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ROLE OF ARTIFICIAL INTELLIGENCE-BASED WEARABLE SENSORS FOR POSTURE MONITORING AND CORRECTION AMONG UNIVERSITY STUDENTS WITH PROLONGED LAPTOP USAGE: A NARRATIVE REVIEW

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Abstract

Background: *College students frequently use laptops for prolonged periods of time, which results in cervicothoracic flexion and forward head posture (FHP) causing neck discomfort. Traditional posture measurement is performed using intermittent evaluations which rely on the observer's input, while the combination of wearable inertial sensors and machine learning provides the opportunity for continuous posture classification and real-time bio- feedback.*

Aim: *To provide a critical summary of the available literature on wearables with artificial intelligence (AI) used for posture correction and monitoring, specifically on university students using laptops.*

Literature approach: *The peer-reviewed literature, which mainly covers the period from 2019 to 2026, was discovered through targeted searches and citations, and it was narratively evaluated against recognized standards such as SANRA, COSMIN, TRIPOD+AI, and CONSORT-AI.*

Major findings: *Wearable systems have demonstrated satisfactory performance in controlled settings, classifying seated and head-neck postures with high accuracy, and vibrating, auditory, and visual feedback can instantly improve the alignment of the body. However, randomized studies are limited and mostly consist of small and short-term trials focusing on workers rather than students, and no trial on AI-based wearable technology in student populations was found. Moreover, aspects such as free-living*

validity, retention of technology over time, adherence to wearables, privacy, and external validity are still poorly studied.

Conclusion: *AI-based wearables, although, appear to have certain prospects as an adjunct in physiotherapy education, the existing evidence does not support the recommendation of their use in clinical practice.*

1. Introduction

Neck pain is one of the most frequently observed causes of disability worldwide. The Global Burden of Disease Study revealed that 203 million people were affected by neck pain in 2020. It was estimated that there would be 269 million cases by 2050, most notably in low- and middle-income countries (1, 2). Forward head posture (FHP) is one of the most common cervical postures and refers to the position of the head in front of the shoulders in the sagittal plane (3, 4). According to a meta-analysis, FHP has a positive correlation with neck pain, however, due to the age factor, the strength and direction of this correlation remain unclear (3).

Undergraduates can be considered a specific group that is at risk of injuries connected with computers. Studies show that using computers leads to musculoskeletal problems in students (5). The study conducted in Pakistan shows that FHP had a strong correlation with neck pain ($r = 0.78$) and appeared more often in students who studied for many hours (6). Laptops are of special interest, as a screen and keyboard cannot be separated: portable computers cause a greater amount of cervical and thoracic flexion and shorter viewing distances when compared to desktop computers (7); in addition, using laptops affects the activity of neck and trunk muscles (8). Therefore, prolonged studying time contradicts the WHO recommendations on limiting sedentary behavior, yet not enough evidence exists to formulate a numerical threshold (9).

In practice, posture is studied using such methods as observation, clinical measurements, photogrammetry, and laboratory motion analysis, with radiography being the ideal way to determine the position of a spine, but its high cost and radiation makes its frequent use impossible (10). Recent technology offers an alternative. Wearable devices incorporating inertial measurement units (IMUs) can record trunk and head–neck kinematics continuously, and machine-learning (ML) and deep-learning (DL) models can convert raw signals into posture classes or risk scores that trigger vibrotactile, auditory or visual feedback (10-13). Reviews have begun to map this field in occupational ergonomics (11, 14) and, more recently, in AI-enabled postural management and musculoskeletal rehabilitation (12, 13).

The data is still limited. Numerous studies that deal with the fitting of feedback devices have relied almost solely on various professional groups, mainly healthcare professionals, as participants (13). The conducted experiments had unsurprisingly small sample sizes and are short-lived (14); moreover, there is a doubt about the effectiveness of the use of artificial intelligence tools in practice where conditions are outside of controlled environment (11). Young people who use their laptops and are yet to form stable patterns of their behavior have not been examined quite enough. A narrative synthesis has been chosen for this literature review owing to the fact that the reviewed literature touches on various fields of human knowledge that are engineering, ergonomics, and physiotherapy and thus cannot be analyzed using the quantitative methods.

Aim: The aim was to produce a narrative literature review that will summarize the available information on the use of wearable technology for the correction of one's posture in an academic setting.

2. Literature Search Approach

The review applies the six domains of SANRA: justification, aims, literature search, referencing, scientific reasoning and data presentation (15). The review is not registered and does not look for

exhaustive extraction but rather pays attention to specific recent scientifically validated studies and papers.

Databases: PubMed/MEDLINE, Scopus, ISI Web of Science, IEEE Xplore, PEDro, Google Scholar (for citations of works applied) and ClinicalTrials.gov (for identification of ongoing clinical trials).

Time frame: 2015-2026, focusing especially on 2019-2026; however, older research papers were also included if they contained relevant information, i.e., explaining the essence of the terms used in the paper (like laptop biomechanics and feedback trials).

Keywords (for OR and AND searches): (i) wearable* OR IMU OR smart garment OR vibrotactile OR biofeedback OR inertial measurement unit; (ii) artificial intelligence OR machine learning OR deep learning OR neural networks; (iii) posture OR forward head posture OR craniovertebral angle; (iv) students* OR college/university OR laptop/computing OR sitting.

Study types: Systematic, scoping and narrative reviews; randomized and quasi-experimental trials; studies of sensor validation and algorithm development; epidemiological studies; and registered study protocols in English only. Studies on non-spinal posture, exoskeletons, and conference abstracts without full text were excluded.

Selection and appraisal: Titles and abstracts were screened for relevance to spinal, head or neck posture in sitting or computer use; wearable sensing or feedback; artificial intelligence/machine learning analyses or students and young adults. Sensor studies were evaluated as per COSMIN measurement property criteria (validity, reliability, measurement error) (16), machine learning development studies using TRIPOD+AI (17) and studies using the CONSORT-AI (18) criteria were identified.

3. Thematic Review of the Literature

Background and Concepts

Posture and FHP: Forward Head Posture (FHP) is commonly quantified using the Craniovertebral Angle (CVA), where values below 48° to 50° (depending on measurement modality and subject age) indicate FHP. The occurrence of FHP in students using screens is high (6), but whether FHP is actually responsible for neck pain is unclear (3).

Laptop-related loading: Due to the need for either prolonged neck flexion or holding of hands up while using smaller screens, laptops are correlated with greater amount of cervical and thoracic flexion and reduced distance at which observe computer screen when compared to desktops (7). Alteration in head position while using laptop affects activity of cervical and trunk muscles (8). Therefore, a posture is considered to be an adjustable variable in the context of interaction of human and machines.

Wearables and AI: A wearable device combines sensing with processing, storage, and communication capabilities that make it feasible for everyday use (19). Posture wearables utilize Inertial Measurement Units (IMUs) as their core technology, incorporating accelerometers, gyroscopes, and occasionally magnetometers (14). It is important to distinguish between simple deterministic threshold biofeedback (which triggers alerts at pre-set angle cutoffs) and true AI/ML systems (such as LSTMs or Decision Trees) that continuously classify dynamic kinematic patterns across multiple axes. In this case, by AI we denote ML and DL algorithms that learn about posture from sensor data rather than relying on fixed angle limitations to determine posture classes or risk levels. Feedback can be concurrent (real-time) or summary (after the task); the difference lies in the capability for immediate postural intervention with concurrent feedback (14).

Behavioral rationale: The effect of posture feedback is attributed to the fact that it relies on

external stimulation that makes individuals aware and leads to a self-correction behavior (20). Therefore, it is more appropriate to refer to this process as an assistive means in behavior change.

Current Approaches: Assessment and Rehabilitation

Assessment: Observation, goniometry/ Inclinometer, and posteroanterior distances assessed via lateral radiographs constitute the main components of clinical assessment; photogrammetry via smartphones has also been utilized to assess cohorts in Pakistan (6). The standard method of assessing spinal alignment is via radiography but it is impractical for repeated application (10). Observation methods are inexpensive but not accurate enough; on the other hand, wearable devices measure movement of parts of the body continuously providing more accurate information (19).

Rehabilitation: In most cases, conservative treatment of neck pain associated with FHP dysfunction is multimodal, including exercise as the main method of treatment (for example, stabilizing and strengthening exercises) together with education and ergonomic counseling (4). These exercises need supervision and self-control, but they do not really resolve the problem of habitual postures used during independent studying. This is where biofeedback comes to help.

Recent Developments-AI-Enabled Wearable Technologies

Sensing modalities: Techniques of sitting posture classification have included pressure mats, IMUs, accelerometers, and flex sensors. A systematic review of 14 studies determined that pressure sensors were the most frequent devices used, and neural networks were the most frequently used classifiers. Only two research studies were conducted in free living conditions, and most studies suffered from ethical or methodological issues. Authors suggested the use of IMUs because they are capable of distinguishing spinal motions and transitional positions, and mentioned the lack of any sitting posture definitions standardization (21). In the sample of 12 studies conducted in work places one or two accelerometers or IMUs were mostly utilized (14).

AI classifiers: In their research, Tang et al. integrated IMUs with a long short-term memory recurrent network to categorize seven varied static sitting postures, such as upright, slump, lean, and lateral bending and twisting postures (22). Regarding neck posture detection, Han et al. used together a magnet-and-magnetometer system along with an accelerometer and ML for estimating neck angle and the risk of forward head posture (FHP) (23). Another group, consisting of Jang et al., employed wearable magnetic sensors with DL in order to identify the issues regarding head and shoulders simultaneously (24). Park and Jung used only one IMU to find out the most suitable spot for FHP detection and received real-time feedback (25). Another possible direction is using camera-based measurement methods: by employing a graph convolutional network, the authors were able to detect the forward head posture (FHP) based on the 3D pose with the accuracy of 78.3% on a mixed public dataset, but the database had a limited diversity of postures (26). The systematic review of the wearable sensors with AI applied in the domain of physical ergonomics states that although this direction is promising in terms of preventive applications, it is still under development (11).

Feedback modalities: In the sample of 12 studies conducted in work establishments it was found that haptic feedback was used in six of them, auditory in five, and visual in three, thus being the most effective type of feedback for posture correction at work (14). In the pilot study a low-priced visual biofeedback tool was used that resulted in a better performance with regard to the peak head position variation than the control group over the course of ten days with the participation of female students (27).

Smart garments: The development of smart shirts that function with mobile phone

applications has provided nurses with an innovative technique for avoiding prolonged working positions that can lead to back pain (28). An upper body support that works by means of vibrotactile feedback provided by the garment was tested on 25 students interacting with laptop computers during one-day work and proved to have positive effects on their seating postures (29).

Convergence with ergonomics: Wearable systems of motion capture provide real-time visualization and feedback but there is no unified approach to posture measurement and evaluation as well as exposure indicators (19). Some rapid reviews of the available literature on biofeedback motion capture methods aimed at preventing negative consequences in the upper body have been published (30).

Clinical Applications

Prevention and awareness training: In students, the most likely function is to form habits: brief instruction to arrive at neutral body posture, followed by discreet cues when prolonged deviation occurs (27, 29).

Adjunct to exercise: Feedback may add value to supervised exercises by incorporating postural adjustment in everyday life.

Remote monitoring: Using artificial intelligence for posture recognition is being increasingly proposed for the purposes of tele-rehabilitation and adherence to treatment (12, 13). Wearable devices may enable doctors to obtain objective information about the time spent in various positions and further tailor their recommendations, a function described in literature for spinal posture devices in a broader sense (10).

Patient outcomes: Systematic review analyses of randomized controlled and quasi-experimentation trials have shown demonstrations of improvement in alignment and body consciousness, increases in functional-task stability plus decreases in muscle activity in unfavorable positions. Nonetheless, it should be noted that presently there is no strong clinical justification for recommending these interventions (20). A feasibility pilot stage of the investigation carried out among 62 healthcare staff has revealed 75% adherence and improved scores on the adopted flexed posture measurement within the subject group (31). A later cluster study with sham control revealed no positive outcome on the measured threshold indicators after one week of trials (32).

Critical Evaluation

References	Study Design	No. of studies/ population	Technology and feedback	Main findings and limitations
Simpson et al., 2019 (10)	Systematic review	37 articles	Wearable spinal-posture systems	Considerable accuracy demonstrated in the observation of spinal alignment in the clinical settings; suggested for use in physiotherapy, musculoskeletal pathology, and work safety.

References	Study Design	No. of studies/ population	Technology and feedback	Main findings and limitations
Kappattanavar et al., 2021 (21)	Systematic review	14 sitting-posture studies	Pressure sensors, IMUs; neural networks most common	Only 2 studies conducted outside of laboratories; most had methodological errors or ethical problems; no uniform definition of posture used in the studies.
Figueira et al., 2024 (14)	Scoping review	12 studies, 304 workers	Mostly prototype accelerometers/IMUs; haptic, auditory, visual	Provided haptic feedback is considered the most effective and the most common in use; testing was done with occupational samples only.
Caixeiro et al., 2026 (20)	Systematic review of RCTs and quasi-experimental studies		Vibrotactile, auditory, visual or tactile wearables	Immediate improvement; heterogeneity of studies and sample size, with a short follow-up period, are not enough to provide recommendations for practice.
Ribeiro et al., 2014 (31)	Feasibility RCT	62 healthcare workers	Lumbopelvic monitor; constant vs intermittent feedback	Level of compliance is about 75% with individuals having a benefit among themselves by means of permanent feedback without any significant differences with outsiders.
Ribeiro et al., 2020 (32)	Sham-controlled cluster RCT	healthcare workers	Lumbopelvic monitor with auditory feedback	No determination of the change in threshold exceedances in week - no difference in comparison with sham.
Du et al., 2017 (29)	Field deployment	25 students on laptops, one day	Smart garment with vibrotactile cues	Effectiveness having been established during sedentary work – this is a single-day case with unknown durability
Emadi Andani et al., 2024 (27)	Pilot controlled study	female students with FHP; 10 days	Low-cost visual biofeedback device	Greater decrease in maximum head-angle deviation than the control subjects experienced such as pilot study outcomes.

References	Study Design	No. of studies/ population	Technology and feedback	Main findings and limitations
Tang et al., 2021 (22); Lee et al., 2024 (26)	Algorithm-development studies		IMU with LSTM; 3D poses with graph network	Classification is feasible having 78.3% accuracy for FHP based on images; data diversity is limited; there are no clinical outcomes.

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Measurement validity: Evidence of accuracy is predominantly obtained in controlled settings (10, 21). Differences between studies regarding reference standards, definitions of posture and procedures hinder direct comparisons; the researchers of (21) propose using 3D camera registration as the gold standard. Low accuracy of FHP through images (26) indicates the difficulty of distinguishing subtle differences in head–neck position. Validating the results against objective assessments of CVA during real laptop use and disclosing reliability and measurement error in accordance with COSMIN principles (16) are not typical.

Effectiveness: Positive outcome is usually immediate and results from small pilot or quasi-experimental research (20, 27, 29). The sham-controlled ELF study (32) and the feasibility trial (31) underline that it is necessary to be careful since novelty and observation effects might overstate benefits and prolonged change in behavior might not be inevitable.

Population transferability: Most research includes work-related participants who have different types of exposure (e.g., bending forward while doing care work), as opposed to students who keep their neck bent while working on laptops (14, 31, 32). Only two minor experiments included students (27, 29), and none of them researched an AI system over time.

What 'AI' adds: Many wearables have fixed markers. It was impossible to find any study that compares feedback based on AI and feedback based on fixed markers, verification across male and female body types, and laptops and is consistent with TRIPOD+AI (17). Thus, the question of generalizability and explainability of the model is still on agenda.

Posture–pain assumption: Because the link between FHP and pain is confounded by age and uncertain in direction (3), and because reducing sedentary time is itself a health goal (9), devices that enforce rigid, continuous static extension may paradoxically increase cervical muscle co-contraction and fatigue. Postural biofeedback should prioritize movement variability, dynamic repositioning, and regular breaks over enforcing a singular 'ideal' posture.

Challenges

Clinical: There is causal uncertainty associated with posture and pain and a lack of agreed posture goals while working using the laptop, plus there are no long-term outcomes proving that posture correction can help prevent symptoms (3, 21).

Technical: Data quality and acceptability are affected by the sensor position, the necessity for adjustment to a certain person's neutral posture and drift, battery life, and comfort level. The absence of regular measures makes it difficult to compare information across devices (19). The models trained on small or not diverse datasets will not be applicable universally (26).

Ethical and governance: The posture and activity information are personal. WHO recommendations on AI use in healthcare are based on six principles they reached the consensus about, namely, data usage, data collection, accountability, and the digital gap (33). Students may be feeling like they are being monitored, while the institutions applying the

system may face questions regarding permission to use data and ownership of data.

Implementation: The studies show that even when the trials are conducted, the approach fails to have 100% usage (31). It is argued that usability and integration into daily life influence the effectiveness of the approach (13, 28) and that cost and availability matter in resource-poor environments (33).

4. Discussion

Synthesis: Three conclusions can be drawn. First, the implementation of wearable tools to measure sitting and head–neck posture is feasible since theAI models can categorize the postures with a high degree of precision in a controlled setting (10, 21-25). Secondly, feedback, specifically haptic feedback, appears to be successful in reversing posture in the short-term (14, 20). Thirdly, the translation into clinical outcomes has not been proven to be effective as the conducted studies have been extremely limited in size, time and numbers of participants (20, 31, 32), and the only conducted studies are those of pilot nature (27, 29).

Comparison with established practice: Exercise, education, and adjustment of the working environment are still the evidence-based therapeutic strategies for managing neck pain caused by FHP (4). Wearables are not meant to replace those methods, but rather they provide continuous objective information and motivation which are not available between the clinical appointments. Compared with traditional methods of assessment such as photogrammetry or X-ray (6, 10), wearables offer an opportunity for continuous assessment however their measuring features are not as sophisticated as those of clinical methods.

Clinical implications: A tiered approach is most suitable for physiotherapists advising learners: (1) ergonomic and behavioral modifications such as increasing screen height, using a separate keyboard, and taking regular movement breaks; (2) specific exercise interventions; (3) biofeedback wearable devices for motivated learners who have difficulties in adopting new postures, with results evaluated objectively. Wearable devices should be regarded as awareness-raising instruments, taking into account privacy and limitations of striving for a 'perfect' posture.

Strengths and limitations of the evidence: Among the strengths are agreements in engineering and clinical assessments regarding practicability and immediate effects. Among the limitations are small sample size, variability of devices and results reported, short follow-up period, absence of placebo control and students' characteristics, and lack of external validation. The limitations of this review include narrative design, single language of publications used, absence of formal risk-of-bias assessment, and fast-paced field of research where some registered studies remain unpublished.

5. Research Gaps and Future Directions

Areas with insufficient evidence: Research has not uncovered randomized trials of an AI-led wearable in college students using laptops; studies on students in the field are either a one-day or a ten-day pilot only (27, 29). Whilst retention of change in posture after feedback cessation and consequent impact on pain, disability and performance is mostly ignored (20). The free-living validity of the device has been rarely demonstrated; analysis of posture studies while sitting has taken place in the real life on only two occasions (21).

Methodological limitations: There is variety in terms of the devices used, the outcomes measured and the definition of posture; sample sizes are usually low and the follow-up time short; in many cases, there is no control group or blinding (20, 32); external validation and complete reporting of ML are limited (17, 26).

Unanswered questions: What are the optimal targets and thresholds for posture and movement variation for computer work tasks? Do the

trained models do better than simple thresholds used as feedback? What is the most effective feedback modality, timing (constant versus intermittent (31)) and amount? Does feedback result in symptom alleviation, rather than changing angles of joint movement? Is sex of the subjects, size of the body and arrangement of devices important for accuracy and acceptance of feedback? What can be said about cost-efficiency and equity in low-resource countries?

Recommended future studies

1. University student participants (FHP or laptop-related neck pain) were involved in sham-controlled randomized trials with a sufficient outcome with a follow-up of at least 12 weeks from the end of the treatment according to the CONSORT-AI guidelines (18).
2. A core outcome set consists of standardized CVA, intensity of neck pain, ability to carry out daily activities, time in flexed position, compliance, usability and side effects.
3. Validation studies based on a criterion measure (3D motion capture or photogrammetry) done on use of laptop by individuals living independently with reference to COSMIN concepts. External validation of ML models was conducted based on TRIPOD+AI guidelines (17).
4. Implementation research on issues related to privacy-by-design and data governance in accordance with WHO principles (33).
5. Studies on behavior and its impact on movement variability and reducing sedentary time (9).

6. Conclusion

AI-based wearable sensors can detect sitting and head–neck posture with encouraging accuracy and can change posture immediately through haptic, auditory or visual feedback (10, 14, 20, 21). For university students with prolonged laptop use, however, the clinical evidence is thin: controlled student studies are small pilots, randomized trials come mainly from workers and show inconsistent or short-lived benefit (27, 29, 31, 32), and the contribution of AI beyond simple thresholds remains untested. Physiotherapists may consider these devices as awareness-raising adjuncts alongside education, workstation adjustment and exercise, but not as stand-alone treatment, and should attend to privacy and movement variety. Future research should deliver pre-registered, adequately powered trials with standardized outcomes, free-living validation and transparent AI reporting before routine recommendation.

Declarations

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Conflicts of interest: None

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