SIN-CHN SCIENTIFIC PRESS PTE.LTD.

Molecular & Cellular Biomechanics 2024, 21(2), 398.
https://doi.org/10.62617/mcb.v21i2.398

Article

Biomechanical factors influencing mental health in college students and the role of physical activity in cognitive resilience

Ganbin Xu

Zhejiang Police College, Hangzhou 310000, China; xgb13588131440@outlook.com

CITATION

Xu G. Biomechanical factors influencing mental health in college students and the role of physical activity in cognitive resilience. Molecular & Cellular Biomechanics. 2024; 21(2): 398. https://doi.org/10.62617/mcb.v21i2.398

ARTICLE INFO

Received: 20 September 2024
Accepted: 8 October 2024
Available online: 6 November 2024

Abstract: The Mental Health (MH) of college students is increasingly becoming a public health concern, with rising rates of depression, anxiety, and stress. This study aims to explore the relationship between Biomechanical Factors (BF), Physical Activity (PA), and MH outcomes in college students, addressing gaps in current research that frequently overlook the biomechanical features of physical well-being. A cross-sectional observational design was employed, involving 200 college students aged 18–24. SP underwent comprehensive assessments, including postural analysis, movement pattern evaluation, and MH screening. Physical activity levels and cognitive resilience were also measured to evaluate their roles in mediating and moderating the relationships between BF and MH. Key findings revealed that poor biomechanical alignment, such as forward head posture and movement asymmetry, were significantly associated with higher levels of depression, anxiety, and stress. Correlation analysis showed that forward head posture correlated positively with depression ($r = 0.52$, $p < 0.01$) and anxiety ($r = 0.47$, $p < 0.01$). Movement asymmetry was also associated with MH disturbances (depression: $r = 0.45$, $p < 0.01$). PA mediated the relationship between BF and MH, with significant indirect effects via PA for forward head posture (0.18, $p < 0.05$). Cognitive resilience emerged as a significant moderator, buffering the negative impact of biomechanical inefficiencies on MH outcomes. Within-subject comparisons indicated improvements in BF and MH scores over a one-month follow-up, with decreases in forward head posture (−2.2 ± 1.5 degrees, $p < 0.05$) and depression scores (−1.5 ± 1.2, $p < 0.01$).

Keywords: biomechanical features; biomechanical alignment; physical activity; mental health; posture and movement

1. Introduction

Mental Health (MH) issues among college students have become a significant public health concern worldwide, with increasing rates of anxiety, depression, and stress reported in this population [1,2]. College students face unique challenges, including academic pressure, social adjustment, and the transition to independence, which can lead to MH disturbances [3]. Physical Activity (PA) is widely recognized for its positive impact on MH, promoting psychological well-being and cognitive resilience [4]. However, less attention has been paid to the role of Biomechanical Factors (BF), such as posture and movement patterns, in manipulating MH outcomes [5,6]. Understanding these factors is crucial, as they may provide a more comprehensive approach to enhancing MH in college students [7].

Biomechanics studies human movement, posture, and the forces acting upon the body [8,9]. Poor biomechanical alignment, such as forward head posture and movement asymmetries, has been associated with musculoskeletal discomfort and may contribute to psychological distress [10]. Prolonged sedentary behavior, shared among students due to long study and screen time hours, can lead to postural deviations and reduced PA levels [11]. This interplay between a sedentary lifestyle, biomechanical inefficiencies, and MH underscores the need for a holistic understanding of how these factors impact students' well-being [12,13].

Current research has primarily emphasized the benefits of PA on MH, highlighting its role in reducing symptoms of depression, anxiety, and stress [14–16]. Studies have shown that regular exercise can enhance cognitive function, mood regulation, and overall psychological resilience [17–19]. However, these studies often overlook the biomechanical features of PA, such as how posture and movement quality may mediate or moderate the MH benefits of exercise [20]. Additionally, the literature on the relationship between biomechanics and MH is limited, with most studies focusing on clinical populations rather than college students [21]. This gap in research highlights the need to explore BF as a potential contributor to MH outcomes in this demographic [22–25].

The current study addresses these limitations by investigating the relationship between BF, PA, and MH among college students [26–30]. Unlike previous research focusing on exercise frequency and intensity, this study will incorporate biomechanical assessments such as postural alignment, movement asymmetry, and gait analysis [31–34]. Furthermore, the study will explore the role of cognitive resilience as a potential moderator in the relationship between biomechanics and MH, providing a nuanced understanding of how physical and psychological factors interact.

The objectives of this study are as follows:

a) To assess the association between BF (e.g., forward head posture, movement asymmetry) and MH outcomes (depression, anxiety, and stress) in college students.
b) To evaluate the mediating role of PA in the relationship between BF and MH.
c) To examine the moderating effect of cognitive resilience on the relationship between BF and MH.
d) To identify temporal changes in BF, MH status, and cognitive resilience over a 1-month follow-up period.
e) To utilize predictive modeling to identify which biomechanical and lifestyle factors significantly predict MH outcomes.

The paper is organized as follows: Section 2 presents the methodology, Section 3 presents the data analysis, and Section 4 concludes the paper.

2. Methodology

2.1. Participants

The study initially enrolled 253 college students (141 males and 112 females) aged between 18.2 and 24.7 years from four universities in China. SP was recruited using a stratified sampling method to ensure diverse representation across academic disciplines, including science (31.7%), engineering (24.9%), humanities (28.3%), and social sciences (15.1%). The inclusion criteria specified full-time students with no history of severe MH disorders or physical disabilities that could interfere with movement assessments. During the eligibility screening phase, SP underwent evaluations of PA and MH status. This process involved self-reported health questionnaires and a clinical valuation conducted by a licensed healthcare professional.

Of the 253 students initially enrolled, 27 were deemed ineligible. Specifically, 11 SP reported MH conditions (e.g., diagnosed anxiety disorders) that could impact the study's focus, while 16 had physical impairments (e.g., musculoskeletal issues) that would interfere with biomechanical assessments. This screening resulted in 226 students meeting the eligibility criteria. Subsequently, a more detailed assessment was conducted to ensure a balanced representation of PA levels among SPs. Students were classified into physically active and sedentary groups using the International Physical Activity Questionnaire (IPAQ). During this phase, 18 SP were excluded due to incomplete or inconsistent IPAQ responses, leading to a shortlist of 208 students for the study. 8 SP (3 Males and 5 Females) withdrew throughout the study. Reasons for withdrawal included academic pressures (4 SP) and personal health issues unrelated to the study (4 SP). This left a final sample size of 200 students (119 Males and 81 Females) who completed the study.

Within the final sample, 97 students were categorized as PA, engaging in moderate to vigorous PA for an average of 165.7 min per week, ranging from 151 to 233 min. The remaining 103 students were classified as sedentary, with PA levels averaging 48.2 min per week, ranging from 21.5 to 57.9 min. The SP's average Body Mass Index (BMI) was 22.46 kg/m^2, with values ranging from 18.34 to 27.84 kg/m^2, reflecting a diverse sample of typical college students. Data on sleep patterns, academic workload, and extracurricular activities were also collected through detailed questionnaires to account for other lifestyle factors potentially affecting biomechanical and MH outcomes. Ethical approval for this study was attained from the institutional review boards of all participating universities. Informed consent was acquired from each SP, following a thorough briefing on the study's objectives, procedures, and any associated risks.

2.2. Study design

This study employed a cross-sectional observational design to explore the relationship between BF, MH, and cognitive resilience among college students. The cross-sectional approach was selected to capture a snapshot of how BF, such as posture, movement patterns, and PA levels, correlate with MH status and cognitive resilience in a diverse college population. The study's observational nature allowed for the assessment of naturally occurring variations in these factors without the imposition of interventions, ensuring that findings are reflective of real-world conditions in the student population. Data was collected over 3 months, with each SP undergoing a comprehensive evaluation. The study included multiple stages: baseline assessments, biomechanical analysis, MH evaluation, and cognitive resilience measurement. Baseline assessments involved collecting demographic data, lifestyle factors (e.g., sleep patterns, academic workload), and PA levels through the International Physical Activity Questionnaire (IPAQ). Following baseline assessments, a detailed biomechanical analysis was conducted. This included posture assessments using a digital postural analysis tool and movement pattern evaluations through 3D motion capture technology to examine aspects like gait and range of motion. MH status was assessed using the Depression, Anxiety, and Stress Scale (DASS-21), a validated instrument for measuring the severity of core MH symptoms in a non-clinical population. Cognitive resilience was measured using the Cognitive Resilience Scale (CRS), which evaluates the SP's ability to cope with cognitive challenges and stressors. Both assessments were administered in a controlled manner to minimize external influences on SP's responses.

SP was divided into two groups based on PA levels determined by IPAQ: the physically active and sedentary. Biomechanical data, MH status, and cognitive resilience scores were then compared between these groups to investigate the potential influence of PA on the BF and their associated impact on MH outcomes. Additionally, correlations between BF (e.g., posture alignment, movement efficiency) and MH indicators were analyzed to identify specific biomechanical risk factors related to MH. The study also included a follow-up component where SP was monitored over 1 month to observe any changes in BF and MH status. Although the primary study design was cross-sectional, this follow-up allowed for preliminary visions into the temporal dynamics between PA, biomechanics, and MH.

2.3. Measurements

To comprehensively explore the relationship between BF, MH, and cognitive resilience, the study utilized a multi-dimensional measurement approach, encompassing biomechanical assessments, MH evaluations, and cognitive resilience measurements.

A. Biomechanical assessments: Postural alignment and movement patterns were the primary focus of biomechanical assessments. Postural analysis was conducted using a digital postural analysis tool, which utilized a series of digital photographs taken from anterior, lateral, and posterior views. These images were analyzed using posture assessment software to identify deviations from the neutral alignment, such as forward head posture, rounded shoulders, and pelvic tilt. Additionally, movement patterns were evaluated using 3D motion capture technology. Student Participants (SP) performed a series of functional movement tasks, including walking, squatting, and reaching, which were recorded to assess gait, joint angles, and range of motion. Data from these tasks provided insights into the efficiency and quality of movements, with specific attention to asymmetries, compensatory movements, and kinematic abnormalities. Muscle activity was also measured using surface electromyography (sEMG) for key muscle groups during these tasks to examine the neuromuscular control associated with various movement patterns.

B. PA levels: SP' PA levels were measured using the IPAQ, a widely recognized self-report instrument that assesses the frequency and duration of vigorous, moderate, and walking activities over the past 7 days. The data collected were used to calculate the total PA score in MET minutes/week, which helped categorize SP into PA and sedentary groups. In addition to self-reporting, accelerometers were provided to a subset of SP (n = 50) to objectively monitor PA over seven consecutive days, offering a cross-validation of the self-reported data.

C. MH evaluations: MH status was assessed using the Depression, Anxiety, and Stress Scale (DASS-21), a 21-item self-report questionnaire that evaluates symptoms of depression, anxiety, and stress. Each item was rated on a 4-point severity scale, providing subscale scores for depression, anxiety, and stress, as well as a total score. Higher scores indicated greater severity of symptoms. To ensure reliability and validity, SP completed the DASS-21 in a quiet and controlled environment, with the average completion time being approximately 5–7 min. The collected data allowed for a detailed analysis of MH status concerning biomechanical and PA variables.

D. Cognitive resilience measurements: Cognitive resilience was measured using the Cognitive Resilience Scale (CRS), a validated tool designed to assess individuals' ability to adapt and maintain cognitive performance under stress. The CRS includes questions that device cognitive flexibility, problem-solving skills, and coping mechanisms in response to cognitive challenges. SP responded to a series of items on a 5-point Likert scale, with higher scores reflecting greater cognitive resilience. The CRS provided a quantitative measure of SP's cognitive coping abilities, which were then analyzed concerning their biomechanical profiles and PA levels.

E. Additional lifestyle factors: To control for confounding variables, additional lifestyle factors such as sleep quality, academic workload, and dietary habits were measured using standardized questionnaires. Sleep quality was assessed with the Pittsburgh Sleep Quality Index (PSQI), while academic workload was quantified by the number of hours spent on academic activities weekly.

3. Analysis

Descriptive statistics (**Table 1** and **Figure 1**) showed that the mean age of SP was 21.47 years (SD = 1.89), ranging from 18.22 to 24.65 years. The mean BMI was 22.46 kg/m^2 (SD = 2.37), ranging from 18.34 to 27.81 kg/m^2. Sleep quality, measured by the PSQI score, averaged 5.83 (SD = 1.27), with scores ranging from 3.02 to 8.97. The average academic workload was 34.17 h per week (SD = 8.68), with a minimum of 20.13 and a maximum of 49.78 h. PA levels averaged 987.6 MET-minutes/week (SD = 324.5), ranging from 211.3 to 2348.9 MET-minutes/week. The mean forward head angle was 42.3 degrees (SD = 8.1), ranging from 28.5 to 58.2 degrees. Shoulder position averaged 8.64 mm (SD = 3.17), with a minimum of 4.14 mm and a maximum of 17.27 mm. Gait speed had a mean of 1.28 m/s (SD = 0.25), ranging from 0.84 to 1.93 m/s. The mean depression score (DASS-21) was 8.72 (SD = 4.13), ranging from 0.57 to 19.86. Anxiety scores averaged 6.87 (SD = 3.52), ranging from 0.43 to 15.92. Stress scores averaged 9.34 (SD = 4.06), ranging from 1.11 to 20.77. Cognitive resilience scores had a mean of 28.39 (SD = 7.48), ranging from 10.24 to 44.95.

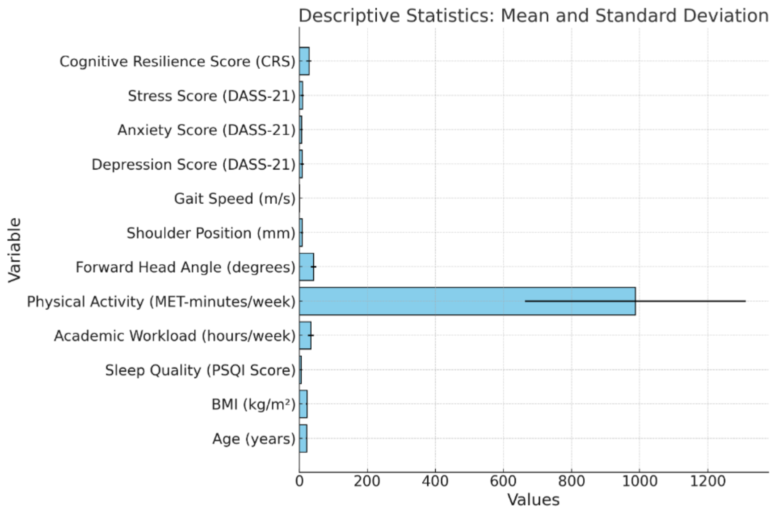

Figure 1. Descriptive statistics.

Table 1. Descriptive statistics.

Variable	**Mean**	**SD**	**Min**	**Max**
Age (years)	21.47	1.89	18.22	24.65
BMI (kg/m^2)	22.46	2.37	18.34	27.81
Sleep Quality (PSQI Score)	5.83	1.27	3.02	8.97
Academic Workload (hours/week)	34.17	8.68	20.13	49.78
PA (MET-minutes/week)	987.6	324.5	211.3	2348.9
Forward Head Angle (degrees)	42.3	8.1	28.5	58.2
Shoulder Position (mm)	8.64	3.17	4.14	17.27
Gait Speed (m/s)	1.28	0.25	0.84	1.93
Depression Score (DASS-21)	8.72	4.13	0.57	19.86
Anxiety Score (DASS-21)	6.87	3.52	0.43	15.92
Stress Score (DASS-21)	9.34	4.06	1.11	20.77
Cognitive Resilience Score (CRS)	28.39	7.48	10.24	44.95

Group comparisons (**Figure 2** and **Table 2**) revealed significant differences between physically active and sedentary SP. Physically active SP had a significantly lower forward head angle (38.4 ± 7.9 degrees) compared to sedentary SP (45.6 ± 8.2 degrees, $p < 0.01$). SP with low depression scores also had a lower forward head angle (37.8 ± 7.3 degrees) compared to those with high depression scores (46.2 ± 8.7 degrees, $p < 0.01$). Shoulder position was better in physically active individuals (7.2 ± 2.8 mm) than in sedentary individuals (9.8 ± 3.1 mm, $p < 0.01$) and was similarly lower in the low depression group (7.1 ± 2.7 mm) versus the high depression group (10.1 ± 3.4 mm, $p < 0.01$). Gait speed was higher among physically active SP (1.38 ± 0.21 m/s) compared to sedentary SP (1.17 ± 0.26 m/s, $p < 0.05$) and higher in the low depression group (1.42 ± 0.19 m/s) compared to the high depression group (1.12 ± 0.27 m/s, $p < 0.05$). Depression scores were significantly lower in physically active SP (6.2 ± 3.5) than in sedentary SP (10.4 ± 4.2, $p < 0.01$). Anxiety and stress scores followed a similar pattern, with lower scores in physically active individuals (4.8 ± 2.9 and 7.3 ± 3.2, respectively) compared to sedentary individuals (8.1 ± 3.6 and 11.2 ± 4.1, respectively,

$p < 0.01$). Cognitive resilience scores were higher in the physically active group (31.7 ± 6.5) compared to the sedentary group (24.9 ± 7.1, $p < 0.01$).

Table 2. Group comparisons.

Parameter	**Physically Active (Mean ± SD)**	**Sedentary (Mean ± SD)**	***p*-value**	**Low Depression Score (Mean ± SD)**	**High Depression Score (Mean ± SD)**	***p*-value (Depression Group)**
Forward Head Angle (degrees)	38.4 ± 7.9	45.6 ± 8.2	< 0.01	37.8 ± 7.3	46.2 ± 8.7	< 0.01
Shoulder Position (mm)	7.2 ± 2.8	9.8 ± 3.1	< 0.01	7.1 ± 2.7	10.1 ± 3.4	< 0.01
Gait Speed (m/s)	1.38 ± 0.21	1.17 ± 0.26	< 0.05	1.42 ± 0.19	1.12 ± 0.27	< 0.05
Depression Score (DASS-21)	6.2 ± 3.5	10.4 ± 4.2	< 0.01	-	-	-
Anxiety Score (DASS-21)	4.8 ± 2.9	8.1 ± 3.6	< 0.01	-	-	-
Stress Score (DASS-21)	7.3 ± 3.2	11.2 ± 4.1	< 0.01	-	-	-
Cognitive Resilience Score (CRS)	31.7 ± 6.5	24.9 ± 7.1	< 0.01	-	-	-

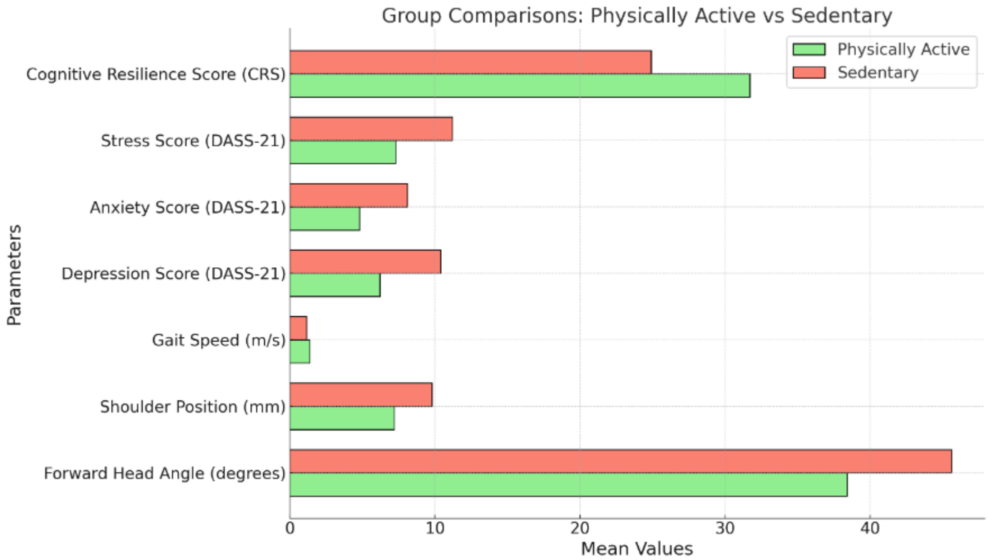

Figure 2. Group comparison results.

Correlation coefficients (**Table 3** and **Figure 3**) indicated significant relationships between BF and MH. Forward Head Posture had a positive correlation with depression ($r = 0.52$, $p<0.01$), anxiety ($r = 0.47$, $p < 0.01$), and stress ($r = 0.49$, $p < 0.01$). Movement Asymmetry was positively correlated with depression ($r = 0.45$, $p < 0.01$), anxiety ($r = 0.38$, $p < 0.05$), and stress ($r = 0.42$, $p < 0.01$). Shoulder Position showed a positive correlation with depression ($r = 0.39$, $p < 0.05$), anxiety ($r = 0.35$, $p < 0.05$), and stress ($r = 0.36$, $p < 0.05$). Gait Speed was negatively correlated with depression ($r = -0.41$, $p < 0.01$), anxiety ($r = -0.37$, $p < 0.05$), and stress ($r = -0.40$, $p < 0.01$).

Table 3. BF and MH: Correlation coefficients.

BF	Depression Score (r)	Anxiety Score (r)	Stress Score (r)	*p*-value (Depression)	*p*-value (Anxiety)	*p*-value (Stress)
Forward Head Posture (degrees)	0.52	0.47	0.49	< 0.01	< 0.01	< 0.01
Movement Asymmetry (%)	0.45	0.38	0.42	< 0.01	< 0.05	< 0.01
Shoulder Position (mm)	0.39	0.35	0.36	< 0.05	< 0.05	< 0.05
Gait Speed (m/s)	−0.41	−0.37	−0.40	< 0.01	< 0.05	< 0.01

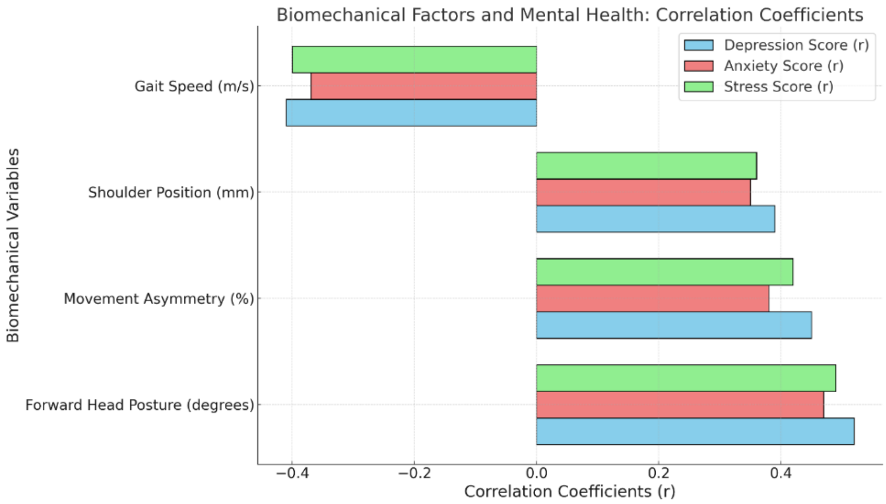

Figure 3. Correlation coefficients of BF and MH.

Multiple regression analyses (**Table 4** and **Figure 4**) identified significant predictors for MH outcomes. For Depression, forward head posture had a positive beta coefficient of 0.35 ($p < 0.01$), indicating a strong direct relationship with higher depression scores. Movement asymmetry (beta = 0.29, $p < 0.05$) and shoulder position (beta = 0.22, $p < 0.05$) were also positively associated with depression. Gait speed showed a negative association (beta = −0.26, $p < 0.05$), suggesting that higher gait speed is linked to lower depression levels. Sleep quality was a strong predictor (beta = 0.41, $p < 0.01$), with poorer sleep quality related to increased depression. PA had a negative beta coefficient of -0.38 ($p < 0.01$), indicating that higher PA is associated with lower depression. For Anxiety, forward head posture was a significant predictor with a beta coefficient of 0.32 ($p < 0.01$). Movement asymmetry (beta = 0.24, $p < 0.05$) and shoulder position (beta = 0.19, $p < 0.05$) were also positively associated with higher anxiety levels. Gait speed had a negative effect (beta = −0.23, $p < 0.05$), indicating that increased gait speed is linked to reduced anxiety. Poor sleep quality (beta = 0.37, $p < 0.01$) and lower PA levels (beta = −0.34, $p < 0.01$) were strong predictors of higher anxiety. For Stress, forward head posture showed a beta coefficient of 0.33 (p < 0.01), indicating a positive relationship with higher stress levels. Movement asymmetry (beta = 0.27, $p < 0.05$) and shoulder position (beta = 0.21, $p < 0.05$) were also significant positive predictors. Gait speed was negatively associated with stress (beta = −0.25, $p < 0.05$). Sleep quality (beta = 0.39, $p < 0.01$) and PA (beta = −0.36, $p < 0.01$) were strong predictors, indicating that poorer sleep and lower PA levels are associated with higher stress.

Table 4. Multiple regression analyses—predictive modeling for MH outcomes.

Predictor Variable	Beta Coefficient (Depression)	*p*-value (Depression)	Beta Coefficient (Anxiety)	*p*-value (Anxiety)	Beta Coefficient (Stress)	*p*-value (Stress)
Forward Head Posture (degrees)	0.35	< 0.01	0.32	< 0.01	0.33	< 0.01
Movement Asymmetry (%)	0.29	< 0.05	0.24	< 0.05	0.27	< 0.05
Shoulder Position (mm)	0.22	< 0.05	0.19	< 0.05	0.21	< 0.05
Gait Speed (m/s)	−0.26	< 0.05	−0.23	< 0.05	−0.25	< 0.05
Sleep Quality (PSQI Score)	0.41	< 0.01	0.37	< 0.01	0.39	< 0.01
PA (MET-minutes/week)	−0.38	< 0.01	−0.34	< 0.01	−0.36	< 0.01

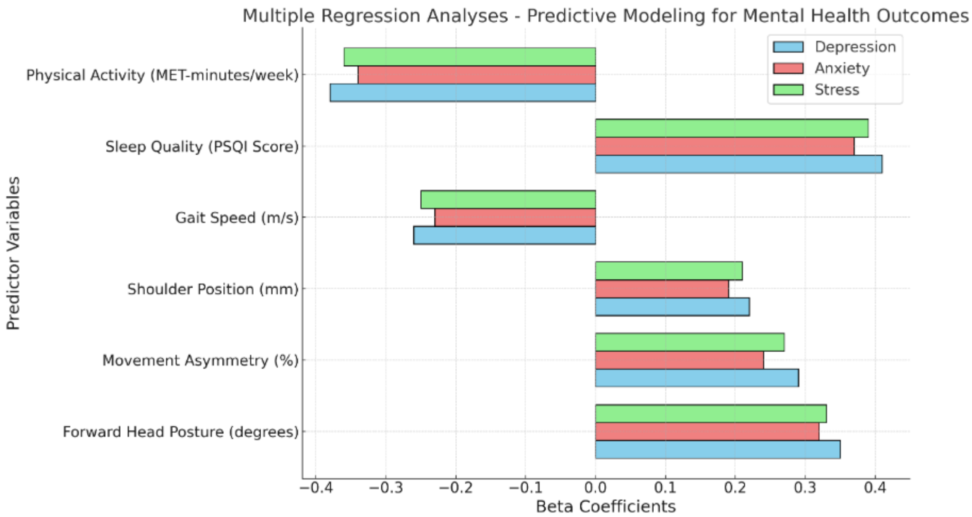

Figure 4. Multiple regression analyses—Predictive modeling for MH outcomes.

Mediation analysis (**Table 5** and **Figure 5**) showed that PA significantly mediated the relationship between BF and depression. For Forward Head Posture, the direct effect on depression was 0.30 ($p < 0.01$), and the indirect effect via PA was 0.18 ($p < 0.05$), resulting in a total effect of 0.48, with a significant Sobel test. For Movement Asymmetry, the direct effect was 0.25 ($p < 0.05$), and the indirect effect via PA was 0.14 ($p < 0.05$), yielding a total effect of 0.39 and a significant Sobel test. For the Shoulder Position, the direct effect was 0.19 ($p < 0.05$), and the indirect effect was 0.11 ($p < 0.05$), with a total effect of 0.30, also showing significance in the Sobel test.

Table 5. Mediation analysis: PA as a mediator.

BF	Direct Effect (BFon Depression)	Indirect Effect (via PA)	Total Effect	*p*-value (Direct Effect)	*p*-value (Indirect Effect)	Mediation Significance (Sobel Test)
Forward Head Posture (degrees)	0.30	0.18	0.48	< 0.01	< 0.05	Significant
Movement Asymmetry (%)	0.25	0.14	0.39	< 0.05	< 0.05	Significant
Shoulder Position (mm)	0.19	0.11	0.30	< 0.05	< 0.05	Significant

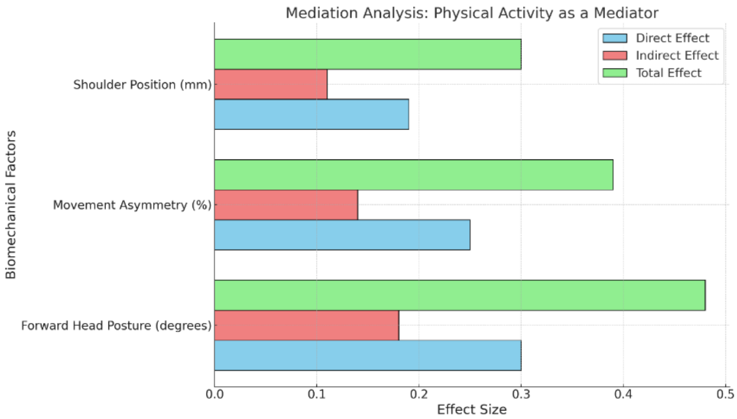

Figure 5. Mediation analysis: PA as a mediator.

Moderation analysis (**Table 6** and **Figure 6**) showed that cognitive resilience significantly moderated the relationship between BFs and depression. For Forward Head Posture, the interaction term was −0.22 ($p < 0.05$), with an effect on depression of 0.45 in low cognitive resilience and 0.23 in high cognitive resilience. For Movement Asymmetry, the interaction term was −0.18 ($p < 0.05$), affecting depression of 0.38 in low cognitive resilience and 0.20 in high cognitive resilience. For Shoulder Position, the interaction term was −0.15 ($p < 0.05$), with an effect on depression of 0.33 in low cognitive resilience and 0.18 in high cognitive resilience.

Table 6. Moderation analysis-cognitive resilience as a moderator.

BF	Interaction Term (BF* Cognitive Resilience)	*p*-value (Interaction)	Effect on Depression (Low Cognitive Resilience)	Effect on Depression (High Cognitive Resilience)	Moderation Significance
Forward Head Posture (degrees)	−0.22	< 0.05	0.45	0.23	Significant
Movement Asymmetry (%)	−0.18	< 0.05	0.38	0.20	Significant
Shoulder Position (mm)	−0.15	< 0.05	0.33	0.18	Significant

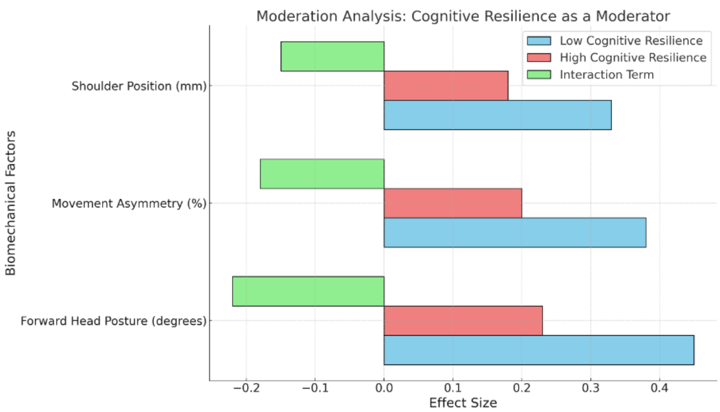

Figure 6. Moderation analysis-cognitive resilience as a moderator.

Exploratory Factor Analysis (**Table 7**) identified three factors explaining the relationship between BF and MH outcomes. Factor 1: Postural Efficiency had high loadings on BF, specifically forward head posture (0.78) and shoulder position (0.72), explaining 32.4% of the variance. Factor 2: Movement Quality was defined by loadings on movement asymmetry (0.69) and gait speed (−0.65), accounting for 28.7% of the variance. Together, these two factors explained a cumulative variance of 61.1%, highlighting key biomechanical constructs related to postural and movement efficiency. Factor 3: MH Disturbance was characterized by high loadings on MH outcomes, including depression (0.82), anxiety (0.75), and stress scores (0.79), explaining an additional 29.5% of the variance. This factor represents the MH domain and, combined with the BF, explains a cumulative variance of 90.6%. These findings suggest that distinct biomechanical constructs such as postural efficiency and movement quality are associated with MH disturbance, indicating a complex interplay between physical and psychological domains.

Table 7. Exploratory factor analysis for biomechanical and MH constructs.

Factor	Loadings on Biomechanical Parameters	Loadings on MH Outcomes	Variance Explained (%)	Cumulative Variance Explained (%)
Factor 1: Postural Efficiency	Forward Head Posture (0.78), Shoulder Position (0.72)	-	32.4	32.4
Factor 2: Movement Quality	Movement Asymmetry (0.69), Gait Speed (−0.65)	-	28.7	61.1
Factor 3: MH Disturbance	-	Depression Score (0.82), Anxiety Score (0.75), Stress Score (0.79)	29.5	90.6

Analysis of temporal changes (**Table 8** and **Figure 7**) over the 1-month follow-up period showed significant improvements in BF and MH status. Forward Head Posture decreased from 42.3 ± 8.1 degrees at baseline to 40.1 ± 7.8 degrees, with a mean change of −2.2 ± 1.5 degrees ($p < 0.05$). Movement Asymmetry reduced from 12.5 ± 4.3% to 10.9 ± 4.1%, showing a mean change of −1.6 ± 1.3% ($p < 0.05$). For MH outcomes, Depression Scores significantly decreased from 8.7 ± 4.1 to 7.2 ± 3.8, with a mean change of −1.5 ± 1.2 ($p < 0.01$). Anxiety Scores dropped from 6.9 ± 3.5 to 5.8 ± 3.2, with a mean change of −1.1 ± 1.0 ($p < 0.05$). Stress Scores also showed a significant decrease from 9.3 ± 4.0 to 8.1 ± 3.7, with a mean change of −1.2 ± 1.1 ($p < 0.05$). Cognitive Resilience Scores improved, increasing from 28.4 ± 7.5 to 30.1 ± 7.2, with a mean change of 1.7 ± 1.4 ($p < 0.01$).

Table 8. Temporal changes over one-month follow-up.

Parameter	Baseline (Mean ± SD)	One-Month Follow-up (Mean ± SD)	Change (Mean ± SD)	*p*-value (Change)
Forward Head Posture (degrees)	42.3 ± 8.1	40.1 ± 7.8	−2.2 ± 1.5	< 0.05
Movement Asymmetry (%)	12.5 ± 4.3	10.9 ± 4.1	−1.6 ± 1.3	< 0.05
Depression Score (DASS-21)	8.7 ± 4.1	7.2 ± 3.8	−1.5 ± 1.2	< 0.01
Anxiety Score (DASS-21)	6.9 ± 3.5	5.8 ± 3.2	−1.1 ± 1.0	< 0.05
Stress Score (DASS-21)	9.3 ± 4.0	8.1 ± 3.7	−1.2 ± 1.1	< 0.05
Cognitive Resilience Score (CRS)	28.4 ± 7.5	30.1 ± 7.2	1.7 ± 1.4	< 0.01

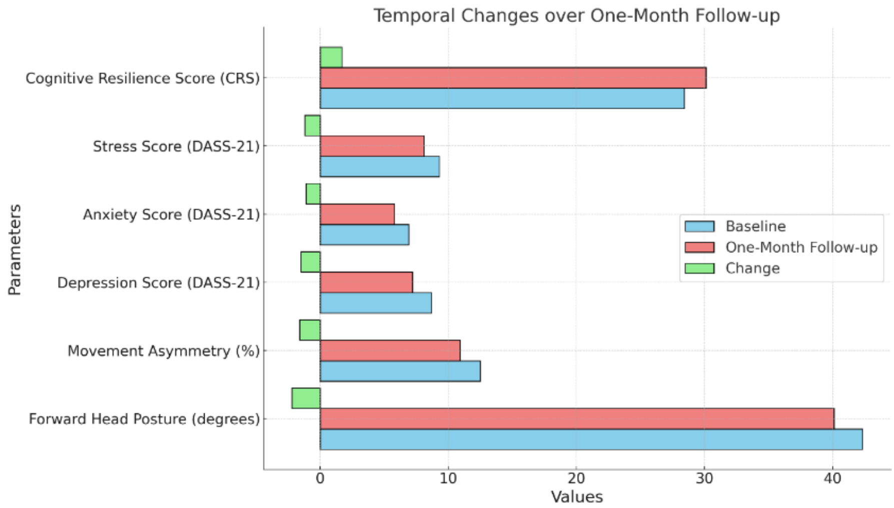

Figure 7. Temporal changes over one-month follow-up.

Within-subject comparisons using paired *t*-tests (**Table 9** and **Figure 8**) further confirmed these significant changes. Forward Head Posture decreased from 42.3 ± 8.1 degrees at baseline to 40.1 ± 7.8 degrees ($t = 2.65$, $p < 0.01$), with an effect size (Cohen's d) of 0.48. Movement Asymmetry reduced from 12.5 ± 4.3% to 10.9 ± 4.1% ($t = 2.42$, $p < 0.05$), with an effect size of 0.42. For MH outcomes, Depression Scores significantly decreased from 8.7 ± 4.1 to 7.2 ± 3.8 ($t = 3.14$, $p < 0.01$), with an effect size of 0.52. Anxiety Scores also showed a significant reduction from 6.9 ± 3.5 to 5.8 ± 3.2 ($t = 2.23$, $p < 0.05$), with an effect size of 0.39. Stress Scores decreased from 9.3 ± 4.0 to 8.1 ± 3.7 ($t = 2.45$, $p < 0.05$), with an effect size of 0.41. Cognitive Resilience Scores significantly increased from 28.4 ± 7.5 to 30.1 ± 7.2 ($t = 3.67$, $p < 0.01$), with a large effect size of 0.59.

Table 9. Within-subject comparisons: Paired *t*-tests.

Parameter	**Baseline (Mean ± SD)**	**Follow-up (Mean ± SD)**	***t*-value**	***p*-value**	**Effect Size (Cohen's *d*)**
Forward Head Posture (degrees)	42.3 ± 8.1	40.1 ± 7.8	2.65	< 0.01	0.48
Movement Asymmetry (%)	12.5 ± 4.3	10.9 ± 4.1	2.42	< 0.05	0.42
Depression Score (DASS-21)	8.7 ± 4.1	7.2 ± 3.8	3.14	< 0.01	0.52
Anxiety Score (DASS-21)	6.9 ± 3.5	5.8 ± 3.2	2.23	< 0.05	0.39
Stress Score (DASS-21)	9.3 ± 4.0	8.1 ± 3.7	2.45	< 0.05	0.41
Cognitive Resilience Score (CRS)	28.4 ± 7.5	30.1 ± 7.2	3.67	< 0.01	0.59

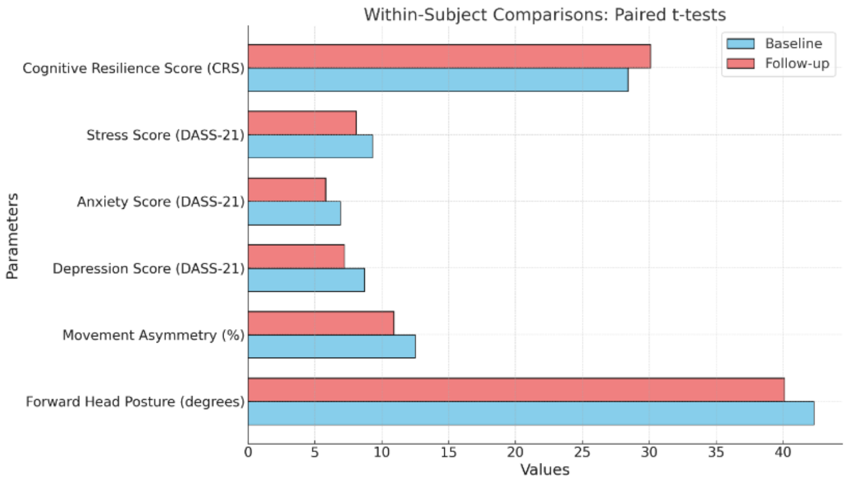

Figure 8. Within-subject comparisons: Paired *t*-tests.

4. Conclusion and future work

This study comprehensively studies the interplay between BF, PA, and MH in college students. The findings reveal that biomechanical inefficiencies, such as forward head posture and movement asymmetry, are significantly associated with increased levels of depression, anxiety, and stress. These associations underscore the importance of considering biomechanical health as a key component of MH in this population. Additionally, PA was identified as a significant mediator in the relationship between biomechanics and MH, indicating that promoting PA can mitigate the negative impact of poor biomechanical alignment on psychological outcomes. Cognitive resilience was found to moderate the effects of BF on MH, suggesting that students with higher cognitive resilience are better equipped to cope with the psychological strain associated with biomechanical inefficiencies. This highlights the potential value of interventions to enhance cognitive resilience alongside biomechanical corrections to support MH in college students. The study also demonstrated temporal improvements in BF and MH outcomes over the one-month follow-up period, indicating that positive changes in posture and movement patterns can contribute to psychological well-being. These findings advocate for a holistic approach to MH interventions in the college student population. Integrating biomechanical assessments with approaches to promote PA and cognitive resilience makes it possible to develop more effective programs that address the multifaceted nature of MH.

Future research should focus on longitudinal studies to further explore biomechanical and PA interventions' causal relationships and long-term effects on MH outcomes.

Funding: This research was supported by The Second Batch of Teaching Reform Projects in the 13th Five-Year Plan for Higher Education in Zhejiang Province "Experimental Research on the Effect of Physical Fitness Curriculum Reform on Psychological Intervention of Police College Students from the Perspective of Healthy China" (Grant No. jg20190500).

Ethical approval: Not applicable.

Conflict of interest: The author declares no conflict of interest.

Reference

1. Dalky HF, Gharaibeh A. Depression, anxiety, and stress among college students in Jordan and their need for mental health services. Nursing Forum. 2018; 54(2): 205–212. doi: 10.1111/nuf.12316
2. Ramón-Arbués E, Gea-Caballero V, Granada-López JM, et al. The Prevalence of Depression, Anxiety and Stress and Their Associated Factors in College Students. International Journal of Environmental Research and Public Health. 2020; 17(19): 7001. doi: 10.3390/ijerph17197001
3. Thompson M, Pawson C, Evans B. Navigating entry into higher education: the transition to independent learning and living. Journal of Further and Higher Education. 2021; 45(10): 1398–1410. doi: 10.1080/0309877x.2021.1933400
4. Kim ES, Tkatch R, Martin D, et al. Resilient Aging: Psychological Well-Being and Social Well-Being as Targets for the Promotion of Healthy Aging. Gerontology and Geriatric Medicine. 2021; 7. doi: 10.1177/23337214211002951
5. Mason-Mackay AR. Gender, Sex and Desk-Based Postural Behaviour: A systematic review re-interpreting biomechanical evidence from a social perspective. Applied Ergonomics. 2024; 114: 104073. doi: 10.1016/j.apergo.2023.104073
6. Schmid S, Bangerter C, Schweinhardt P, et al. Identifying Motor Control Strategies and Their Role in Low Back Pain: A Cross-Disciplinary Approach Bridging Neurosciences with Movement Biomechanics. Frontiers in Pain Research. 2021; 2. doi: 10.3389/fpain.2021.715219
7. Campbell F, Blank L, Cantrell A, et al. Factors that influence mental health of university and college students in the UK: a systematic review. BMC Public Health. 2022; 22(1). doi: 10.1186/s12889-022-13943-x
8. Azeez TO, Lamina S, Chukwunenye O. Human biomechanics: Basic and applied. Federal University of Technology, Owerri and Tropical Publishers Nigeria. 2016.
9. Hazari A, Maiya AG, Nagda TV. Conceptual Biomechanics and Kinesiology. Springer Singapore; 2021. doi: 10.1007/978-981-16-4991-2
10. Grabara M, Bieniec A. Functional Movement Patterns, Spinal Posture and Prevalence of Musculoskeletal Symptoms among Elite Ice Hockey Players: A Cross Sectional Study. Journal of Human Kinetics. 2023; 87: 59–70. doi: 10.5114/jhk/161548
11. Feng D, Zhang Y, Li HM, et al. Prevalence and influencing factors of poor body posture among university students: a cross-sectional study from a university in eastern China. 2024. doi: 10.21203/rs.3.rs-4215551/v1
12. Tafuri F, Martinez-Roig R, Susanto N, et al. Physically Active Lifestyles within the School context: Morpho-Physiological and Functional Aspects. Retos. 2024; 58: 48–60. doi: 10.47197/retos.v58.106154
13. Fitzgerald C, Burley DC, Wright DK, et al. Improving mental health, pain and quality of life in persons living with osteoporosis and depression or anxiety: a systematic review. Journal of Clinical Exercise Physiology. 2024; 13(s2): 516–516. doi: 10.31189/2165-7629-13-s2.516
14. Stanton R, To QG, Khalesi S, et al. Depression, Anxiety and Stress during COVID-19: Associations with Changes in Physical Activity, Sleep, Tobacco and Alcohol Use in Australian Adults. International Journal of Environmental Research and Public Health. 2020; 17(11): 4065. doi: 10.3390/ijerph17114065
15. Andermo S, Hallgren M, Nguyen TTD, et al. School-related physical activity interventions and mental health among children: A systematic review and meta-analysis. Sports Medicine - Open. 2020; 6(1). doi: 10.1186/s40798-020-00254-x
16. Ekkekakis P. Routledge Handbook of Physical Activity and Mental Health. Routledge; 2023. doi: 10.4324/9781003423430
17. Arida RM, Teixeira-Machado L. The Contribution of Physical Exercise to Brain Resilience. Frontiers in Behavioral Neuroscience. 2021; 14. doi: 10.3389/fnbeh.2020.626769
18. Belcher BR, Zink J, Azad A, et al. The Roles of Physical Activity, Exercise, and Fitness in Promoting Resilience During Adolescence: Effects on Mental Well-Being and Brain Development. Biological Psychiatry: Cognitive Neuroscience and Neuroimaging. 2021; 6(2): 225–237. doi: 10.1016/j.bpsc.2020.08.005
19. San Román-Mata S, Puertas-Molero P, Ubago-Jiménez JL, et al. Benefits of Physical Activity and Its Associations with Resilience, Emotional Intelligence, and Psychological Distress in University Students from Southern Spain. International Journal of Environmental Research and Public Health. 2020; 17(12): 4474. doi: 10.3390/ijerph17124474
20. Pilotti J. The Science of Movement, Exercise, and Mental Health. Jessica Kingsley Publishers. 2023.
21. Johnston HA. Integrating Biomechanics and Health Psychology: Biophysical and Psychological Considerations for Spine and Shoulder Musculoskeletal Disorders. 2021.

22. Indumathi N et al., Impact of Fireworks Industry Safety Measures and Prevention Management System on Human Error Mitigation Using a Machine Learning Approach, Sensors, 2023, 23 (9), 4365; DOI:10.3390/s23094365.
23. Parkavi K et al., Effective Scheduling of Multi-Load Automated Guided Vehicle in Spinning Mill: A Case Study, IEEE Access, 2023, DOI:10.1109/ACCESS.2023.3236843.
24. Ran Q et al., English language teaching based on big data analytics in augmentative and alternative communication system, Springer-International Journal of Speech Technology, 2022, DOI:10.1007/s10772-022-09960-1.
25. Ngangbam PS et al., Investigation on characteristics of Monte Carlo model of single electron transistor using Orthodox Theory, Elsevier, Sustainable Energy Technologies and Assessments, Vol. 48, 2021, 101601, DOI:10.1016/j.seta.2021.101601.
26. Huidan Huang et al., Emotional intelligence for board capital on technological innovation performance of high-tech enterprises, Elsevier, Aggression and Violent Behavior, 2021, 101633, DOI:10.1016/j.avb.2021.101633.
27. Sudhakar S, et al., Cost-effective and efficient 3D human model creation and re-identification application for human digital twins, Multimedia Tools and Applications, 2021. DOI:10.1007/s11042-021-10842-y.
28. Prabhakaran N et al., Novel Collision Detection and Avoidance System for Mid-vehicle Using Offset-Based Curvilinear Motion. Wireless Personal Communication, 2021. DOI:10.1007/s11277-021-08333-2.
29. Balajee A et al., Modeling and multi-class classification of vibroarthographic signals via time domain curvilinear divergence random forest, J Ambient Intell Human Comput, 2021, DOI:10.1007/s12652-020-02869-0.
30. Omnia SN et al., An educational tool for enhanced mobile e-Learning for technical higher education using mobile devices for augmented reality, Microprocessors and Microsystems, 83, 2021, 104030, DOI:10.1016/j.micpro.2021.104030 .
31. Firas TA et al., Strategizing Low-Carbon Urban Planning through Environmental Impact Assessment by Artificial Intelligence-Driven Carbon Foot Print Forecasting, Journal of Machine and Computing, 4(4), 2024, doi: 10.53759/7669/jmc202404105.
32. Shaymaa HN, et al., Genetic Algorithms for Optimized Selection of Biodegradable Polymers in Sustainable Manufacturing Processes, Journal of Machine and Computing, 4(3), 563-574, https://doi.org/10.53759/7669/jmc202404054.
33. Hayder MAG et al., An open-source MP + CNN + BiLSTM model-based hybrid model for recognizing sign language on smartphones. Int J Syst Assur Eng Manag (2024). https://doi.org/10.1007/s13198-024-02376-x
34. Bhavana Raj K et al., Equipment Planning for an Automated Production Line Using a Cloud System, Innovations in Computer Science and Engineering. ICICSE 2022. Lecture Notes in Networks and Systems, 565, 707–717, Springer, Singapore. DOI:10.1007/978-981-19-7455-7_57.