)	.602	.967	.001	.001
Exact Sig. [2*(1-tailed Sig.)]	.624	.967	.001	.001

Table 3: Mann-Whitney U Test Results for Pre- and Post-Test Systolic and Respiration Rate

Table 3 illustrates Mann-Whitney U test was employed to compare pre- and post-test measurements of systolic blood pressure and respiration rate across groups. For systolic measurements, the pre-test comparison yielded a U-value of 100.000 and a Z-value of -0.521, with an asymptotic significance (2-tailed) of 0.602, indicating no significant difference between the groups at the pre-test phase. For post-test systolic comparisons, the U-value was 33.000 and the Z-value was -3.303, with a significant asymptotic value of 0.001, suggesting a statistically significant difference between the post-test systolic readings across the groups. Similarly, for respiration rate, pre-test comparison showed no significant difference with a U-value of 111.500, a Z-value of -0.042, and a p-value of 0.967. However, the post-test comparison for respiration rate indicated a significant difference, with a U-value of 34.000, a Z-value of -3.272, and a p-value of 0.001.The exact significance values, not corrected for ties, confirmed these findings with a significant difference in both post-test systolic and respiration rate measurements. These findings indicate that **Post-test systolic** for the experimental group (Utkatasana) is significantly lower than the pre-test systolic for the same group. Similarly, **Post-test respiration rate** for the experimental group is significantly lower than the pre-test rate. No such significant changes were noted for the control group in either systolic or respiration rate comparisons, suggesting the potential effectiveness of Utkatasana in improving both parameters for the experimental group.

4.6 Comparative Analysis of Pre and Post-Test Systolic and Respiration Rate: Utkatasana vs without Utkatasana Interventions

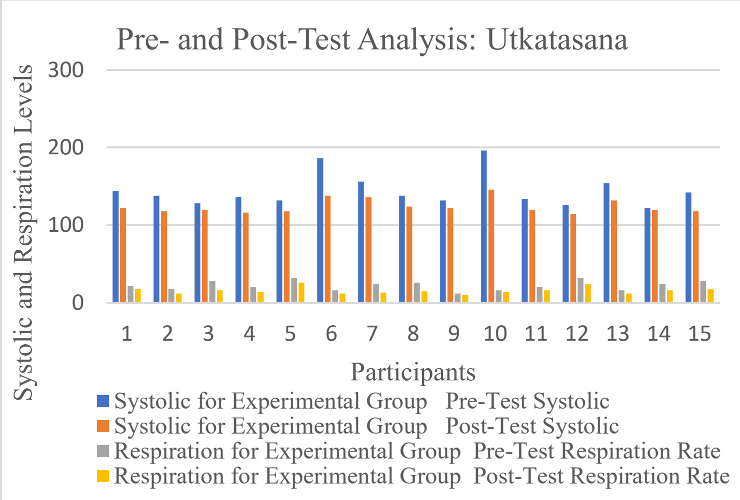


Fig. 8 Pre- and Post-Test Analysis: Utkatasana

The figure 8 displays the pre- and post-test analysis for the Utkatasana experimental group, as illustrated in the graph, highlights significant improvements in both systolic blood pressure and respiration rates. In the graph, **blue bars** represent the pre-test systolic levels, ranging from 122 to 196, while the **orange bars** indicate the post-test systolic levels, which were reduced across all participants, with values between 114 and 146. For respiration rates, the **grey bars** show pre-test rates, varying from 12 to 32, and the **yellow bars** indicate the post-test respiration rates, which decreased to values between 10 and 26. These findings suggest that practicing Utkatasana leads to measurable decreases in both systolic blood pressure and respiration rates, indicating potential benefits for cardiovascular and respiratory health in stress management contexts.

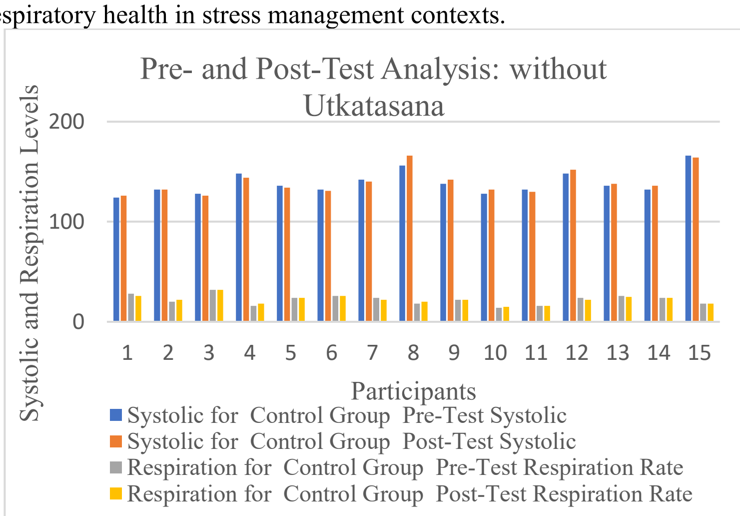


Fig. 9 Pre- and Post-Test Analysis: without Utkatasana

The figure 9 displays control group's data for systolic blood pressure and respiration rates, represented in the graph, shows minimal changes between pre- and post-test measurements. The **blue bars** indicate pre-test systolic blood pressure levels ranging from 124 to 166, while the **orange bars** show post-test systolic levels, which remained similar, ranging from 126 to 166. For respiration rates, the **Grey bars** reflect pre-test values between 14 and 32, and the **yellow bars** represent post-test values, showing little variation with a range of 15 to 32. These results suggest that, unlike the experimental group, the control group did not experience significant reductions in systolic blood pressure or respiration rates, highlighting Utkatasana's effectiveness in improving these health parameters.

5.CONCLUSION

Based on the comparative analysis of goniometer and simulation methods for measuring dorsiflexion, knees, hips, and shoulders, this study aims to assess the accuracy of a real-time pose recognition simulation system by comparing its joint angle measurements to those obtained through traditional goniometer methods and mathematical models. The findings indicate that both techniques provide highly similar and accurate results, with minor variations being negligible, suggesting that the simulation tool is just as reliable and precise as the traditional goniometer for assessing joint angles. These results support the use of the simulation system as a valid alternative to conventional goniometric measurements, offering a consistent method for evaluating joint movements in clinical and research settings. To further substantiate these findings, mathematical modelling was employed to describe the motion and positioning of joints and limbs during Utkatasana. The pre- and post-test analysis for the Utkatasana experimental group highlighted significant improvements in both systolic blood pressure and respiration rates, with systolic levels decreasing from a pre-test range of 122 to 196 to a post-test range of 114 to 146, and respiration rates dropping from 12 to 32 pre-test to 10 to 26 post-test. In contrast, the control group showed minimal changes in both parameters, indicating that Utkatasana effectively contributes to enhancing stress management by improving cardiovascular and respiratory health while also assisting in stress relief, enhancing postural stabilization, and supporting routine physical activities. A mathematical model of human kinetic movement was developed and analysed using both simulation software and traditional goniometer measurements. This model not only validates the effectiveness of Utkatasana in promoting proper alignment and enhancing physical stability but also serves as a foundation for evaluating other asanas in future research. By applying this mathematical framework, researchers can further explore the biomechanical aspects of various yoga poses, assessing their impacts on posture, balance, and overall physical health[44][45] [46] [47].

6.Declaration of competing interest

The authors have no competing interests to declare that are relevant to the content of this article.

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