



# Validation of AI-Based Finger Joint Angle Estimation Using MediaPipe and OpenPose during Computer Mouse Use

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## ABSTRACT

**Background:** Accurate quantification of finger joint kinematics is essential for ergonomic assessment, particularly in computer-based work environments where repetitive hand movements may contribute to musculoskeletal disorders.

**Objective:** This pilot study evaluates the performance of two Artificial Intelligence (AI) based markerless pose estimation systems; MediaPipe and OpenPose for measuring the Proximal Interphalangeal (PIP) joint angle of the index finger during computer mouse use, using an electrogoniometer as the ground truth.

**Material and Methods:** In this methodological validation study, thirteen right-handed participants performed a 3-minute unscripted computer mouse task. At the same time, finger joint angles were simultaneously recorded via an electrogoniometer and two commercial digital cameras (frontal and lateral views). Joint angles were extracted using Python-based implementations of MediaPipe and OpenPose.

**Results:** Results showed that MediaPipe with lateral view achieved the highest validity, with an RMSE (Root Mean Square Error), of 4.22°, and 92.7% of measurements within 5% error. OpenPose in frontal view performed poorly, with low correlation and high error margins. Processing time differed substantially between methods: MediaPipe averaged 331 seconds per video on modest hardware, whereas OpenPose required 2,612 seconds on a high-end system.

**Conclusion:** These findings suggest that MediaPipe offers a more accurate, accessible, and efficient solution for finger-level ergonomic assessment in office environments. The results highlight the influence of camera view and algorithm choice in markerless motion capture, and support the future integration of AI-based tools into non-invasive ergonomic risk evaluation systems. This finding has implications for Realtime ergonomic risk monitoring.

## Keywords

Artificial Intelligence; Biomechanical Movement Capture; Ergonomic Assessment; Finger Joints; Joint Range of Motion; Task Performance and Analysis

## Introduction

Although the formal study of posture and ergonomics is relatively recent, interest in assessing working postures dates back well before the emergence of ergonomics as a distinct scientific discipline. Accurate definition and measurement of working posture are fundamental to ergonomic assessment and the

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development of effective interventions. Such evaluation of working posture is essential for identifying biomechanical risk factors and interventions that enhance workplace design [1-4].

The widespread adoption of computer-based tasks in modern occupational environments has led to increasing concern over WMSDs (Work-related Musculoskeletal Disorders), particularly those affecting the upper extremities. As computer mouse usage has become an integral part of daily work routines, the incidence of conditions affecting the hand and the wrist namely tendinitis, carpal tunnel syndrome and osteoarthritis has grown substantially [5]. These disorders are particularly prevalent in professions involving sustained fine motor activity, raising significant ergonomic challenges.

Among the biomechanical risk factors, finger joint kinematics have emerged as a critical area of interest for understanding musculoskeletal strain and developing preventive strategies [6]. Systematic reviews over the past decade confirm that office workers and intensive computer users are particularly vulnerable, with a high prevalence of pain reported in the neck, shoulders, and hand/wrist regions [7, 8]. These health concerns not only degrade individual well-being and reduce productivity but also raise healthcare expenditures and impose broader economic costs [9-11]. Sustained non-neutral postures, such as finger extension and ulnar deviation, are among the primary ergonomic risk factors, placing neuromuscular structures under considerable stress. [7, 12]. Consequently, precise and objective measurement of hand and finger kinematics during computer use is a cornerstone of modern ergonomic evaluation [13].

The joints of the index finger, particularly the metacarpophalangeal and proximal interphalangeal joints, play a central role in mouse clicking and scrolling tasks [14]. Repetitive or sustained flexion of this joint has been implicated in the development of upper-limb

disorders [15-17]. Accurate measurement of finger joint angles during realistic tasks is therefore vital for ergonomic risk assessment, workstation optimization, and injury prevention.

In the context of joint angle measurements, one method considered as a ground truth is the electrogoniometer, which offers high temporal/angular resolution in both laboratory and field settings [18, 19]. Despite their precision, electrogoniometers present several limitations: they are costly and fragile, require expert handling, and often interfere with natural hand movement due to the physical attachment of sensors [19, 20]. These drawbacks reduce their suitability for large-scale studies and limit their applicability in naturalistic workplace settings. To overcome these constraints, recent ergonomic research has increasingly turned to AI and computer vision technologies for motion analysis [21]. Markerless motion capture systems, using deep learning to estimate human pose from standard RGB video, offer a non-invasive, low-cost, and scalable alternative. Prominent among these are OpenPose and MediaPipe, which provide real-time 2D and 3D hand pose estimation [22, 23]. These systems facilitate unobtrusive assessment in laboratory, clinical, and occupational settings [24-27].

Several studies have validated the use of OpenPose and MediaPipe for tracking finger joint angles, reporting acceptable error margins compared to marker-based systems [21]. However, most existing research has focused on generalized hand gestures or large joint movements (e.g., shoulder, knee), rather than fine finger motions during task-specific activities such as computer mouse use [28-30].

Previous validation studies of markerless pose estimation systems have primarily focused on large-joint kinematics or generalized hand movements, with limited attention to delicate finger joint motion during task-specific occupational activities. Studies evaluating OpenPose have reported acceptable accuracy

for upper- and lower-limb joints, including the shoulder, elbow, wrist, and hip–knee–ankle alignment, with typical errors below  $3^\circ$  under controlled experimental conditions when compared against screen-based goniometry or radiographic reference methods [31, 32]. In contrast, accuracy for finger joint angle estimation appears to be substantially lower and highly task dependent. Gionfrida et al. (2022) reported errors of up to  $11^\circ$  for MCP (metacarpophalangeal) and PIP (proximal interphalangeal) joint angles during finger abduction and adduction tasks using OpenPose, when validated against a marker-based motion capture system [33]. To date, no study has systematically evaluated the validity, agreement, and processing efficiency of AI-based pose estimation systems for index finger PIP joint angle measurement during realistic computer mouse use.

The present study addresses this gap by assessing the accuracy and performance of MediaPipe and OpenPose in estimating the index finger PIP angle during a standardized computer mouse task, using electrogoniometry as the reference standard. Both frontal and lateral camera perspectives are employed to simulate practical ergonomic monitoring conditions in real-world workspaces. Through a rigorous comparison of joint-level angle accuracy, the objectives of this study include:

- Determination of the concurrent validity of MediaPipe and OpenPose relative to electrogoniometry;
- Identification of the limits of agreement across systems;
- Evaluation of the feasibility of AI-based tools for ergonomic risk assessment in occupational settings.

By bridging the gap between gold-standard instrumentation and scalable, non-contact alternatives, the findings aim to support broader adoption of AI-powered motion capture in ergonomics, ultimately contributing to more effective WMSD prevention in digitally intensive work environments.

## Material and Methods

### Participants

This methodological validation study, involved 13 right-handed individuals (five females, eight males; mean age  $32.7 \pm 8.2$  years) who volunteered to take part. The recruitment did not apply specific criteria for age or gender. To be included in the study, individuals had to be willing to participate and confirm they had no history of musculoskeletal disorders, neurological conditions, pain, or any prior injuries affecting their hands or upper limbs. Additionally, participants were required to be regular computer users, spending at least four hours per day on the computer.

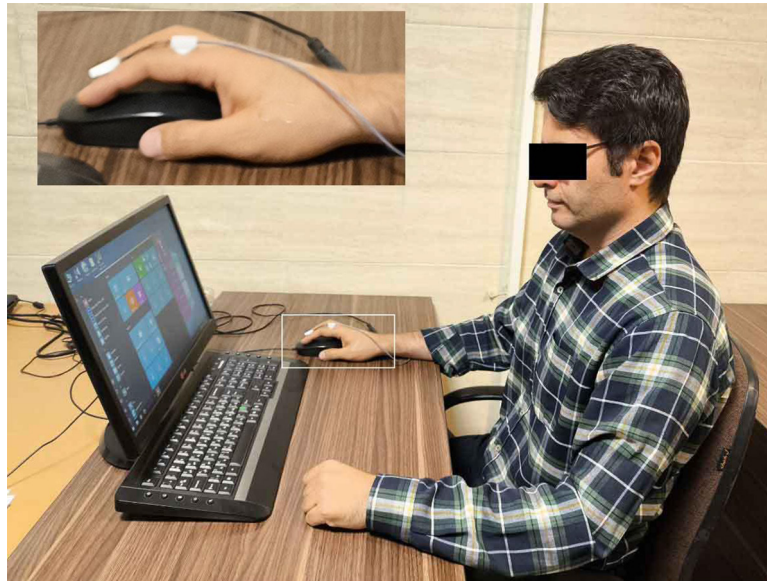
### Experimental Task

Upon arrival, participants were briefed on the study procedure and provided informed consent. Each participant then performed a standardized computer-use task that involved typical mouse interactions such as clicking and scrolling. The task was intentionally semi-naturalistic: participants were instructed to use the computer freely (e.g., browsing, selecting, and interacting with on-screen elements), which included moving the cursor, single-clicking, double-clicking, and using the scroll wheel. This approach was chosen to capture a range of naturalistic movements. Each session lasted approximately three minutes and was conducted at a typical office workstation, with an average temperature of  $28^\circ\text{C}$  and illumination of 504 lux. The workstation consisted of a standard-height office desk (80 cm) and an adjustable office chair (Figure 1). A standard three-button optical computer mouse was connected to a desktop computer for the experimental task. All experiments were conducted at the same workstation to ensure consistency across subjects (Figure 2).

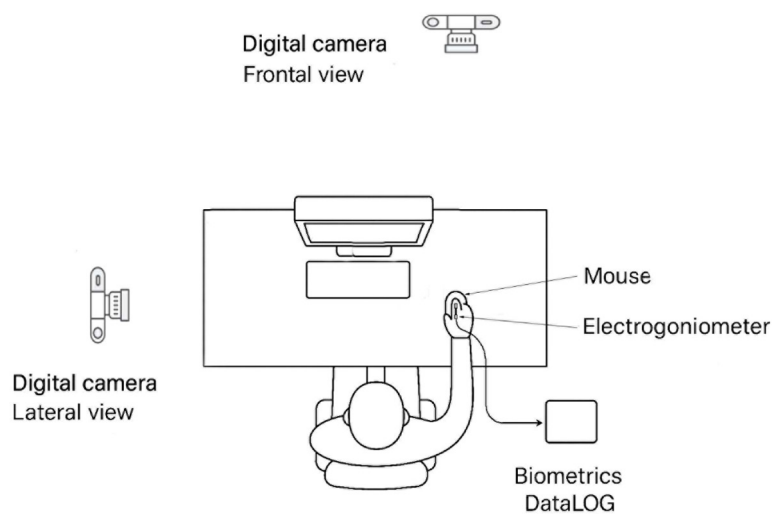
### Data Collection

#### 1. Electrogoniometer

To establish ground-truth measurements, a



**Figure 1:** Workstation



**Figure 2:** Experiment setup

Biometrics F35 electrogoniometer (Biometrics, UK) was attached to the index finger's PIP joint using double-sided tape. The placement was aligned with anatomical landmarks, following established biomechanical protocols. The goniometer's axis was aligned with the PIP joint's axis of rotation. The F35 sensor was connected to a Biometrics DataLOG unit (Biometrics, UK). Calibration was performed according to the manufacturer's guidelines:

the participant was asked to place their hand flat on a desk surface, and the sensor was then set to zero. The electrogoniometer captured joint angle data at a sampling rate of 100 Hz, which was subsequently downsampled to 30 Hz to match the video frame rate for comparison.

## 2. Video Recording

Video data were recorded using two Canon SX600 HS digital cameras (Canon, Japan)

positioned approximately two meters from the participant. Two views were captured simultaneously: a frontal view (facing the subject in the coronal plane) and a lateral view (from the left side in the sagittal plane) (Figure 2). This dual-angle setup enabled comparison of system performance across different perspectives. Each camera was positioned on a tripod and set to record in resolution 1920\*1080 at 30 FPS (frames per second). All recordings were conducted under the same lighting conditions.

### Pose Estimation

Two widely used markerless motion capture AIs, OpenPose and MediaPipe, were employed to extract joint kinematics from the recorded videos. Both were implemented using custom Python (version 3.10) scripts developed in Microsoft Visual Studio Code, which automated the frame-by-frame extraction of index finger joint positions. Although these algorithms are relatively straightforward, there are still several adjustable settings that can significantly impact the results. Various parameter configurations were tested, and the following settings were ultimately found to yield the most accurate outcomes.

- OpenPose: pre build GPU Version 1.7.0 based on the CMU-Perceptual Computing Lab's framework configured with (hand-scale-number=6, hand-scale-range=0.4).
- MediaPipe: Hand tracking solution from Google AI (Version 0.10.21), configured with (model-complexity=0, min-detection-confidence=0.5, min-tracking-confidence=0.5)

The coordinates corresponding to the index finger's MCP, PIP, and DIP (distal interphalangeal) joints were extracted, and the PIP angle was similarly calculated using the vertex formed by these three points. PIP joint angles ( $\theta$ ) were computed using Eq. (1).

$$\theta = \text{Arcos} ((v_1 \cdot v_2) / (\|v_1\| \|v_2\|)) \quad (1)$$

where:

- $\theta$  = PIP joint flexion angle in radians

- $v_1$  = vector from MCP to PIP joint
- $v_2$  = vector from PIP to DIP joint

From both systems, 2D coordinates of the relevant landmarks were extracted and used to compute the index finger PIP joint angles using trigonometric analysis. Frame rate alignment (30 Hz) was ensured across all datasets.

### Data Processing

The results from electrogoniometer, MediaPipe and OpenPose were visually inspected. The provided data from MediaPipe and OpenPose contained noise and were not suitable for analysis without filtering. In order to find the most effective filter and after a thorough review, five filters were selected: three types of moving average (simple, weighted, and adaptive), a hybrid moving average combined with a median filter, and a hybrid moving average combined with a Butterworth filter. A Python script was used to test all five filters with various plausible window sizes and parameter settings to determine the most suitable one. Ultimately, the simple moving average with a window size of eighteen was found to be the most effective, providing the best match with the electrogoniometer data.

The downsampled electrogoniometer data (30 Hz) and the frame-by-frame angle data from MediaPipe and OpenPose (also at 30 Hz) were imported into Microsoft Excel. A distinct, easily identifiable event such as the first sharp mouse click, which was visible in the video and produced a signal artifact in the electrogoniometer data was used as a temporal landmark to manually align the starting points of the three data streams for each trial.

To evaluate the computational efficiency of the two AI algorithms, the time taken by each Python script (MediaPipe and OpenPose) to process each 3-minute video file from start to finish was recorded using Python's time module. It is worth noting that the systems used for OpenPose and MediaPipe were different. MediaPipe relies solely on the CPU for computation and does not require a powerful GPU.

Therefore, the analysis using this algorithm was conducted on a laptop with moderate processing power (Windows 10, 64-bit, Intel Core i5-6200U CPU @ 2.30 GHz, two cores, four threads, 8 GB RAM, and integrated Intel HD Graphics 520 GPU). In contrast, OpenPose was run on a more powerful PC (Windows 11 Pro, Intel Xeon Processor (Cascade Lake, 2.90 GHz), 16 GB RAM, and an NVIDIA RTX 3080 GPU with 12 GB VRAM).

### Data Analysis Procedures

Data for front-view and side-view recordings were analyzed separately. The concurrent validity of MediaPipe and OpenPose relative to the electrogoniometer was assessed using correlation analysis. Initial assessments used the **Pearson correlation coefficient**. **Bland-Altman plots** were also generated to visualize the agreement between AI-based methods and the electrogoniometer, including limits of agreement ( $\pm 1.96$  SD). To quantify the level of agreement, the ICC (Intraclass Correlation Coefficient) (two-way mixed effects, absolute agreement, single rater model) was calculated. ICC values were interpreted as: <0.5 (Poor), 0.5-0.75 (Moderate), 0.75-0.9 (Good), and >0.9 (Excellent).

Statistical analyses were conducted by **IBM SPSS Statistics** (Version 27) and Microsoft Excel. All tests were performed at a significance level of  $\alpha = 0.05$ . Statistical results were interpreted to evaluate both **validity** and **practical feasibility** of OpenPose and MediaPipe for estimating PIP joint angles during realistic computer tasks.

## Results

### Agreement Between Methods and the Electrogoniometer

The accuracy and agreement of MediaPipe and OpenPose with the electrogoniometer measurements were evaluated using ICC, RMSE (Root Mean Square Error), Pearson correlation coefficients, mean differences with SD (standard deviation), and LOA (limits of agreement) Bland–Altman (limits of agreement). Results for each method under both frontal and lateral view conditions are presented in Table 1.

Among the tested configurations, **MediaPipe with lateral view** demonstrated the highest agreement with the electrogoniometer. This configuration yielded an ICC of 0.92 (95% CI: 0.92–0.92), an RMSE of 4.22°,

**Table 1:** Agreement of the Electrogoniometer and two methods.

	ICC 95% Confidence Interval	The mean difference with Electrogoniometer (°), (SD)	RMSE (°)	<i>P</i>	LOA
Mediapipe frontal view	0.15 (0.14, 0.16)	-0.08 (15.55)	13.18	0.15	(-30.56, 30.41)
Mediapipe lateral view	0.92 (0.92, 0.92)	0.43 (4.22)	4.22	0.92	(-7.84, 8.71)
Openpose frontal view	-0.04 (-0.05, -0.03)	21.44 (36.38)	34.06	-0.073	(-49.87, 92.75)
Openpose lateral view	0.73 (0.73, 0.73)	2.19(9.24)	9.19	0.77	(-15.91, 20.30)

ICC: Intraclass Correlation Coefficient, RMSE: Root Mean Square Error, LOA: Bland-Altman limits of agreement, *P*: Pearson Correlation *P* value

and a Pearson correlation coefficient of 0.92. The mean difference between MediaPipe and the electrogoniometer was  $0.43^\circ$  (SD=4.22°), with LOA ranging from  $-7.84^\circ$  to  $8.71^\circ$ .

**MediaPipe with frontal view** exhibited moderate agreement, with an ICC of 0.15 (95% CI: 0.14–0.16), RMSE of  $13.18^\circ$ , and a Pearson correlation coefficient of 0.15. The mean difference was  $-0.08^\circ$  (SD=15.55°), and LOA extended from  $-30.56^\circ$  to  $30.41^\circ$ .

For OpenPose, the **lateral view** condition demonstrated acceptable validity. The ICC was 0.73 (95% CI: 0.73–0.73), an RMSE of  $9.19^\circ$ , Pearson correlation of 0.77, and a mean difference of  $2.19^\circ$  (SD=9.24°). The corresponding LOA ranged from  $-15.91^\circ$  to  $20.30^\circ$ .

By contrast, **OpenPose with a frontal view** exhibited poor agreement with the electrogoniometer. The ICC was  $-0.04$  (95% CI:  $-0.05$  to  $-0.03$ ), with an RMSE of  $34.06^\circ$  and a Pearson correlation coefficient of  $-0.073$ . The mean difference reached  $21.44^\circ$  (SD=36.38°), and the LOA extended widely from  $-49.87^\circ$  to  $92.75^\circ$ .

Bland–Altman plots for all four configurations (Figures 3-6) visually support these findings. The MediaPipe lateral view condition displayed the narrowest agreement range and fewest outliers, confirming its superior consistency

with the electrogoniometer.

### Percent Error Analysis

To evaluate the relative accuracy of each method, percent error metrics were computed, including the proportion of values falling within <5%, <10%, <25%, and <50% error thresholds. The complete results are provided in Table 2.

**MediaPipe with lateral view** achieved the lowest mean percent error at 2.02% (SD=2.08), with 92.7% of measurements within 5% error, 99.2% within 10%, and 100% within 50%.

**MediaPipe frontal view** recorded a higher mean percent error of 7.71% (SD=7.08), with 43.1% of measurements under 5% error and 99.7% within 50%.

**OpenPose with lateral view** demonstrated better performance than its frontal counterpart, with a mean percent error of 4.19% (SD=5.00). Approximately 73.2% of values were within 5% error, and 100% fell below the 50% threshold.

**OpenPose frontal view** presented the highest error, with a mean percent error of 19.67% (SD=18.02). Only 19.8% of measurements were below 5% error, and 90.4% were within 50%.

These results further confirm that lat-

**Table 2:** Percent error of the measurements of the two methods

	Mean Percent error (SD)	Percentage of values with percent error of			
		<5 (%)	<10 (%)	<25 (%)	<50 (%)
Mediapipe frontal view	7.71 (7.08)	43.1	72	97.3	99.7
Mediapipe lateral view	2.02 (2.08)	92.7	99.2	99.9	100
Openpose frontal view	19.67 (18.02)	19.8	39.6	72.4	90.4
Openpose_ lateral view	4.19 (5.00)	73.2	92.8	98.5	100

eral view configurations, particularly with MediaPipe, provide the most accurate and reliable measurements for finger joint angle estimation.

### Processing Time

The computational efficiency of each method was assessed by recording the average time required to process a 3-minute video. Results are summarized in Table 3. MediaPipe significantly outperformed OpenPose in terms of speed, with a mean processing time of 331 seconds (SD=12). In contrast, OpenPose required an average of 2,612 seconds (SD=109) per video. This substantial difference underscores the practical advantage of MediaPipe for real-time or large-scale ergonomic assessments, where processing time and scalability are critical factors.

### Discussion

The purpose of this study was to evaluate the validity of two prominent AI-based motion capture systems, MediaPipe and OpenPose, in quantifying index finger PIP joint kinematics during computer mouse use, using a gold-standard electrogoniometer for comparison. The findings indicate that MediaPipe, particularly when used with lateral camera views, offers a valid and scalable alternative to traditional electrogoniometry for assessing finger posture in office environments. However, while these markerless tools show significant promise for ergonomic applications, their effectiveness is highly dependent on camera viewing angle, with a notable trade-off between analytical accuracy and computational efficiency. These

results suggest that low-cost AI tools can replace traditional motion sensors in specific ergonomic assessments, provided the camera angle is strictly controlled.

### Accuracy and Agreement

The primary important finding of this study is the superior performance of the MediaPipe algorithm when used with a lateral camera view. This configuration achieved excellent agreement with the electrogoniometer, as demonstrated by a high ICC (0.92), a strong Pearson correlation coefficient ( $r=0.92$ ), and the smallest RMSE of all tested conditions ( $4.22^\circ$ ). Furthermore, the error analysis confirmed its reliability, showing that over 92% of its measurements had less than 5% error. This level of accuracy suggests that MediaPipe, under the correct observational conditions, is a highly valid tool for ergonomic practitioners seeking to assess finger postures non-invasively. The success of the lateral view is likely attributable to the unmistakable, unobstructed silhouette of the finger joints it provides, which minimizes self-occlusion and allows the algorithm to robustly identify the necessary anatomical landmarks (MCP, PIP, DIP) for angle calculation.

Conversely, this study shows that the frontal view is not suitable for reliable finger joint angle measurement. Both AI systems exhibited a significant performance drop from this perspective. Most notably, the **OpenPose frontal view method performed very poorly** to establish a meaningful relationship with the gold-standard measurements. This was evidenced by a negative ICC (-0.04), a near-zero correlation ( $r=-0.073$ ), and an exceptionally high RMSE of  $34.06^\circ$ . This failure indicates that from a frontal perspective, where the finger joints occlude one another and are visually foreshortened, the algorithm is unable to correctly locate the key points in 2D space to reconstruct the angle. These findings strongly support the view-dependent nature of markerless AI systems for fine joint angle estimation.

**Table 3:** Mean processing time of the two methods

	Mean processing time (seconds) (SD)
Mediapipe	331 (12)
Openpose	2612 (109)

The lateral view likely provides more precise visualization of finger flexion and joint displacement, especially for the PIP joint, which is crucial [34] self-occlusion and angle misinterpretation due to perspective distortion and lack of depth estimation. This finding carries a critical practical implication: without a standardized and validated camera setup protocol, data gathered using these powerful tools can be misleading or entirely invalid. The lateral, or sagittal plane, view should be considered the standard for this type of ergonomic assessment.

### Comparison with Previous Work

These findings are consistent with prior studies reporting the superior performance of MediaPipe in controlled hand-tracking tasks and the lower robustness of OpenPose for fine finger articulation under occlusion [35], as well as with the study by Okumura et al. which reported acceptable error rates for OpenPose in recognizing hand kinematics during cooking activities [34]. Most validation studies using OpenPose and MediaPipe have focused on gross motor tasks (e.g., gait analysis, upper limb posture) [33] with limited evidence supporting their use in finger-level joint analysis during task-specific activities. This study contributes novel data by directly comparing the two algorithms under a simulated office task and quantifying their deviation from gold-standard electrogoniometry.

### Implications for Ergonomics

A key practical difference was identified in computational speed: OpenPose was approximately eight times slower than MediaPipe, requiring over 40 minutes to process a 3-minute video clip, compared to just over 5 minutes for MediaPipe. This substantial difference in efficiency has direct implications for ergonomic research and digital musculoskeletal risk assessment. MediaPipe's high accuracy particularly in the lateral view and low computational requirements make it suitable for

scalable, non-invasive ergonomic evaluations in office environments. The algorithm ran efficiently on mid-range hardware (Intel Core i5, 8 GB RAM), highlighting its accessibility for field deployment.

In contrast, OpenPose required significantly more processing time and high-end hardware, relying heavily on a GPU to achieve reasonable speeds. For instance, it performs best with powerful GPUs such as the NVIDIA RTX 3080, limiting its practicality for real-time or large-scale applications. MediaPipe, on the other hand, runs efficiently on CPU and is compatible with most systems that have moderate hardware specifications. This makes MediaPipe a far more practical tool for large-scale studies or applications where real-time feedback is desired.

The speed and accuracy of MediaPipe, especially from the lateral view, make it an excellent candidate for integration into proactive ergonomic software that can assess and mitigate injury risks in real time. The practical implications of these findings are substantial. Lateral-view MediaPipe measurements demonstrated sufficient accuracy (RMSE  $<5^\circ$ ) to identify clinically relevant PIP flexion or repetitive motions and other risk factors resulting in MSDs [36]. This precision, combined with near-real-time processing capability, enables previously impractical applications: large-scale workplace surveillance, longitudinal exposure monitoring, and instant postural feedback systems which can be beneficial in both workplaces and rehabilitation [37-40]. However, our data unequivocally contraindicate frontal-view implementations until multi-view 3D solutions mature. Practitioners should prioritize sagittal plane capture at 1.5-2-meter distances with palm-relative camera angles to optimize landmark visibility.

For successful deployment in real office environments, several practical strategies must accompany the lateral camera placement. First, lighting consistency is crucial; systems should be used in well-lit conditions to mini-

mize sharp shadows that confuse edge-detection algorithms. A simple protocol involving a quick check of camera feed clarity before assessment is recommended. Second, concerning background clutter, users should aim for a high-contrast, non-patterned background behind the hand (e.g., a neutral-colored desk pad) to isolate the hand. Third, regarding anthropometric variability, while the AI models are trained on diverse datasets, extreme variations may affect landmark precision. A calibration step such as recording a brief sequence of known postures (full extension, full flexion) at the start of a session could help normalize outputs for individual hand proportions.

Future work must explicitly test these systems in uncontrolled office settings to quantify performance degradation and refine these protocols. Furthermore, the development of adaptive algorithms that can account for variable lighting and background in real-time, or the use of consumer-grade depth sensors (e.g., Intel RealSense) to provide supplementary data, represents promising research directions to bridge the gap between laboratory validation and field readiness.

### Strengths and Limitations

This pilot study presents several strengths, including the use of electrogoniometry as a reference standard, the application of multiple performance metrics (ICC, RMSE, LOA, percent error), and the inclusion of two camera views and two AI algorithms. The ecological nature of the task further enhances the relevance of the findings for real-world applications.

The task in this study was designed to simulate real-world office work, involving unscripted mouse use. This enhances ecological validity and underscores the potential of AI-based vision systems for capturing naturalistic movement patterns without encumbering the user. Several methodological considerations warrant reflection. While our unscripted task design enhanced ecological validity, it intro-

duced movement variability that may have amplified measurement error. The fixed 2-meter camera distance, though standardized, may not have optimized visibility for all hand anthropometrics. Additionally, even though the Biometrics Ltd. F35 electrogoniometer sensor has very small endplates (15 mm \* 8 mm), it still blocks a fair amount of finger and it might impede the recognition of finger and estimation of its landmark coordination and leading to measurement errors in both pose estimation AI algorithms. Moreover, the study was conducted in a controlled laboratory setting; performance in real-world office environments with variable lighting and backgrounds may differ. Finally, the processing time comparison was not normalized across identical hardware configurations (because, since MediaPipe and Openpose have different hardware requirements the former mainly relies on CPU for its computations while the latter uses GPU). However, the results still offer practical insight into real-world feasibility. These limitations notwithstanding, our multi-method validation approach with dual-view analysis provides robust evidence for redefining best practices in ergonomic assessment.

As for the lighting conditions, no specific measurements were taken for example, no use of speed lights or video editing. We aimed to keep the environment as realistic as possible, replicating a typical office setting where employees work at a computer. In other words, to make the experimental conditions closely resemble a real workstation, we did not adjust the lighting. Instead, the lighting was kept natural not too dark or too bright typical of a standard computer workstation.

While this study focused on pragmatic, single-camera 2D solutions, the fundamental limitation of monocular views (occlusion and lack of depth information) highlights the potential of multi-camera or 3D reconstruction approaches. Stereoscopic vision using two calibrated cameras could directly resolve the self-occlusion problem inherent in the fron-

tal view, enabling accurate angle estimation from more flexible viewing angles suitable for office assessments. However, these approaches currently demand more complex setup, calibration, and computational resources, which may offset the ease-of-use advantage of markerless systems. Future research should directly compare the trade-offs between the enhanced accuracy of such 3D/multi-view systems and the practicality of the single lateral-camera protocol validated in this study.

### Future Directions

Several promising avenues for future research emerge from the current findings and limitations. First, validation studies with larger and more diverse participant cohorts are essential to ensure the generalizability of AI-based pose estimation systems across populations and ergonomic scenarios. Additionally, algorithm performance should be evaluated across a broader range of tasks and mouse designs including vertical and ergonomic models and in prolonged or repetitive use contexts, such as gaming or CAD work.

To improve accuracy and robustness, future work should explore multi-view fusion techniques such as stereo triangulation to address the depth ambiguity and occlusion challenges inherent in single-camera setups. Training view-specific models with synthetic occlusion data may further enhance performance in visually complex or obstructed environments. Additionally, integrating depth sensing and developing real-time ergonomic monitoring platforms represent significant opportunities to advance non-contact risk assessment tools.

The integration of pose estimation systems like MediaPipe into wearable augmented reality platforms could enable real-time ergonomic feedback during actual work tasks. Complementing this, the development and validation of automated, event-based synchronization methods could enhance the temporal precision of future validation studies.

Although this pilot study was conducted

under controlled conditions, the high validity and low hardware requirements of MediaPipe suggest strong potential for generalization to actual workplace settings. Future deployment studies will be crucial for evaluating robustness under real-world lighting, occlusion, and multitasking scenarios.

We did not observe notable anthropometric effects among participants, but future studies should investigate this aspect more systematically.

### Conclusion

The present study demonstrates that AI-based, markerless motion capture specifically using the MediaPipe framework with a lateral camera view is a valid, reliable, and efficient tool for assessing index finger posture during computer mouse use. With high reliability (ICC >0.9), clinically acceptable accuracy (RMSE <5°), and near-real-time processing capabilities, the lateral-view MediaPipe approach marks a significant advancement over traditional, time-consuming techniques such as electrogoniometry.

Overall, this research lays a strong foundation for integrating accessible, AI-driven systems into ergonomic practice. When properly configured, MediaPipe offers a scalable solution for proactive, data-informed injury prevention in workplace settings. Continued development of multi-view 3D systems and real-world implementation studies will be essential to fully realize the potential of these emerging technologies in ergonomic assessment and intervention.

### Authors' Contribution

A. Sahraneshin Samani contributed to data analysis and processing and writing original draft preparation. AR. Choobineh contributed to conceptualization and study design review, and editing. M. Abdoli-Eramaki contributed to methodology development and design and review, and editing. M. Razeghi contributed to the review and editing. F. Negahdari contrib-

uted to data collection. All authors read and approved the final manuscript.

## Ethical Approval

The experimental protocol was reviewed by the Shiraz University of Medical Sciences Ethics Committee, ensuring compliance with institutional ethical standards (IR.SUMS.SCHEANUT.REC.1403.023).

## Informed Consent

Written informed consent was obtained from all participants.

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## Conflict of Interest

None

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