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Article

# Biomechanical approaches to improving mental health in college students through physical posture and movement

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**Abstract:** Poor posture and inefficient movement patterns have been linked to increased stress, anxiety, and mood disturbances, particularly in college students who often lead sedentary lifestyles. This study investigates the impact of biomechanical interventions—specifically postural correction exercises and dynamic movement training—on college students' physical and psychological outcomes. The aim was to assess how posture and movement efficiency improvements influence mental health indicators, such as perceived stress, anxiety, and mood. A total of 126 participants were recruited from three universities in China. Pre- and post-intervention assessments were conducted using Motion Capture Systems (MCS), surface electromyography (sEMG), and ground reaction force plates to evaluate postural alignment, muscle activation, movement efficiency, and force distribution. Psychological outcomes were measured using the Perceived Stress Scale (PSS), Generalized Anxiety Disorder 7-item (GAD-7) scale, and Positive and Negative Affect Schedule (PANAS). Key findings revealed significant improvements in physical outcomes, including a 14.9% reduction in thoracic kyphosis (from 43.7° to 37.2°) and a 30.9% increase in rectus abdominis activation (from 42.3% to 55.4%). Movement efficiency improved, with a 66.7% reduction in compensatory movements during step-ups. Psychologically, overall stress levels decreased by 30.9% as measured by the PSS, while anxiety levels dropped by 38.5% according to the GAD-7. Also, positive affect increased by 29.5%, and negative affect decreased by 30.3%. These results suggest that targeted biomechanical interventions can significantly improve physical alignment and mental well-being. The findings support the potential for integrating posture and movement training into mental health strategies for college students, offering a holistic approach to managing stress, anxiety, and mood disturbances.

**Keywords:** biomechanical interventions; physical alignment; mental well-being; movement training; posture; Perceived Stress Scale; force distribution

## 1. Introduction

The interplay between physical posture, movement, and Mental Health (MH) has garnered increasing attention in recent years, as studies suggest that biomechanical factors may significantly influence Psychological Well-Being (PWB) [1]. College students, in particular, are vulnerable to physical health (PH) and MH challenges due to prolonged periods of sedentary behavior, academic stress, and irregular physical activity [2,3]. The combination of these factors often leads to poor postural habits, such as slouched sitting, which can exacerbate stress, anxiety, and other MH concerns [4–6]. While the cognitive and emotional consequences of stress and anxiety in students are well-documented, the potential role of physical posture and movement in mitigating these effects remains underexplored [7].

Biomechanics, the study of mechanical principles applied to biological systems, offers an intriguing lens to understand the relationship between body alignment, movement patterns, and MH [8,9]. Proper posture and movement efficiency are essential for musculoskeletal health and appear to influence neurological and psychological processes [10]. Research suggests that poor posture, particularly forward head posture and slouched shoulders, may contribute to feelings of stress, anxiety, and even depression [11,12]. Conversely, improving posture and movement efficiency through targeted interventions may alleviate physical discomfort and reduce psychological symptoms, enhancing overall well-being [13,14].

The growing interest in neuro-biomechanics underscores the importance of understanding how the nervous system interacts with musculoskeletal function to affect MH. Studies have shown that corrective exercises to improve posture and movement efficiency can lead to measurable improvements in MH [15,16]. For instance, engaging in postural correction exercises and dynamic movement training can reduce physical tension, enhance muscle activation, and improve balance, all contributing to reduced stress and anxiety [17]. Additionally, activating core and back muscles through biomechanical training may improve body stability, improve emotional regulation, and decrease adverse effects [18].

This study investigates the effects of biomechanical interventions—specifically postural correction exercises and dynamic movement training—on college students' physical and psychological outcomes [19]. This research aims to comprehensively analyze how improving physical posture and movement patterns can influence MH by employing a mixed-methods approach that integrates biomechanical assessments with psychological evaluations. Specifically, the study focuses on changes in postural alignment, muscle activation, movement efficiency, ground reaction forces, and reductions in perceived stress, anxiety levels, and mood disturbances [20].

In doing so, this research addresses a critical gap in the literature by linking improvements in biomechanics with MH benefits, particularly in the context of a high-stress population such as college students [21,22]. The findings from this study are expected to provide new insights into the potential of biomechanical approaches for promoting mental well-being, offering a novel, integrative approach to managing stress, anxiety, and mood disorders. By exploring the relationship between body mechanics and MH, this study contributes to a growing body of research advocating holistic health interventions incorporating physical and psychological elements.

The primary objective of this study is to assess the impact of biomechanical interventions on both physical and psychological outcomes among college students.

1) Examine the effects of postural correction exercises and dynamic movement training on postural alignment, muscle activation, movement efficiency, and ground reaction forces.
2) Evaluate the influence of these biomechanical improvements on perceived stress levels, anxiety, and mood as measured by validated psychological scales.
3) Explore the correlations between physical improvements and MH outcomes, establishing a link between better posture and movement patterns and enhanced emotional well-being.

By integrating these components, the study seeks to provide a comprehensive understanding of how targeted physical interventions can serve as effective strategies for improving MH in vulnerable populations.

The rest of the paper is organized as follows: Section 2 discusses the theoretical framework; Section 3 presents the experimental process; Section 4 analyzes the results; and Section 5 concludes the work.

## 2. Theoretical framework

### 2.1. Biomechanical principles of posture and movement

Posture and movement are fundamental components of human biomechanics, which encompasses studying the mechanical aspects of the human body in motion and at rest. Proper posture (**Figure 1**) involves maintaining body alignment to minimize stress on muscles, joints, and ligaments while performing daily activities, whether sitting, standing, or moving. The interaction between muscular control, skeletal alignment, and external forces like gravity determines it [23–25]. Good posture is essential for efficient body function, as it allows muscles to work more effectively, reduces fatigue, and helps prevent injury. Conversely, poor posture leads to muscle imbalances and increased strain on the spine and joints, contributing to chronic pain and decreased mobility.

On the other hand, movement refers to the body's ability to perform tasks requiring muscle and joint coordination in dynamic actions. Movements (**Figure 2**) are categorized into different types, such as linear, angular, rotational, or a combination. For example, walking involves coordinated linear and angular movements of the legs, while reaching for an object involves both linear and rotational movements of the arms. Effective movement depends on balance, flexibility, strength, and coordination [26,27]. When biomechanical principles are applied to movement, emphasis is placed on how forces are distributed across the body to avoid unnecessary strain, ensuring optimal function.

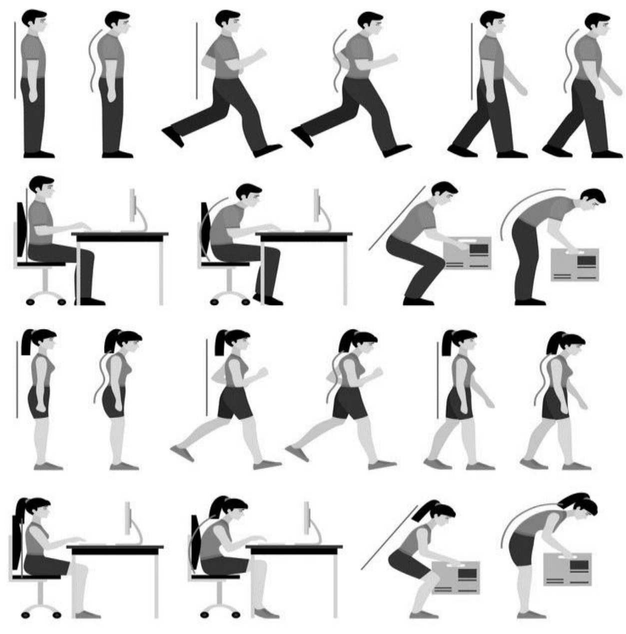

**Figure 1.** Correct and incorrect posture.

Source: https://thenaturalposture.com/.

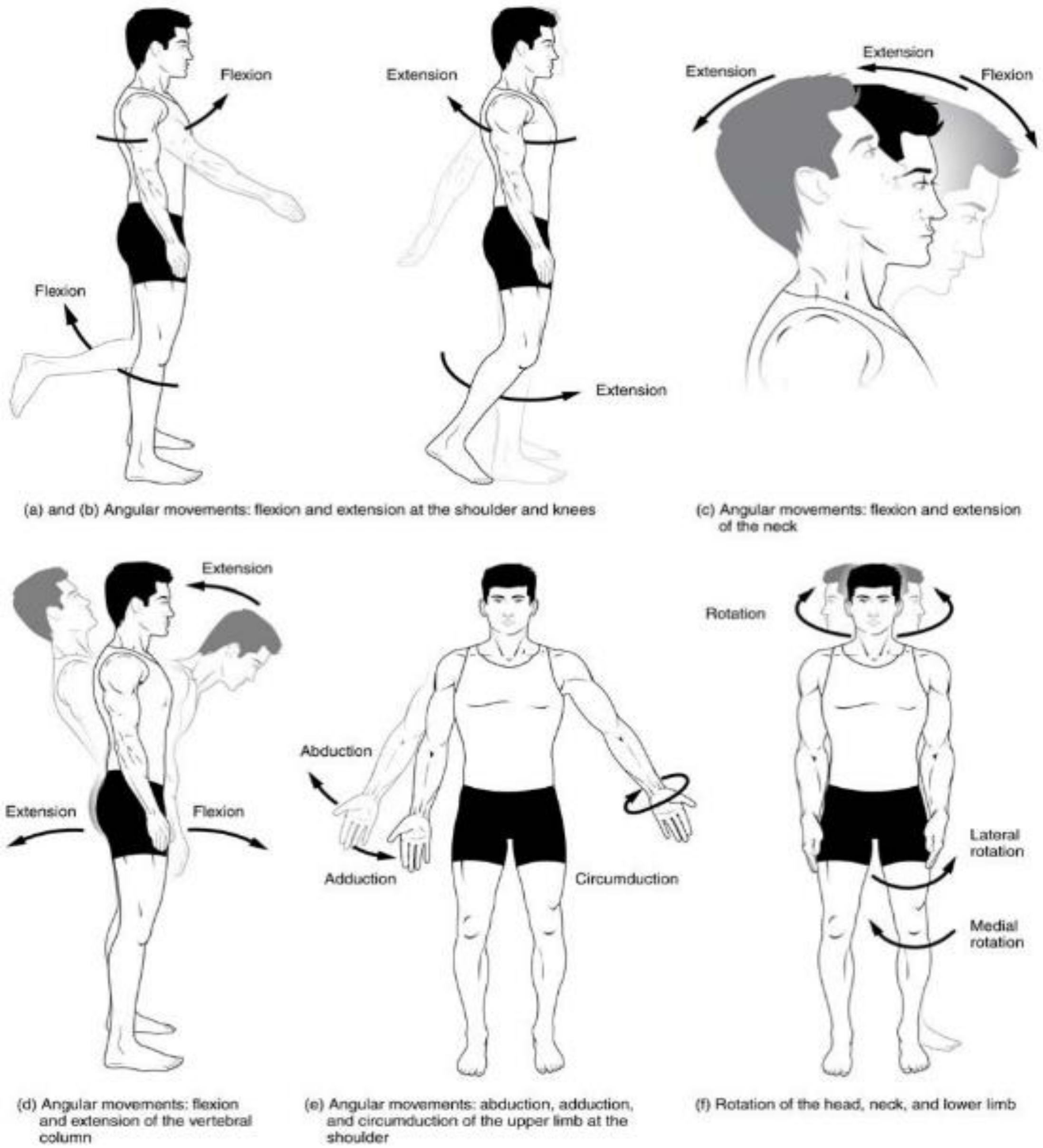


**Figure 2.** Types of movement.

Source: https://www.knowlative.com/.

Biomechanical principles emphasize several vital factors, including joint alignment, muscle engagement, and force distribution. Joint alignment is crucial, as misaligned joints can lead to inefficient movement patterns and overuse injuries [28,29]. Muscle engagement ensures that the right muscles are activated to stabilize and move the body efficiently. For example, the core muscles are central in maintaining posture during movement, while the legs and arms muscles facilitate dynamic actions. Additionally, understanding how forces are distributed through the body during movement is essential for preventing injury. For instance, during running or jumping, the forces exerted on the lower limbs and joints must be managed to avoid damage to the knees or ankles.

Moreover, biomechanical principles also consider external factors such as gravity and ground reaction forces, which interact with the body during static postures and movement. Gravity exerts a constant downward force on the body, and maintaining proper alignment helps the body resist the pull of gravity in a method that minimizes stress. Ground reaction forces, which occur when the body contacts the ground, also play a significant role in movement, particularly in high-impact activities like running or jumping. Understanding how the body interacts with these forces improves movement efficiency and reduces injury risk [30–32].

In sum, the biomechanical principles of posture and movement provide a framework for understanding how the body can function optimally in static and dynamic conditions. Individuals can maintain better posture, improve their movement efficiency, and reduce the risk of injury by ensuring proper joint alignment, muscle engagement, and force distribution. These principles are fundamental in improving PH and MH, as poor posture and inefficient movement can lead to musculoskeletal issues that negatively affect physical and emotional well-being. Through targeted interventions aimed at correcting posture and enhancing movement patterns, it is possible to promote both PH and MH in populations such as college students, who are often at risk for both physical inactivity and MH challenges.

## 2.2. Neuro biomechanics and MH

Neuro biomechanics is an interdisciplinary field that explores the relationship between the nervous system and the mechanical functions of the human body, with a particular focus on how neural control influences movement and posture. The nervous system regulates muscle activity, joint stability, and movement coordination. At the same time, the brain processes and integrates sensory information from the body's movements, adjusting posture and controlling movement in response to external stimuli. This bidirectional relationship between the nervous system and biomechanics has significant implications for PH and MH, particularly in populations prone to stress, anxiety, and other psychological challenges, such as college students.

The influence of biomechanics on MH arises from the body's feedback mechanisms, which connect physical posture and movement with emotional states. Research has shown that specific postural and movement patterns can trigger neurological responses linked to stress, anxiety, and mood disorders. For example, slouched or forward-leaning postures, which are common among individuals experiencing stress or depression, can reinforce negative emotional states through feedback loops between the brain and the body. This phenomenon, known as "embodied cognition", suggests that the body's physical state can significantly impact cognitive processes and emotional well-being. Neuro-biomechanical interventions that correct postural misalignments can influence MH by altering the body's feedback to the brain.

Furthermore, neuro-biomechanics examines how movement patterns, such as repetitive or constrained motions, influence neurological function. When muscles, joints, and ligaments are repeatedly strained or misused, the nervous system adapts to these faulty movement patterns, leading to chronic pain, fatigue, and mood disturbances. This is particularly relevant in modern, sedentary lifestyles, where poor posture during prolonged sitting or screen time can exacerbate musculoskeletal problems and negatively affect mental well-being. The nervous system continuously monitors these biomechanical conditions and can contribute to increased stress and anxiety levels when the body is not functioning optimally.

In contrast, improving posture and movement through neuro-biomechanical interventions has positively affected MH. Studies suggest that upright, open, and balanced postures are associated with reduced stress and improved mood. This is partly because such postures optimize the activation of the parasympathetic nervous system, which is responsible for relaxation and recovery. In contrast, slouched or restricted postures can stimulate the sympathetic nervous system, which governs the body's fight-or-flight response, and increase stress levels. By altering these neurobiological responses through biomechanical corrections, individuals can experience reduced anxiety stress, and enhanced emotional regulation.

Additionally, movement-based therapies incorporating biomechanical principles, such as yoga, tai chi, or Pilates, have improved MH by engaging both the body and the brain. These practices emphasize controlled, fluid movements that promote muscle balance, joint stability, and neural coordination while stimulating mental focus and relaxation. Neuro-biomechanically, these forms of movement encourage the release of endorphins, serotonin, and other neurotransmitters that contribute to positive mood states and reduce feelings of stress and depression. These therapies offer a holistic approach to improving MH through biomechanics by integrating movement and mental relaxation.

In college students who frequently face heightened levels of stress due to academic pressures, social challenges, and physical inactivity, neuro-biomechanical approaches can be particularly beneficial. Students may experience better focus, reduced anxiety, and enhanced well-being by improving body alignment and incorporating mindful movement practices. Interventions aimed at correcting posture and promoting healthy movement patterns can also mitigate the physical symptoms of stress, such as muscle tension and headaches, which are common in individuals who spend extended h studying or working on computers. Over time, these improvements in physical and neural function can help break the cycle of stress and poor posture, leading to better MH outcomes.

## 3. Methodology

### 3.1. Population and sample

From **Table 1** the study was conducted among college students in China, a population known for facing considerable academic and social pressures, making them a relevant group for examining the effects of biomechanical interventions on MH. 126 students (68 males and 58 females) were selected from three universities in Beijing, Shanghai, and Guangzhou. These universities were chosen to represent diverse geographical and cultural backgrounds, ensuring the sample was not skewed toward one particular demographic group. The age range of the participants was between 18 and 24 years, with an average age of 21.2 years (SD = 1.5).

**Table 1.** Demographic breakdown.

| Category | Subcategory | Count (%) |
|---|---|---|
| Gender Distribution | Males | 68 (54%) |
| | Females | 58 (46%) |
| Age Distribution | 18–19 years | 24 (19%) |
| | 20–21 years | 42 (33%) |
| | 22–24 years | 60 (48%) |
| Academic Year | Freshmen (1st year) | 38 (30%) |
| | Sophomores (2nd year) | 34 (27%) |
| | Juniors (3rd year) | 30 (24%) |
| | Seniors (4th year) | 24 (19%) |
| Physical Activity Level | Low (no regular exercise) | 35 (28%) |
| | Moderate (exercise 1–2 times/wk) | 57 (45%) |
| | High (exercise 3+ times/wk) | 34 (27%) |
| MH Status | Low Stress | 31 (25%) |
| | Moderate Stress | 62 (49%) |
| | High Stress | 33 (26%) |

Students were selected through a stratified random sampling method to ensure representation across different academic years, physical activity levels, and self-reported stress levels. The inclusion criteria required participants to have no prior injuries or musculoskeletal disorders that could interfere with the study's biomechanical interventions. Participants were informed about the nature of the study and provided written consent. Ethical approval was obtained from the relevant university ethics committees.

## 3.2. Experimental design

The experimental design for this study involved comprehensive biomechanical assessments of posture and movement patterns, followed by a structured intervention protocol. Participants underwent these assessments and interventions in a controlled laboratory setting to minimize external variables. A pretest-posttest model was used to evaluate changes in posture, movement efficiency, and MH outcomes after the intervention.

### 3.2.1. Participant preparation

Before the start of the experiment, all participants were given detailed information about the study's objectives, procedures, and expected outcomes. Each participant was asked to wear form-fitting clothing (such as athletic gear) to ensure that markers and sensors could be accurately placed for biomechanical measurements. To minimize variability, participants were instructed to refrain from strenuous physical activity 24 h before their assessments and to avoid caffeine or heavy meals two h before each session.

Upon arriving at the lab, participants underwent a brief health screening to confirm that they met the study's inclusion criteria (no recent injuries or medical conditions affecting posture or movement). After the screening, participants were introduced to the experimental procedure, and the importance of natural movement and relaxed posture during the assessments was emphasized. They were encouraged to perform movements as usual without consciously attempting to "correct" their posture or movement.

#### 3.2.2. Instructions given

To standardize the process, participants were given clear, concise instructions for each assessment phase:

1) Static posture assessment: Participants were asked to stand in a neutral position for 30 s and sit in a relaxed position for another 30 s. The instructions emphasized standing as usual, not attempting to "stand up straight" to ensure natural posture was captured. They were then asked to perform a series of poses, such as slight forward bends, and shoulder stretches, to assess the natural range of motion and alignment.
2) Dynamic movement assessment: For the dynamic tests, participants were instructed to perform movements such as walking, squatting, and lunging at a comfortable pace. They were told to maintain their usual form without attempting to alter their movement style. The researcher demonstrated each movement before the participant performed the exercise to ensure consistency across all participants.
3) Gait analysis: During the gait analysis, participants were asked to walk at an average pace across a 10 m walkway equipped with force plates and motion capture cameras. They were instructed to walk naturally without altering their stride or foot placement. Each participant completed five walking trials, with short rest periods between trials to prevent fatigue.

Before each test, the researcher reviewed the instructions with the participants to ensure they understood what was required. Participants were also given opportunities to ask questions before proceeding.

#### 3.2.3. Biomechanical assessments of posture and movement patterns

Once participants were prepared and briefed, the biomechanical assessments were conducted using various technologies, including Motion Capture Systems (MCS), force plates, and surface electromyography (sEMG). The MCS, which utilized reflective markers placed on key joints (e.g., ankles, knees, hips, shoulders, and spine), provided real-time data on body alignment and movement patterns. The force plates recorded the ground reaction forces during dynamic activities like walking and squatting, allowing the researchers to evaluate balance, joint loading, and symmetry.

The participants' body alignment was analyzed for static posture assessments while standing and sitting in a relaxed position. Key points of interest included spinal curvature, shoulder positioning, and hip alignment. Dynamic movement assessments involved squats, lunges, and walking, during which joint angles, muscle activation, and movement coordination were evaluated.

#### 3.2.4. Intervention protocols: Postural correction exercises and dynamic movement training

After the initial biomechanical assessments, participants were enrolled in a six-week intervention program. This program was designed to correct postural misalignments and improve movement efficiency through two main components: postural correction exercises and dynamic movement training.

a) Postural correction exercises: Participants performed specific exercises to improve core strength, spinal alignment, and shoulder stability. Instructions were given for each exercise, with a focus on maintaining the correct form:
   - Core strengthening exercises such as planks and dead bugs were prescribed to improve postural stability.
   - Shoulder retraction exercises like rows and scapular squeezes were included to correct rounded shoulders.
   - Hip mobility drills, such as glute bridges and hip flexor stretches, were performed to alleviate lower back strain.

These exercises were completed 3 times a week for 30 min per session. During the first 2 weeks, participants attended supervised sessions to ensure proper technique. Afterward, they were given home exercise routines to perform independently, with periodic check-ins to monitor progress.

b) Dynamic Movement Training: Participants also practiced dynamic movement training twice weekly. This training emphasized improving movement coordination, balance, and flexibility:
   - Functional movement exercises enhanced lower limb stability and strength, including squats and lunges.
   - Balance and proprioception drills, such as single-leg balances, were designed to improve coordination and prevent injury.
   - Flexibility routines, such as dynamic stretching, focused on improving joint mobility.

Each dynamic training session lasted 45 min, increasing intensity and complexity. Participants were encouraged to perform these exercises in a relaxed environment to simulate real-world conditions.

## 3.3. Apparatus and data collection

This study's apparatus and data collection methods were designed to capture biomechanical and psychological data, ensuring a comprehensive analysis of the effects of posture and movement on MH. The apparatus used for kinematic analysis allowed for precise measurements of body movement and alignment, while the psychological assessments provided valuable insights into the participants' MH before and after the intervention.

### 3.3.1. Tools or kinematic analysis

Advanced MCS and posture analyzers were employed to measure the participants' posture and movement patterns. These tools provided highly accurate, real-time data on joint angles, muscle activation, and overall body mechanics.

- MSC: The primary tool for capturing kinematic data was a 3D-MCS, which involved placing reflective markers on key anatomical landmarks of the participants' bodies, such as the spine, shoulders, hips, knees, and ankles. The markers were tracked by an array of infrared cameras around the lab, recording their movements in 3-D space. This system allowed for detailed analysis of the participants' posture while standing, sitting, and performing dynamic movements like walking, squatting, and lunging. The data captured included joint angles, body alignment, and movement efficiency, providing a comprehensive view of how each participant's body moved and reacted during the tasks.

- Posture analyzers: In addition to the MCS, a specialized posture analyzer was used to evaluate static postural alignment. The posture analyzer utilized laser-guided imaging and pressure sensors to assess spinal curvature, shoulder tilt, and pelvic alignment while participants stood and sat in neutral positions. This tool identified standard postural deviations, such as forward head posture, rounded shoulders, or excessive lumbar lordosis. The measurements from the posture analyzer were critical in designing individualized postural correction exercises for each participant.
- Surface electromyography (sEMG): Surface electromyography sensors were placed on the participants' major muscle groups (e.g., core, back, and lower limbs) to record muscle activity during both static and dynamic movements. The sEMG data helped assess muscle engagement and identify any imbalances or weaknesses that could contribute to poor posture or inefficient movement patterns. This tool was particularly useful in tracking changes in muscle activation patterns before and after the intervention, allowing the researchers to evaluate the effectiveness of the postural correction exercises.
- Force plates: Force plates were used during dynamic movement tests to measure ground reaction forces to complement the motion capture data. These plates recorded the forces exerted on the body during walking, jumping, or squatting. The force data provided insights into how weight was distributed across the body and how participants managed balance and joint loading. Any asymmetries in force distribution were flagged for correction during the intervention phase.

#### 3.3.2. Psychological assessments

In addition to the biomechanical data collected, psychological assessments were administered to evaluate the participants' MH before and after the intervention. These assessments focused on stress levels, anxiety, and overall mood, key indicators of mental well-being in college students.

- Stress levels (Perceived Stress Scale—PSS): The Perceived Stress Scale (PSS) was used to measure participants' perceived stress levels. This self-report questionnaire includes 10 items that assess how overwhelmed, stressed, or in control participants felt during the past month. Participants rated each item on a 5-point Likert scale, with responses ranging from "never" to "very often." The PSS provided a global measure of stress, offering insights into how stress levels fluctuated before and after the postural and movement interventions.
- Anxiety levels (Generalized Anxiety Disorder 7-Item scale-GAD-7): Anxiety was assessed using the Generalized Anxiety Disorder 7-item (GAD-7) scale, a widely used tool for screening and measuring anxiety symptoms. Participants answered questions about how frequently they experienced symptoms such as nervousness, worry, and restlessness over the past two weeks, using a 4-point Likert scale ranging from "not at all" to "nearly every day". This tool helped identify participants with high levels of anxiety and allowed for a comparison of anxiety levels before and after the biomechanical interventions.

- Mood assessment (Positive and Negative Affect Schedule-PANAS): The Positive and Negative Affect Schedule (PANAS) assessed participants' mood states. This tool consists of two scales: positive affect (enthusiasm, alertness, and inspiration) and negative affect (distress, anger, and nervousness). Participants rated their mood using a 5-point scale (from "very slightly" to "extremely") based on how they felt during the past week. This measure provided a detailed picture of participants' emotional states and allowed the researchers to track changes in mood before and after the intervention.
- Post-intervention assessments: After completing the six-week intervention program, participants were asked to complete the same set of psychological assessments. This allowed the researchers to compare pre-and post-intervention stress, anxiety, and mood levels, providing insight into the psychological effects of improved posture and movement. The post-intervention data were crucial in determining whether the biomechanical corrections significantly impacted MH outcomes.

### 3.3.3. Data collection procedure

The data collection process was carried out in pre-intervention and post-intervention. For the pre-intervention stage, participants underwent biomechanical assessments, where their posture, movement, and muscle activity were analyzed using the MCS, posture analyzer, sEMG, and force plates. Immediately after, they completed the psychological assessments to record their initial stress, anxiety, and mood levels.

After the six-week intervention program, the same assessments were repeated in the post-intervention stage. The data collected from both stages were compared to evaluate the interventions' effectiveness in improving PH and MH. All data were anonymized to protect participant privacy and stored securely for analysis.

# 4. Results

## 4.1. Biomechanical outcomes

The intervention substantially improved spinal curvature shoulder and hip alignment (**Figure 3**). As indicated in **Table 2**, thoracic kyphosis decreased by 14.9%, while lumbar lordosis was reduced by 12.1%, suggesting better spinal alignment. This reduction in curvature indicates that the postural correction exercises effectively targeted the spine, leading to improved back posture and reduced strain on the vertebral column. The most significant changes were observed in shoulder alignment, where forward shoulder posture improved by 29.9%. This suggests that exercises aimed at shoulder retraction were efficient, improving participants' upper body posture and reducing the forward tilt commonly associated with sedentary lifestyles.

Additionally, pelvic tilt improved by 29.1%, demonstrating a positive effect on hip alignment and lower back posture, which are critical for reducing lower back pain and enhancing overall body balance. The hip alignment also showed remarkable improvements, with a 41.7% reduction in right hip drop and a 32.4% reduction in left hip drop. This highlights the intervention's success in balancing the pelvic region, which is crucial in movement efficiency and injury prevention during dynamic activities.

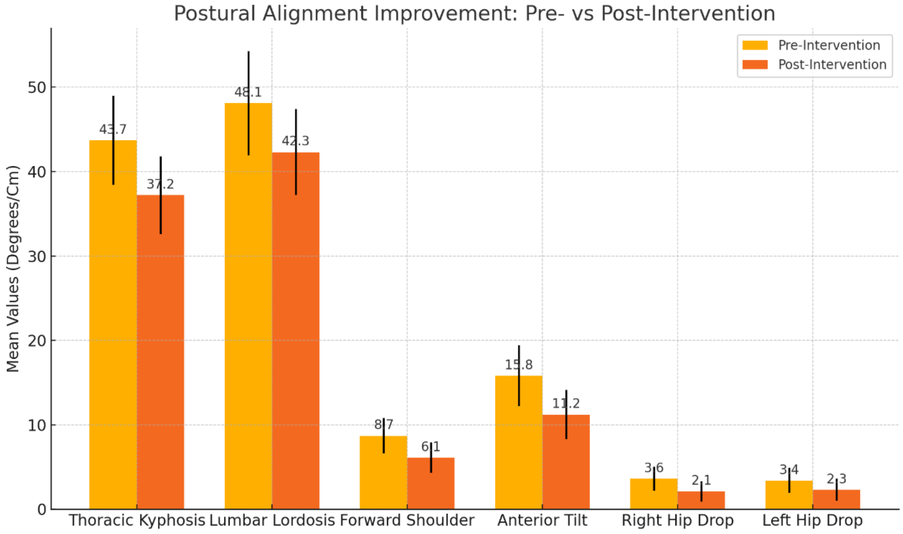


**Figure 3.** Postural alignment improvement.

**Table 2.** Postural alignment improvement.

| Postural Aspect | Pre-Intervention (Mean ± SD) | Post-Intervention (Mean ± SD) | Change (%) |
|---|---|---|---|
| Spinal Curvature (Thoracic Kyphosis) | 43.7 ± 5.3 | 37.2 ± 4.6 | −14.9% |
| Spinal Curvature (Lumbar Lordosis) | 48.1 ± 6.2 | 42.3 ± 5.1 | −12.1% |
| Shoulder Alignment (Forward Shoulder) | 8.7 cm ± 2.1 cm | 6.1 cm ± 1.8 cm | −29.9% |
| Pelvic Tilt (Anterior Tilt) | 15.8 ± 3.6 | 11.2 ± 2.9 | −29.1% |
| Hip Alignment (Right Hip Drop) | 3.6 ± 1. | 2.1 ± 1.2 | −41.7% |
| Hip Alignment (Left Hip Drop) | 3.4 ± 1.5 | 2.3 ± 1.3 | −32.4% |

Regarding muscle activation, the intervention successfully enhanced engagement across core, back, and limb muscles (**Table 3** and **Figure 4**). The rectus abdominis and obliques showed a 30.9% and 32.2% increase in activation, respectively, reflecting improved core strength and stability, essential for maintaining proper posture during movement. The erector spinal muscles also exhibited a 37.5% increase in activation, indicating enhanced support for the spine, leading to better posture control. Improvements were also observed in agonist-antagonist muscle balance. For instance, quadriceps activation increased by 10.9%, while hamstring activation improved by 22.0%. This balance between opposing muscle groups is crucial for maintaining stability and preventing muscle imbalances that could lead to injury. Similarly, the increase in both biceps (8.5%) and triceps (18.6%) activation shows better upper-body muscle coordination, further contributing to movement efficiency and overall strength.

**Table 3.** Muscle activation and balance.

| Muscle Group | Pre-Intervention (Mean Activation % ± SD) | Post-Intervention (Mean Activation % ± SD) | Change (%) |
|---|---|---|---|
| Core (Rectus Abdominis) | 42.3% ± 8.6% | 55.4% ± 7.9% | +30.9% |
| Core (Obliques) | 39.1% ± 7.4% | 51.7% ± 6.8% | +32.2% |

**Table 3.** (*Continued*).

| **Muscle Group** | **Pre-Intervention (Mean Activation % ± SD)** | **Post-Intervention (Mean Activation % ± SD)** | **Change (%)** |
|---|---|---|---|
| Back (Erector Spinae) | 33.8% ± 6.2% | 46.5% ± 5.7% | +37.5% |
| Quadriceps (Agonist) Activation | 56.7% ± 9.1% | 62.9% ± 8.3% | +10.9% |
| Hamstrings (Antagonist) Activation | 21.4% ± 4.3% | 26.1% ± 3.9% | +22.0% |
| Biceps (Agonist) Activation | 61.3% ± 10.8% | 66.5% ± 9.6% | +8.5% |
| Triceps (Antagonist) Activation | 24.2% ± 5.6% | 28.7% ± 4.9% | +18.6% |

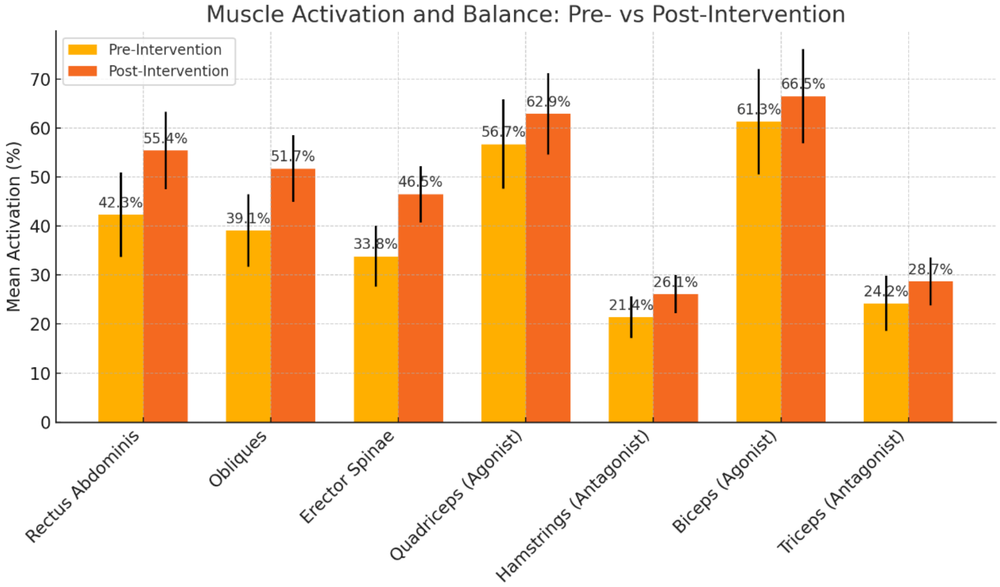


**Figure 4.** Muscle activation and balance.

The results presented in **Table 4** and **Figure 5** highlight significant improvements in movement efficiency, with changes in joint angles during dynamic movements and reductions in compensatory movements. Squat knee flexion angle improved by 14.2%, indicating that participants could perform deeper squats with better form post-intervention. This was accompanied by a 60.9% reduction in compensatory movements, such as knee valgus or excessive forward lean, further suggesting enhanced movement quality. Similarly, hip flexion angle during lunges increased by 16.7%, and knee extension improved by 12.9% during step-ups, reflecting better lower limb flexibility and control. The reduction in compensatory movements for lunges (58.8%) and step-ups (66.7%) highlights the intervention's impact on reducing asymmetries and improving stability. Walking gait also saw improvements, with hip adduction angle decreasing by 39.8%, leading to a more symmetrical gait pattern and reducing the risk of overloading one side of the body. Additionally, ankle dorsiflexion angle during jumping increased by 19.6%, showing improved ankle mobility and balance, which is critical for activities that involve impact, such as running or jumping.

**Table 4.** Movement efficiency.

| Movement Type | Joint Angle (Pre-Intervention Mean ± SD) | Joint Angle (Post-Intervention Mean ± SD) | Change (%) | Compensatory Movements (Pre) | Compensatory Movements (Post) | Reduction (%) |
|---|---|---|---|---|---|---|
| Squat (Knee Flexion Angle) | 82.9 ± 9.4 | 94.7 ± 7.8 | +14.2% | 23 occurrences | 9 occurrences | −60.9% |
| Lunge (Hip Flexion Angle) | 73.2 ± 8.1 | 85.4 ± 6.9 | +16.7% | 17 occurrences | 7 occurrences | −58.8% |
| Step-Up (Knee Extension Angle) | 57.4 ± 5.8 | 64.8 ± 5.1 | +12.9% | 15 occurrences | 5 occurrences | −66.7% |
| Walking Gait (Hip Adduction Angle) | 9.3 ± 2.4 | 5.6 ± 1.8 | −39.8% | 12 occurrences | 4 occurrences | −66.7% |
| Jumping (Ankle Dorsiflexion Angle) | 23.5 ± 4.2 | 28.1 ± 3.9 | +19.6% | 18 occurrences | 6 occurrences | −66.7% |

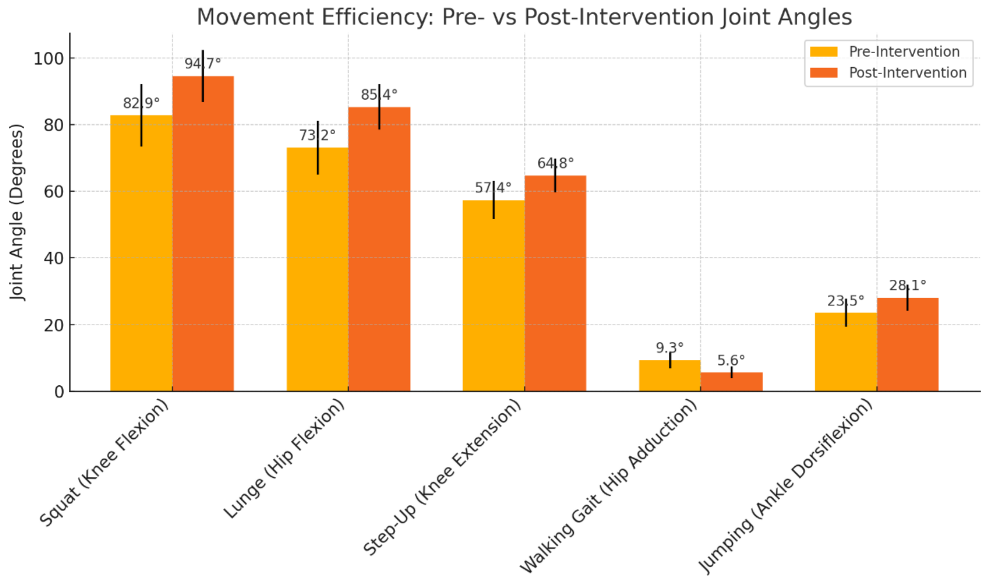


**Figure 5.** Movement efficiency.

**Table 5** and **Figure 6** analyze ground reaction forces (GRF) during walking, squatting, lunging, jumping, and step-ups. Across all movements, there was a decrease in uneven force distribution and a significant improvement in force symmetry. For instance, vertical force symmetry improved by 7.7% during walking, corresponding to a 63.6% reduction in uneven force incidents. This suggests that participants distributed their weight more evenly between both legs, reducing the likelihood of overloading specific joints. Similarly, squatting saw a 12.3% improvement in anterior-posterior force symmetry and a 66.7% reduction in uneven force incidents, indicating better balance and joint loading during dynamic movements. Lunging and jumping also showed significant gains in force symmetry, with reductions in uneven force incidents of 66.7% and 65.0%, respectively. The improvement in vertical forces during step-ups (9.5% increase in symmetry) further reflects the success of the intervention in promoting balanced, efficient movement patterns, reducing the risk of injury by minimizing excessive forces on individual joints.

**Table 5.** Ground reaction forces.

| Movement Type | Pre-Intervention Ground Reaction Force (Mean ± SD) | Post-Intervention Ground Reaction Force (Mean ± SD) | Force Symmetry Pre (%) | Force Symmetry Post (%) | Symmetry Improvement (%) | Uneven Force Incidents (Pre) | Uneven Force Incidents (Post) | Reduction in Incidents (%) |
|---|---|---|---|---|---|---|---|---|
| Walking (Vertical Force) | 1.23 BW ± 0.08 BW | 1.18 BW ± 0.07 BW | 88.3% | 95.1% | +7.7% | 22 | 8 | −63.6% |
| Squatting (Anterior-Posterior Force) | 0.37 BW ± 0.05 BW | 0.32 BW ± 0.04 BW | 82.5% | 92.6% | +12.3% | 18 | 6 | −66.7% |
| Lunging (Medio-Lateral Force) | 0.19 BW ± 0.03 BW | 0.15 BW ± 0.02 BW | 85.2% | 94.8% | +11.3% | 15 | 5 | −66.7% |
| Jumping (Vertical Force) | 2.17 BW ± 0.12 BW | 2.08 BW ± 0.11 BW | 80.6% | 90.4% | +12.2% | 20 | 7 | −65.0% |
| Step-Up (Vertical Force) | 1.45 BW ± 0.09 BW | 1.38 BW ± 0.08 BW | 83.7% | 91.7% | +9.5% | 17 | 6 | −64.7% |

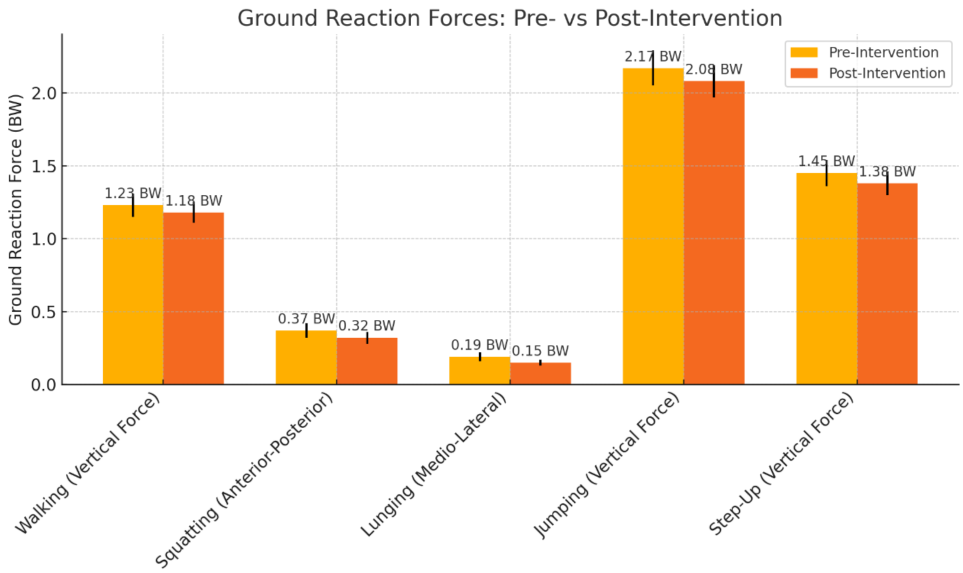


**Figure 6.** Ground reaction forces.

## 4.2. Psychological outcomes

**Table 6** and **Figure 7** show that the intervention considerably reduced perceived stress levels. As measured by the PSS total score, the overall stress level decreased by 30.9%, from a pre-intervention score of 23.6 to a post-intervention score of 16.3. This indicates that participants experienced significant relief from stress after improving their posture and movement patterns. This reduction was particularly evident in physical stress, which saw a 32.1% reduction, and emotional stress, which decreased by 32.9%. The improvement in physical stress suggests that participants felt less bodily tension, likely due to the biomechanical interventions that corrected postural misalignments and enhanced movement efficiency. The correlation between biomechanical improvements and stress reduction was notable, with a moderate negative correlation of $r = -0.67$ for overall stress, indicating that participants who showed greater biomechanical improvements experienced more significant reductions in stress. Similarly, the correlations for physical stress ($r = -0.62$) and emotional stress

($r$ = −0.65) further demonstrate that improved posture and movement positively affected participants' physical and emotional states.

**Table 6.** Perceived stress levels (Pre- and Post-Intervention).

| Perceived Stress Level | Pre-Intervention PSS Score (Mean ± SD) | Post-Intervention PSS Score (Mean ± SD) | Change in PSS Score (%) | Correlation with Biomechanical Improvement ($r$) |
|---|---|---|---|---|
| Overall Stress Level (PSS Total) | 23.6 ± 5.8 | 16.3 ± 4.7 | −30.9% | −0.67 |
| Physical Stress | 8.4 ± 2.1 | 5.7 ± 1.6 | −32.1% | −0.62 |
| Emotional Stress | 7.9 ± 2.0 | 5.3 ± 1.5 | −32.9% | −0.65 |
| Interpersonal Stress | 7.3 ± 1.9 | 5.3 ± 1.6 | −27.4% | −0.58 |

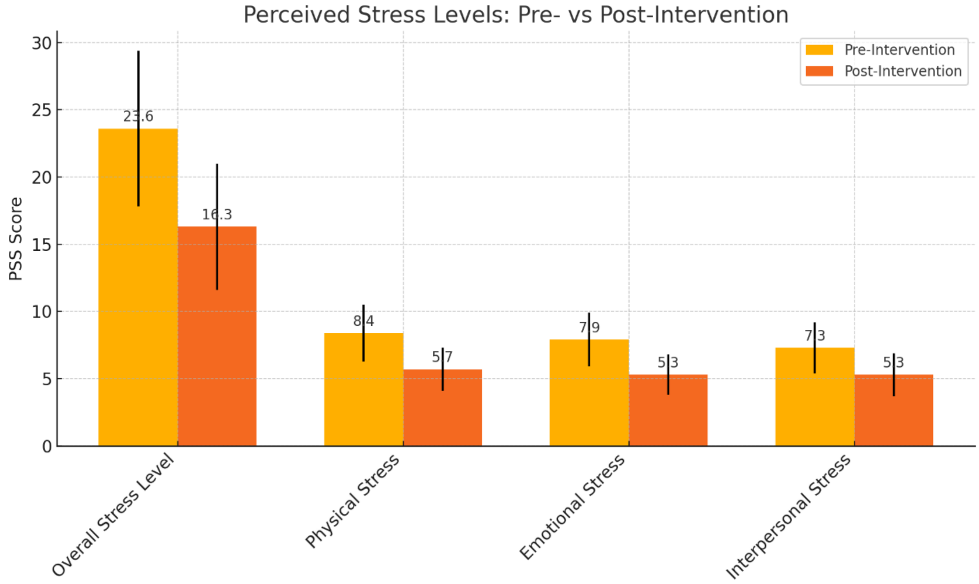


**Figure 7.** Perceived stress levels.

The intervention also substantially reduced anxiety levels, as measured by the GAD-7 scale (**Table 7**). The overall anxiety score dropped by 38.5%, from 11.7 pre-intervention to 7.2 post-intervention, reflecting a marked improvement in participants' ability to manage anxiety. This anxiety reduction was particularly pronounced in restlessness, which decreased by 44.7%, and worry, which dropped by 39.0%. The improvement in restlessness indicates that participants were less physically agitated and more at ease after the intervention, likely due to the enhanced balance and muscle activation resulting from biomechanical training. The correlation analysis shows a robust negative relationship between biomechanical improvements and anxiety reduction, with an overall correlation of r = −0.69. This suggests that participants who experienced more significant gains in posture and movement efficiency also saw more considerable reductions in anxiety symptoms. The strong correlation for restlessness (r = −0.72) indicates that improvements in movement coordination and balance contributed heavily to reduced anxiety, particularly regarding physical agitation.

**Table 7.** Anxiety levels (Pre- and Post-Intervention).

| Anxiety Measure | Pre-Intervention GAD-7 Score (Mean ± SD) | Post-Intervention GAD-7 Score (Mean ± SD) | Change in GAD-7 Score (%) | Correlation with Posture & Movement Improvements (r) |
|---|---|---|---|---|
| Overall Anxiety (GAD-7 Total) | 11.7 ± 3.4 | 7.2 ± 2.8 | −38.5% | −0.69 |
| Nervousness | 3.8 ± 1.2 | 2.6 ± 1.1 | −31.6% | −0.61 |
| Worry | 4.1 ± 1.3 | 2.5 ± 1.1 | −39.0% | −0.66 |
| Restlessness | 3.8 ± 1.1 | 2.1 ± 1.0 | −44.7% | −0.72 |

Improvements in participants' moods were also evident from the results in **Table 8** and **Figure 8**, which show positive and negative affect changes. Positive affect increased by 29.5%, from 25.8 pre-intervention to 33.4 post-intervention, with solid gains in enthusiasm (30.4%) and alertness (39.0%). The significant improvement in alertness suggests that participants felt more mentally sharp and attentive, likely due to better physical posture and movement, which may have reduced fatigue and improved focus. Conversely, negative affect decreased by 30.3%, with notable reductions in distress (32.4%) and irritability (33.9%). The reduction in negative affect highlights the MH benefits of the intervention, showing that participants felt less overwhelmed, frustrated, and emotionally strained after the biomechanical improvements.

The correlations between biomechanical improvements and mood changes were strong, with positive affect showing a positive correlation of $r = +0.72$ and negative affect demonstrating a negative correlation of $r = -0.74$. These results indicate that participants who experienced more significant biomechanical gains also felt more positive and fewer negative emotions, reinforcing the close connection between PH and emotional well-being.


**Figure 8.** Mood improvement.

**Table 8.** Mood improvement (Pre- and Post-Intervention).

| Mood Measure | Pre-Intervention PANAS Score (Mean ± SD) | Post-Intervention PANAS Score (Mean ± SD) | Change in PANAS Score (%) | Correlation with Posture & Movement Improvements (r) |
|---|---|---|---|---|
| Positive Affect (Total) | 25.8 ± 5.9 | 33.4 ± 6.2 | +29.5% | +0.72 |
| Enthusiasm | 4.6 ± 1.4 | 6.0 ± 1.5 | +30.4% | +0.68 |
| Alertness | 4.1 ± 1.2 | 5.7 ± 1.4 | +39.0% | +0.73 |
| Negative Affect (Total) | 28.4 ± 6.7 | 19.8 ± 5.8 | −30.3% | −0.74 |
| Distress | 6.8 ± 1.7 | 4.6 ± 1.5 | −32.4% | −0.69 |
| Irritability | 6.2 ± 1.6 | 4.1 ± 1.4 | −33.9% | −0.71 |

## 5. Conclusion and future work

This study demonstrates that targeted biomechanical interventions, such as postural correction exercises and dynamic movement training, can significantly improve physical and psychological outcomes in college students. The findings revealed substantial improvements in postural alignment, muscle activation, movement efficiency, and ground reaction force symmetry, translating into enhanced physical well-being. More importantly, these physical improvements were strongly correlated with reductions in perceived stress and anxiety levels and improvements in mood, including increased positive and reduced negative affect. The reduction in stress and anxiety, combined with mood enhancements, suggests that improving posture and movement patterns can profoundly impact MH. These results highlight the potential for integrating biomechanical approaches into MH strategies, especially for populations such as college students vulnerable to physical inactivity and MH challenges. By addressing physical and psychological health dimensions, this study supports the growing body of evidence advocating for holistic interventions that combine physical exercise with MH care. The integration of biomechanical training into everyday routines could offer a practical, non-pharmacological approach to managing MH challenges like stress, anxiety, and mood disorders.

Future research should explore the long-term effects of such interventions and investigate their applicability to broader populations.

**Ethical approval:** Nor applicable.

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