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PHYSIOLOGICAL POSTURAL HAND TREMOR IN FEMALE STUDENTS WITH DIFFERENT ANXIETY LEVELS UNDER ACADEMIC STRESS CONDITIONS

Tetiana Korol , Solomiia Bychkova , Iryna Gnatchuk 

Ivan Franko National University of Lviv , 4 Hrushevsky St., Lviv 79005, Ukraine

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Background. Physiological postural tremor is considered an objective indicator of motor instability and emotional reactivity; however, its relationship with anxiety levels in female students under academic stress conditions remains insufficiently studied.

Materials and Methods. The study involved 20 right-handed female students aged 18–20 years. The research was conducted in accordance with the Declaration of Helsinki. The frequency and amplitude of the physiological tremor of the right and left hands were recorded using an MPU6050 accelerometer in free and postural positions of the limb along the X-, Y-, and Z-axes. Spectral characteristics were analyzed using the fast Fourier transform. Relative change in tremor amplitude (Δ Amplitude, %) during the transition from free to postural position was calculated and analyzed using a factorial model including stress condition (module completion assessment vs no assessment), hand, and axis. Anxiety level was assessed using the validated DASS-21 questionnaire and analyzed as a continuous variable.

Results. Moving the hand from a free to a postural position significantly increased tremor amplitude, while tremor frequency remained unchanged. The magnitude of postural tremor enhancement was primarily axis-dependent, with the largest relative increases observed along the Z-axis (approximately 130–217 %). No significant main effect of academic stress on tremor enhancement was detected. Anxiety level did not exert a global effect on tremor amplitude. However, exploratory correlation analysis revealed a moderate positive association between the DASS score and Δ Amplitude along the Z-axis of the non-dominant hand under the stress condition (Spearman $\rho = 0.462$, $p = 0.040$, $n = 20$).

Conclusions. Postural enhancement of physiological tremor in female students is predominantly determined by biomechanical direction, particularly along the Z-axis. Anxiety appears to modulate direction-specific tremor responses under academic stress rather than inducing a generalized increase in tremor amplitude.

Keywords: physiological tremor, end-of-module assessment, accelerometry



INTRODUCTION

Physiological tremor is a low-amplitude movement of body parts in healthy individuals with a frequency of 8–12 Hz (Vial *et al.*, 2019). These movements are involuntary and oscillatory. Under normal conditions, they are not visually detectable but can be recorded using an accelerometer. Two parameters are used to describe tremor kinematics – frequency and amplitude. Physiological tremor of the upper limbs is most often studied (Sirisena *et al.*, 2009; Paredes-Acuna *et al.*, 2024). In the free position of the limb, it is practically asymptomatic and unnoticeable. Physiological tremor is more pronounced when the limb is held in a particular position and is referred to as postural tremor.

The modulation of physiological tremor amplitude occurs via β -adrenergic receptors in skeletal muscles (Marsden *et al.*, 1967; Pan, 2025); therefore, under the influence of stressors, it may increase beyond the expected values. In such cases, enhanced physiological tremor develops, which is predominantly recorded in the limb's postural position.

It is known that under the influence of stressors in healthy volunteers, the amplitude of physiological finger tremor in both free and postural hand positions increased, while its frequency decreased (Growdon, 2000).

Among the stressors affecting students are academic (educational) stressors. Some students experience increased anxiety during their studies at university. A certain level of anxiety caused by academic stress may have a positive effect on academic performance and serve as a driving force for educational achievements; however, excessive anxiety poses a threat to physical health and emotional well-being (Liu & Lu, 2012). For example, moderate and high levels of academic anxiety were observed in 40.1 % and 46.5 % of future nurses, respectively (Ghattas & El-Ashry, 2024). The level of academic stress positively correlates with anxiety ($r = 0.57$) and depression ($r = 0.56$) among adolescents aged 14–19 years (Zhu *et al.*, 2021).

Examinations and module completion assessments (end-of-module assessments) induce a complex psychophysiological response of the body (elevated blood pressure, increased concentration of attention, etc.) to the need for intensive mental activity under time constraints. A deterioration in cardiovascular system responses to psychoemotional stress has been reported in students during module completion assessments, and especially during exams (Sokolova, 2014).

A relationship has been established between increased neuro-emotional and intellectual load and an increase in limb tremor. During mental calculation tasks, F. Budini *et al.* (2022) recorded a 29.0 % increase in physiological postural hand tremor in study participants. In a subsequent study, the same authors found that complex mental calculations accompanied by stress related to time pressure and the need to correct errors increased postural hand tremor by 30.9 % compared with control conditions without mental calculations. During mathematical calculations without time constraints (non-stressful task performance), postural hand tremor increased by only 15.0 % compared with the control group values, and this increase was likely caused by cognitive activity itself. Thus, task performance under more stressful conditions was accompanied by a greater increase in physiological hand tremor. However, it remains unclear whether tasks without time constraints were indeed non-stressful and whether, in this case, the observed tremor enhancement was solely due to cognitive load rather than stress (Budini *et al.*, 2024).

Physiological tremor is of particular importance in medical students, especially those who will become surgeons. Hand tremor can impair fine motor skills during surgery, potentially reducing the stability of instrument handling and, consequently, the

quality and efficiency of procedures. It is known that a reduction in physiological tremor improves the performance of surgical manipulations in ophthalmology (Singh *et al.*, 2022). However, in medical students, resting tremor did not affect manual dexterity. Furthermore, the correlation between anxiety and tremor at rest was weak and not statistically significant (Hanrahan *et al.*, 2018).

Physiological tremor is not subject to voluntary control. For most students, knowledge assessment situations are stressful and lead to increased anxiety levels, which in turn affect the functional state of the nervous system and manifest as changes in psychophysiological parameters, including physiological tremor.

Studying physiological tremor as an indicator of emotional tension enables an objective assessment of the body's reaction to stress and the identification of individual differences in stress resistance among students. Special attention should be paid to studying this response in female students, as women are more prone to higher levels of situational anxiety (Eman *et al.*, 2012; Harris *et al.*, 2019; Gao *et al.*, 2020). Investigating the relationship between anxiety levels and changes in physiological tremor under academic stress conditions allows for a deeper understanding of the mechanisms of psychophysiological adaptation and stress resilience in female students. Therefore, the aim of our study was to investigate physiological hand tremor parameters in female students in relation to individual anxiety levels immediately before the module completion assessment.

MATERIALS AND METHODS

The study involved 20 female students from the Faculty of Biology at Ivan Franko National University of Lviv, aged 18–20 years. The research was conducted in accordance with the World Medical Association Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects. All participants provided written informed consent. All students were right-handed.

Tremor recordings were performed immediately before the end-of-module assessment and on academic days without knowledge assessment. The students did not consume coffee or strong tea and did not engage in intense physical activity before the study. None of the participants had neurological disorders accompanied by hand tremor.

All participants in the study did not engage in professional sports and exhibited comparable levels of physical activity, with BMI values within the normal range.

Tremor frequency and amplitude were recorded in two hand positions: a free position (the hand hanging from a supporting surface with the palm facing downward) and a postural position (the outstretched hand held with the palm facing downward). Measurements were performed using an MPU6050 accelerometer (InvenSense, China), which was placed on the hand 2 cm proximal to the second metacarpophalangeal joint. The recording duration was 30 seconds for each hand position.

Tremor was recorded along three mutually perpendicular axes: X, Y, and Z. Around the Z-axis of the accelerometer, tremor generated during flexion-extension movements of the wrist joint was recorded; around the Y-axis, tremor caused by abduction and adduction of the hand; and around the X-axis, tremor resulting from distal hand movements.

During recording, the students were seated comfortably on a chair 46 cm in height with a straight backrest. The forearms were placed on the armrests so that the olecranon process was aligned with the edge of the armrest surface. The elbow joint flexion angle was 90°, and the shoulder joint was slightly abducted. Proper body and limb positioning was maintained to minimize movement artifacts that could distort the accelerometer signal.

We created our own solution on the Arduino platform for Atmega328p MCUs, using NRF24L01 transceivers for the data link and MPU-6050 sensors as a data source. We used an RF link to prevent any impact on movement detection while maintaining a steady data flow from sensors to the PC. An additional data logger on a PC, connected via UART to the receiving node, collected raw data and saved it for further processing. Acceleration data were acquired at a sampling rate of 100 Hz over a 30 s interval. The obtained acceleration values were imported into OriginPro (OriginLab Corporation, Northampton, MA, USA), where acceleration–time plots were generated. Frequency and amplitude characteristics were obtained using the fast Fourier transform (FFT) function in OriginPro. For further analysis, the frequency and amplitude of the dominant spectral component within the 2–30 Hz range were used.

The analysis was performed within a frequency range of 2–30 Hz, which allowed separation of physiological tremor components from ballistic cardiac impulses.

To assess anxiety levels, all study participants completed the validated DASS-21 questionnaire (Henry & Crawford, 2005) in electronic format (Google Forms). The DASS anxiety score was calculated according to standard scoring procedures and treated as a continuous variable in statistical analysis.

The study was conducted in accordance with the principles outlined in the Declaration of Helsinki, with ethical approval obtained from the Bioethics Review Committee of Ivan Franko National University of Lviv (approval No. 55-12-2025 dated December 10, 2025).

Statistical analysis. Statistical analysis was performed using Python (version 3.x; Python Software Foundation, Wilmington, DE, USA) with the SciPy and Statsmodels statistical packages. The normality of distributions was assessed using the Shapiro–Wilk test. Data are presented as mean \pm standard error of the mean (SEM) unless otherwise specified.

Relative change in tremor amplitude (Δ Amplitude, %) was calculated as (Postural – Free) / Free \cdot 100 for each axis, hand, and stress condition. The effects of Stress condition (module assessment vs no assessment), Hand (right vs left), and Axis (X, Y, Z) on Δ Amplitude were evaluated using a mixed factorial model with subject treated as a random effect. Degrees of freedom were estimated using Satterthwaite approximation.

To examine the association between anxiety level and postural tremor enhancement, the DASS score was analyzed as a continuous predictor. Because Δ Amplitude values demonstrated deviations from a normal distribution and included extreme observations, non-parametric correlation analysis was applied. Specifically, the Spearman rank correlation coefficient (ρ) was calculated to assess monotonic relationships between the DASS score and Δ Amplitude. Correlations were examined separately for each hand and stress condition. Due to occasional missing or technically invalid Δ Amplitude values (e.g., resulting from signal artifacts or near-zero baseline values in the free position that precluded reliable percentage calculation), correlation analyses were performed using complete-case data only ($n = 20$).

Given the pronounced axis-dependent effects observed in the factorial analysis, correlation analysis was primarily focused on Δ Amplitude along the Z-axis. Bootstrap resampling (1,000 iterations) was used to estimate 95 % confidence intervals for correlation coefficients.

A p-value < 0.05 was considered statistically significant. Correlation analyses were regarded as exploratory.

RESULTS AND DISCUSSION

Changes in physiological hand tremor during the transition from a free to a postural hand position. Physiological tremor is known to intensify during postural maintenance (e.g., an outstretched arm) compared with a free-hanging limb (Albert & Kording, 2011). It is likely that under the influence of a stressor (module completion assessment), changes in physiological tremor parameters in the postural position of the hand compared with its free position would be more pronounced than on a regular academic day without a knowledge assessment. For this purpose, we determined the percentage change in physiological tremor parameters of the right and left hands of female students in the postural position compared with the free position of the hand. Subsequently, we compared the changes in amplitude and frequency of physiological hand tremor immediately before the end-of-module assessment and on a day without a knowledge assessment.

To test whether academic testing affects the magnitude of tremor increase during the transition from free to postural position, we compared tremor changes on a no-assessment day and immediately before the module completion assessment (test condition).

Paired comparisons between free and postural positions showed that tremor frequency did not change significantly under either condition. In contrast, tremor amplitude increased during the transition from free to postural position (**Fig. 1**).

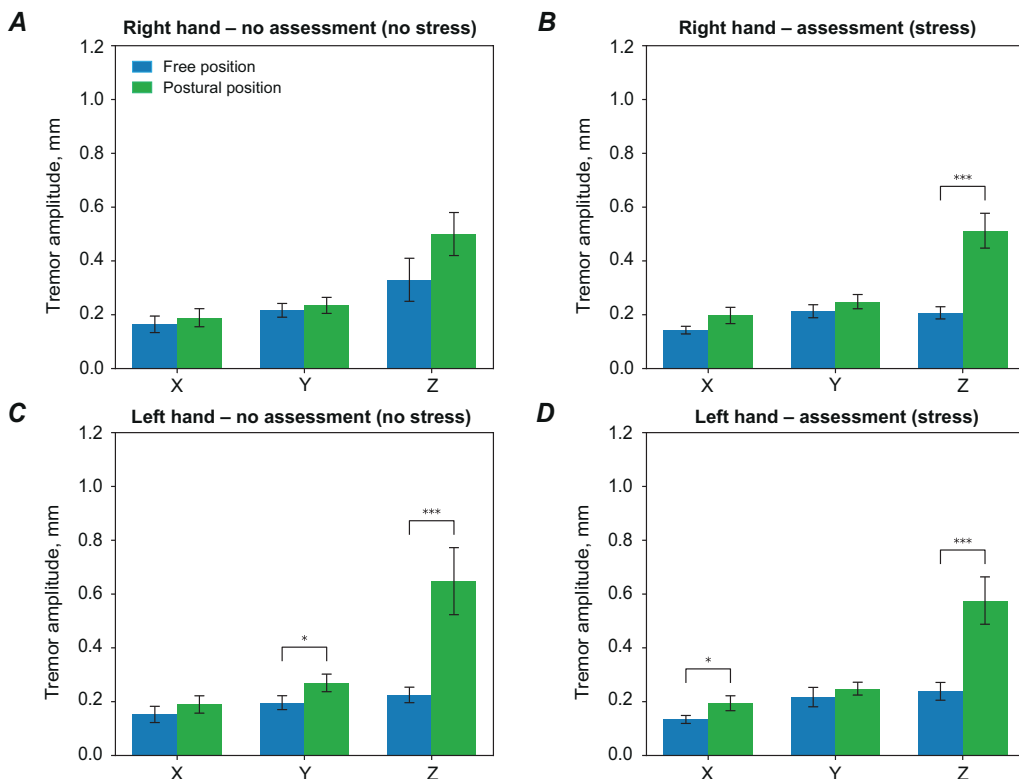


Fig. 1. Changes in the amplitude of physiological tremor of the upper limbs in the postural hand position compared with the free hand position: right hand (**A** – without knowledge assessment; **B** – before the module completion assessment); left hand (**C** – without knowledge assessment; **D** – before the module completion assessment). Asterisks indicate significant differences between free and postural positions within each panel (* $p < 0.05$; *** $p < 0.001$)

The most pronounced effects were observed along the Z-axis. In the dominant right hand, a significant increase in tremor amplitude was detected before the module completion assessment, amounting to 147.5 %, whereas no significant increase was observed on the no-assessment day.

For the non-dominant left hand, tremor amplitude along the Z-axis increased significantly under both conditions. Changes along the X- and Y-axes were smaller and reached statistical significance only in selected conditions.

Multivariate analysis of tremor amplitude. Although pairwise analysis confirmed the presence of statistically significant differences in tremor amplitude, it does not allow differentiation of the relative contribution of individual predictors. The use of a factorial model was necessary to quantify the effect of the stressor (end-of-module assessment) while accounting for covariates such as lateralization (right vs. left hand) and spatial orientation of movement (axis).

To quantify the magnitude of this postural increase, the relative change in tremor amplitude (Δ Amplitude, %) was calculated for each axis as $(\text{Postural} - \text{Free}) / \text{Free} \cdot 100$ for both hands under two conditions: a no-assessment academic day and immediately before the module completion assessment (test condition).

These Δ Amplitude values were analyzed using a linear mixed-effects model including Stress condition (module completion assessment [test] vs no-assessment day), Hand (right vs left), and Axis (X, Y, Z) as within-subject factors, with subject as a random effect.

A significant main effect of Axis was observed ($F(2, 193) = 6.13, p = 0.0026$, partial $\eta^2 = 0.060$), indicating that the magnitude of tremor increase during the transition from free to postural position differed across axes, with the largest increases along the Z-axis.

No significant main effects of Stress condition ($F(1, 193) = 1.81, p = 0.180$) or Hand ($F(1, 193) = 0.30, p = 0.585$) were detected. Likewise, no significant interactions between factors were found (all $F < 0.90$, all $p > 0.41$), indicating that the axis-dependent pattern was consistent across both hands and both experimental conditions (test and no-test).

Descriptive statistics for Δ Amplitude (%) are presented in **Table**.

Relative change in tremor amplitude (Δ Amplitude, %) during hand transition from a free to a postural position in female students (mean \pm SEM)

Hand	Condition	Axis X	Axis Y	Axis Z
Right	No assessment	28.9 \pm 28.1	11.0 \pm 10.1	129.3 \pm 37.8
	Assessment	18.7 \pm 12.4	16.5 \pm 9.4	159.9 \pm 32.8
Left	No assessment	123.6 \pm 42.6	52.9 \pm 14.4	217.3 \pm 34.9
	Assessment	45.4 \pm 17.2	40.5 \pm 14.6	186.2 \pm 40.8

The largest relative increases in tremor amplitude were observed along the Z-axis for both hands in both experimental conditions. For the dominant right hand, Δ Amplitude along the Z-axis reached 159.9 % before the module completion assessment and 129.3 % on the no-assessment day. For the non-dominant left hand, Z-axis values were even higher, reaching 186.2 % before assessment and 217.3 % on the no-assessment day.

In contrast, relative changes along the X- and Y-axes were substantially smaller across conditions.

Although descriptively higher Δ Amplitude values for the dominant right hand along the Z-axis were observed before the module completion assessment compared with the no-assessment day, these differences did not reach statistical significance in the mixed-effects model.

Overall, the magnitude of tremor increase during the transition from free to postural position was primarily determined by the recording axis rather than by the stress condition.

Relative changes in physiological hand tremor parameters in relation to individual anxiety level. It has been suggested that tremor observed in individuals with elevated anxiety most often represents enhanced physiological tremor (Milanov, 2007). This type of tremor is considered to arise from an amplified responsiveness of the motor system to emotional or stress-related stimuli. The effectiveness of β -blockers in reducing manifestations of enhanced physiological tremor further supports the role of peripheral and central adrenergic mechanisms, particularly in professions requiring high precision of movement and motor stability (Fargen *et al.*, 2015).

Experimental evidence also supports a link between anxiety and tremor. Mice with knockout of the GABA transporter GAT1 exhibit both high-frequency tremor and anxiety-like behavioral features (Chiu *et al.*, 2005). In these animals, excess extracellular GABA enhances tonic inhibition within the cerebellum and disrupts local oscillatory activity, which has been proposed as a mechanism underlying tremor generation.

Importantly, associations between tremor and anxiety symptoms have also been reported in pediatric populations. In a study of movement disorders in children, A. Cherian *et al.* (2025) identified elevated anxiety levels as a significant comorbid factor correlating with the severity of motor manifestations.

Taken together, these findings suggest that anxiety may modulate tremor through multiple interconnected mechanisms, including amplification of physiological motor oscillations and alterations in limbic-prefrontal and cerebellar networks.

To determine whether individual anxiety level influenced postural enhancement of physiological tremor in our sample, the DASS anxiety score was analyzed as a continuous variable. Relative change in tremor amplitude (Δ Amplitude, %) served as the dependent variable.

In a mixed factorial model including the DASS score, Stress condition (module completion assessment vs no-assessment day), Hand (right vs left), and Axis (X, Y, Z), no significant main effect of the DASS score on Δ Amplitude was detected ($p > 0.05$). Furthermore, no significant interactions between the DASS score and Stress condition or Hand were observed (all $p > 0.05$).

Given the pronounced axis-dependent effects identified in the previous analysis, exploratory correlation analyses were conducted specifically for Δ Amplitude along the Z-axis. Because Δ Amplitude values showed a non-normal distribution and contained outliers, the Spearman rank correlation was applied. These correlation analyses were considered exploratory.

A moderate positive association between the DASS score and Δ Amplitude along the Z-axis of the non-dominant (left) hand under the stress condition (before the module completion assessment) was observed (Spearman $\rho = 0.462$, $p = 0.040$, $n = 20$). This exploratory finding suggests that higher anxiety levels may be associated with greater postural enhancement of tremor amplitude in this specific condition.

No statistically significant correlations were detected for the dominant (right) hand or for recordings obtained on a no-assessment day (all $p > 0.05$).

Thus, anxiety level did not demonstrate a global effect on physiological tremor enhancement in the present sample. Instead, anxiety appeared to be related to direction-specific modulation of tremor amplitude, particularly along the Z-axis of the non-dominant hand under the stress condition.

The associations between the DASS anxiety score and Δ Amplitude along the Z-axis under the stress condition are shown in **Fig. 2**.

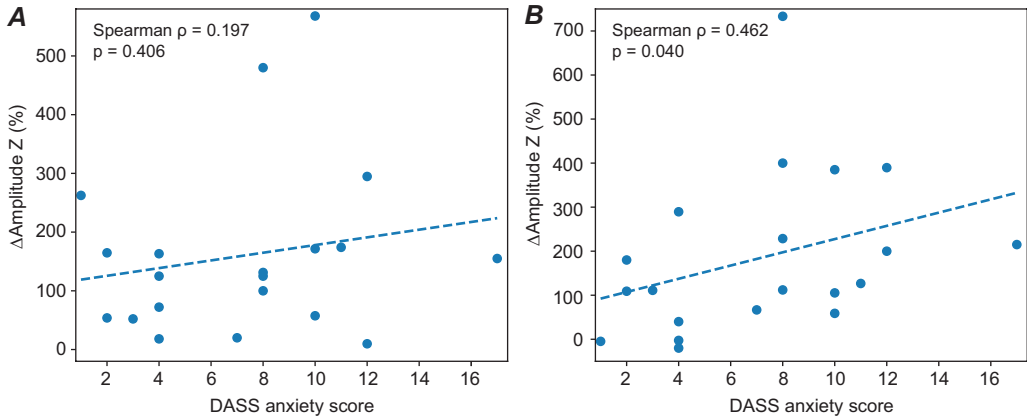


Fig. 2. Association between DASS anxiety score and relative change in tremor amplitude (Δ Amplitude, %) along the Z-axis under the stress condition (before module completion assessment): **(A)** right hand; **(B)** left hand. Spearman rank correlation coefficients (ρ) and corresponding p -values are indicated within each panel

In order to gain a deeper understanding of the physiological mechanisms underlying tremor, the initial model was expanded to include an indicator of the subjective anxiety level (the DASS-21). This allowed us to test whether tremor amplitude is a direct response to an external event (knowledge assessment) or whether it is influenced by the individual student's internal level of anxiety.

The extended model revealed a trend toward a positive association between DASS scores and Δ Amplitude on the Z-axis of the non-dominant hand immediately before the module (slope estimate $\approx +14.9$ % per point; $p \approx 0.061$). This finding is consistent with the Spearman correlation coefficient obtained in our analysis.

To further assess the robustness of this association, a cluster bootstrap procedure was applied. Although the classical linear model did not reach statistical significance ($p = 0.136$), cluster bootstrap analysis (5000 resamples) supported the stability of the association between anxiety and tremor amplitude increase in the Z-axis of the non-dominant hand during assessment ($\beta \approx +15$ % per DASS point; 95 % CI [4.15, 32.76]; $p_{boot} = 0.008$). The association did not reach significance in classical regression; however, cluster bootstrap analysis indicated a stable positive effect, suggesting the robustness of the association.

Neuroimaging studies indicate a close relationship between emotional reactivity and motor instability. In patients with tremor, processing of emotional stimuli has been associated with increased functional connectivity between the left amygdala and the left middle frontal gyrus (Espay *et al.*, 2018). This pattern has been interpreted as enhanced interaction between limbic structures and prefrontal regions involved in emotional regulation, attention, and motor control. Under such conditions, emotional signals may exert modulatory influences on motor networks.

Considering that the left amygdala has frequently been linked to cognitively mediated emotional processing and vulnerability to anxiety, this neural pattern may provide a mechanistic framework for understanding direction-specific modulation of tremor amplitude in relation to anxiety.

Some asymmetry was observed in the postural enhancement of tremor amplitude between the right and left hands. Unilateral onset of Parkinson's disease symptoms, including tremor, more frequently involves the dominant side in both right- and left-handed individuals (Uitti *et al.*, 2005; Yust-Katz *et al.*, 2008; Barrett *et al.*, 2010), although findings in healthy individuals remain inconsistent.

A. Beuter *et al.* (2000) reported no differences in tremor amplitude between dominant and non-dominant hands during bilateral postural tasks, possibly due to the distribution of attention across both limbs. D. J. Serrien *et al.* (2003) demonstrated that unimanual movements are primarily controlled by the contralateral hemisphere, whereas the dominant hemisphere contributes more strongly during bimanual coordination.

In healthy individuals, tremor intensity has often been reported as similar between dominant and non-dominant hands (Machowska-Majchrzak *et al.*, 2011). However, M. Bilodeau *et al.* (2009) observed approximately 30 % greater acceleration amplitude in the non-dominant hand. Moreover, in a large cohort study ($n = 117$; 114 right-handed), J. Raethjen *et al.* (2000) demonstrated a greater difference between postural and free tremor amplitude in the left hand compared with the right.

Our findings of pronounced postural enhancement along the Z-axis, particularly involving the non-dominant limb under specific conditions, are consistent with the notion that lateralized motor control mechanisms may contribute to variability in tremor responses.

Motor control is generally more efficient in the dominant hand due to long-term practice of precise movements. Improved coordination and stabilization of antagonist muscles in the dominant limb may contribute to more stable postural control and reduced variability of tremor parameters compared with the non-dominant limb.

Accelerometric assessment of physiological tremor has been proposed as a sensitive marker of emotional stress (Zillmer *et al.*, 2014). In the present study, female students reported increased anxiety prior to the module completion assessment. Neural circuits involved in tremor generation and emotional regulation are complex and interconnected (Lin *et al.*, 2025).

However, our results suggest that anxiety did not exert a global effect on tremor enhancement. Instead, anxiety level demonstrated a moderate, condition-specific association with postural tremor amplitude along the Z-axis of the non-dominant hand under the stress condition. This pattern supports the interpretation that anxiety may modulate direction-specific components of motor control rather than uniformly increasing tremor amplitude across all axes and conditions.

We investigated physiological postural tremor of the upper limbs in female students under conditions of neuro-emotional strain prior to academic assessment. Postural enhancement of tremor amplitude was primarily axis-dependent, with the Z-axis demonstrating the most pronounced increase. The observed association between anxiety level and tremor enhancement appeared to be condition- and direction-specific rather than generalized, highlighting the complex interaction between emotional state and motor control mechanisms.

The increase in postural tremor along the Z axis during psycho-emotional stress is related to the biomechanical sensitivity of this axis to gravitational loading and the need for postural control. These Z-axis-specific oscillations enhance stress-induced adrenergic activation and anxiety-related CNS effects, but they do not cause a generalized increase in tremor.

CONCLUSIONS

Postural enhancement of physiological hand tremor amplitude was confirmed when the limb was transferred from the free to the postural position, whereas tremor frequency remained unchanged. The magnitude of tremor enhancement was primarily axis-dependent, with the most pronounced relative increases observed along the Z-axis (approximately 130–217 %), corresponding to the direction of gravitational load.

Academic stress associated with module completion assessment did not produce a global increase in tremor enhancement across axes and conditions. However, exploratory analyses revealed a moderate positive association between anxiety level (the DASS score) and tremor amplitude increase along the Z-axis of the non-dominant hand under the stress condition (Spearman $\rho = 0.462$).

These findings suggest that physiological postural tremor amplitude reflects direction-specific characteristics of motor control and may be selectively modulated by individual anxiety levels under academic stress. Rather than acting as a universal marker of stress, tremor enhancement appears to be influenced by the interaction between emotional state and biomechanical control mechanisms.

LIMITATIONS AND DIRECTIONS FOR FUTURE RESEARCH

Several considerations should be kept in mind when interpreting the present findings, although they do not undermine the main conclusions regarding the axis-dependent nature of postural tremor enhancement and its direction-specific association with anxiety.

First, the study was conducted on a relatively small and homogeneous sample ($n = 20$ right-handed female students aged 18–20 years from a single faculty). This design was intentional and appropriate for a focused exploratory investigation, particularly given the well-documented sex differences in situational anxiety that justify a female-only cohort. Nevertheless, the modest sample size reduces statistical power for detecting small-to-moderate effects of academic stress and limits generalizability to male students, other age groups, left-handed individuals, etc.

Second, the timing of tremor measurement warrants consideration. Recordings were obtained in the minutes immediately preceding the module completion assessment. Future work using fully wearable, ambulatory sensor configurations that permit continuous recording immediately before, during, and after the assessment would allow the temporal evolution of tremor modulation across all phases of the academic stress response to be resolved.

Third, the intensity of the stressor itself should be considered. An end-of-module assessment likely evokes a more moderate psychoemotional response than a final examination. This may help explain the absence of a global main effect of Stress condition on tremor amplitude.

Despite these limitations, the present study provides novel accelerometric evidence that postural enhancement of physiological hand tremor in female students is primarily shaped by biomechanical direction and is selectively modulated by individual anxiety under academic stress conditions – observations that establish a methodological and conceptual foundation for future, larger-scale investigations of psychophysiological adaptation to academic stressors.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of Interest: the authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Animal Rights: this article does not contain any studies involving animals performed by any of the authors.

Human Rights: the study was conducted in accordance with the principles outlined in the Declaration of Helsinki, with ethical approval obtained from the Bioethics Review Committee of Ivan Franko National University of Lviv (approval No. 55-12-2025 dated December 10, 2025).

AUTHOR CONTRIBUTIONS

Conceptualization, [T.V.; S.V.]; methodology, [I.Yu.]; validation, [T.V.; S.V.; I.Yu.]; formal analysis, [T.V.; S.V.]; investigation, [I.Yu.; T.V.; S.V.]; resources, [I.Yu.]; writing – original draft preparation, [T.V.; S.V.]; writing – review and editing, [T.V.; S.V.; I.Yu.]; visualization, [S.V.]; supervision, [T.V.]; project administration, [T.V.]; funding acquisition, [–]. All authors have read and agreed to the published version of the manuscript.

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ФІЗІОЛОГІЧНИЙ ПОСТУРАЛЬНИЙ ТРЕМОР КИСТІ СТУДЕНТОК ІЗ РІЗНИМ РІВНЕМ ТРИВОЖНОСТІ В УМОВАХ НАВЧАЛЬНОГО СТРЕСУ

Тетяна Король, Соломія Бичкова, Ірина Гнатчук

*Львівський національний університет імені Івана Франка
вул. Грушевського, 4, Львів 79005, Україна*

Обґрунтування. Фізіологічний постуральний тремор розглядають як об'єктивний показник моторної нестабільності й емоційної реактивності, проте його зв'язок із рівнем тривожності студенток в умовах навчального стресу залишається недостатньо вивченим.

Матеріали та методи. У дослідженні взяли участь 20 студенток-правшів віком 18–20 років. Дослідження проведено відповідно до принципів Гельсінської декларації. Частоту й амплітуду фізіологічного тремору правої та лівої рук реєстрували за допомогою акселерометра MPU6050 у вільному і постуральному положеннях кінцівки вздовж осей X, Y та Z. Аналіз спектральних характеристик здійснювали методом швидкого перетворення Фур'є. Відносну зміну амплітуди тремору (Δ Amplitude, %) під час переведення кисті з вільного у постуральне положення розраховували та проаналізували за допомогою факторної моделі, яка включає умови стресу (модульний контроль проти відсутності оцінювання), руку та вісь. Показники порівнювали безпосередньо перед модульним контролем та у звичайний навчальний день без контролю знань. Рівень тривожності оцінювали за допомогою валідованого опитувальника DASS-21 і аналізували як безперервну змінну.

Результати. Переміщення кисті з вільного у постуральне положення зумовило збільшення амплітуди тремору, тоді як частота тремору залишилася без змін. Посилення постурального тремору кисті залежало від осі, причому його максимальне відносне збільшення спостерігали вздовж осі Z (приблизно 130–217 %). Не виявлено впливу навчального стресу на посилення тремору. Рівень тривожності не мав глобального впливу на амплітуду тремору. Однак за результатами експлораторного кореляційного аналізу ми виявили помірний позитивний зв'язок між рівнем тривожності за шкалою DASS-21 та Δ Amplitude тремору, зареєстрованого для недомінантної руки вздовж осі Z в умовах стресу (Spearman $\rho = 0,462$, $p = 0,040$, $n = 20$).

Висновки. Посилення фізіологічного постурального тремору кисті студенток здебільшого зумовлене біомеханічним напрямком, зокрема, вздовж осі Z. Тривожність, імовірно, модулює вісь-специфічні реакції тремору в умовах навчального стресу, а не спричиняє генералізоване збільшення його амплітуди.

Ключові слова: фізіологічний тремор, модульний контроль, акселерометрія