Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/AN16.20260043
Published: June 23, 2026

Prevalence of Musculoskeletal Distress in Economy-Class Flights: A Temporal and Postural Observational Study

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Abstract

Passenger comfort has been a key consideration for airlines seeking to remain competitive. Understanding passengers' behaviour in the aircraft cabin, including their actions and postures, can help assess their comfort while flying. This study seeks to find passenger's perceptions of comfort by examining their activities and body positions throughout a two-hour flight. The passengers' activities were observed and examined using an ergonomic assessment based on the RULA method. With the scores, the most prevalent in-flight activities and their accompanying body postures were identified and classified. The findings revealed that most passengers spent their time resting or sleeping, followed by using electronic gadgets and reading. During most activities, neck flexion continued to increase, resulting in increased discomfort, with the lower back (80%) and neck (75%) most severely affected. The positions of the neck, upper arm, lower arm, wrist, torso, and legs were analysed to identify postural behaviours. An elliptical structural diagram was used to depict these postures to better understand body movement and support. A questionnaire was also administered to determine discomfort driven by the seat and cabin atmosphere. Based on these results, recommendations were made to enhance the seat and cabin design, with an emphasis on improved support, usability, and adjustability. Particular attention was paid to design elements such as adjustable headrests and improved lumbar support, which are known to reduce neck and lower back discomfort.

Keywords
Human Factors, Musculoskeletal Disorders, Seat Comfort Analysis, Ergonomic Analysis, Ergonomic Risk Assessment.

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1. Introduction

The International Air Transport Association (2025) reported a 4.9% growth in air passenger traffic in 2025, with the Asia-Pacific region experiencing the highest increase at 7.3%. According to Akar et al. (2025), the aircraft industry significantly contributes to global economic expansion, with a global output valued at 4.1 trillion dollars in 2023. The industry serves as an input for other sectors and accounts for 3.9% of global revenue. The Air Transport Action Group (2024) identifies aviation as a major global employment sector, supporting 86.5 million direct, indirect, and induced jobs. Kaya and Aydın (2024) analysed data from 91 countries and confirmed a long-term relationship between economic growth and the roles of air transport in tourism, logistics, and freight.

In the current decade, short-haul markets across Europe and North America account for a substantial portion of airline capacity, with seat supply expanding in response to increased demand for shorter passenger trips (Klophaus and Yu, 2023). In India, 136.1 million people travelled domestically, with domestic traffic rising from 72.9% to 78.2% over a decade. Projections estimate that air passenger numbers will increase at an average annual rate of 5.6% over the next twenty years (International Air Transport Association, 2025).

Extended periods of sitting in confined spaces can result in non-neutral body positions and restricted movement. The Society of Diagnostic Medical Sonography (2019) notes that musculoskeletal disorders, also known as cumulative trauma disorders, develop gradually due to the constrained environments encountered by passengers, cabin crew, and maintenance personnel in civil aviation.

Prolonged awkward postures, repetitive movements, and insufficient rest negatively impact muscles, ligaments, and tendons throughout the body (Health and Safety Executive, 2018). Despite extensive research on aviation growth and its economic implications, limited studies have investigated the effects of in-flight seating conditions on musculoskeletal comfort among regular passengers on short-haul flights. Further evidence is required to establish a connection between sustained postures during flights and passengers' reported experiences. This study aims to examine the frequency of postural changes in an economy-class environment.

1.1 Objectives

- This study investigates the in-flight postural behaviour of passengers in economy-class settings, focusing on posture duration, frequency of positional changes, and the maintenance of non-neutral joint angles over specified time intervals.
- The objective is to determine the prevalence and distribution of musculoskeletal discomfort across various anatomical regions among passengers.
- Additionally, the study seeks to identify the anatomical regions most significantly affected by discomfort and pain intensity, and to evaluate their association with observed postural patterns throughout the flight duration.

2. Literature Review

Numerous studies have examined the ergonomic challenges faced by air passengers. Sitting positions are typically categorized into five primary groups: neutral, laptop/iPad use, reading, sleeping, and other postures such as baby-holding and eating (Aparicio Martín-Romo, 2015). In 2010, the National Civil Aviation Agency introduced the ANAC Label to inform passengers at the time of ticket purchase about seat characteristics on both domestic and international flights (National Civil Aviation Agency, 2009).

The literature indicates that restricted seating dimensions, limited posture variation, pressure accumulation, and prolonged static sitting are the primary ergonomic challenges in economy-class air travel. Research demonstrates that design parameters such as seat pitch, armrest height, backrest inclination, and cushion design directly affect passenger posture and comfort. A health survey by the Occupational Health Research Consortium in Aviation in the United States found that 47% of flight attendants experienced work-related illnesses, with 33% attributed to musculoskeletal and human-factor-related causes (Mulay et al., 2019). Porta et al. (2019) found that economy-class seats are frequently inadequate for accommodating increasing body sizes, mass, and height, as well as changing human proportions. Furthermore, seat pitch, legroom, and seat width influence safety by increasing the risk of deep vein thrombosis and digestive discomfort.

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Recent studies highlight ongoing ergonomic challenges in economy-class air travel. Russo et al. (2023) reported that current aircraft seat configurations frequently lack adequate support for passenger comfort and well-being, emphasizing the necessity for ergonomic redesign. Porta et al. (2023) demonstrated that standard economy-class seat dimensions do not sufficiently accommodate a substantial proportion of passengers, particularly regarding seat width and legroom. Tan et al. (2024) found that discomfort in the neck, shoulders, and lower back increases significantly with longer flight durations. Additionally, Tang et al. (2022) established that seat-armrest configuration can substantially influence neck posture during smartphone use. Collectively, these findings highlight the importance of evaluating passenger postures and musculoskeletal discomfort to inform evidence-based improvements in seat design. Russo et al. (2023) utilized CATIA ergonomics software with demographically diverse mannequins and concluded that airlines, in efforts to maximize passenger capacity within limited space, reduce seat spacing, which diminishes comfort and proper fit. As air travel demand increases and cabin densities rise, prioritizing human-centred seat design and posture assessment will be essential for mitigating musculoskeletal discomfort in economy-class flights. Okine et al. (2026) observed that human factors research in aviation predominantly focuses on pilots, rather than adopting a comprehensive approach that includes flight crew, cabin crew, ground staff, and maintenance personnel, despite significant risks related to fatigue, situational awareness, workload, automation, and stress.

2.1 Ergonomic Practices in Civil Aviation

Ergonomic awareness in aviation originated with the design of cockpit controls and displays, as well as efforts to mitigate pilot fatigue and enhance flight performance. Subsequent investigations by engineers, designers, and psychologists revealed that many accidents resulted from inadequate design rather than pilot error, prompting the adoption of human-centred design principles. The present study examines several applied techniques for addressing ergonomic challenges in civil aviation (Table 1).

Table 1. Ergonomic issues during in-flight activities and design parameters.

S. No.	Ergonomic Issue	Design Parameter	References
1.	Smartphones during flights cause neck flexion, static upper body and forward-head posture, risking vulture neck and muscle strain	Armrest height directly influences neck angle and flexion, significantly improving comfort during device use.	Tang et al. (2022)
2.	Limited legroom in economy seating restricts lower-limb movement and increases the risk of lower-limb oedema.	Comfort builds with dynamicity in lower-body shifts and variations.	Zhang and Yang (2024)
3.	Reports a high pressure at the seat-body interface due to fatigue and postural discomfort	Seat-pan design is a crucial factor for pressure distribution and seat contour, as it distributes pressure evenly and provides a larger contact area.	Fiorillo et al. (2021)
4.	Poor backrest recline angles on a plane seat cause muscle activation and trigger contractions.	A reclined backrest angle up to approximately 55.5° can improve sleep comfort, but beyond this point, it may decrease depending on the seat design.	Alawneh et al. (2024)

Due to the variety of sitting postures and limited space in economy seating, objective posture assessment tools are required to evaluate ergonomic risk.

2.2 Rapid Upper Limb Assessment (RULA)

Posture assessment tools such as RULA, REBA, NIOSH, OWAS, QEC, and the Strain Index enable visual evaluation of body posture for rapid risk screening and field assessment. Observational tools are cost-effective, efficient to implement, and applicable in diverse settings including workplaces, office environments, industrial sites, and seating studies (David, 2005).

RULA is an observational ergonomic tool that employs a rapid screening method to assess postural risks in the neck, trunk, and upper limbs, as well as muscle use and force exertion during tasks. The tool generates a final score indicating the level of musculoskeletal risk and the urgency of intervention required (Joshi and Deshpande, 2019). RULA assigns action levels ranging from acceptable posture to recommendations for medium-term investigation, urgent corrective measures, or immediate intervention, based on the passenger's seating posture in aircraft settings (Russo et al., 2023).

3. Methods

This section aims to establish a framework for assessing passenger use of economy-class aeroplane seats through observational methods combined with a RULA-based ergonomic assessment.

Nine passengers (P1-P9), selected at random, were observed on Air India Express Flight IX2152 from Indira Gandhi International Airport to Navi Mumbai, with a total flight duration of approximately 2 hours and 10 minutes. Verbal consent was obtained from the cabin crew prior to the observation, and passengers were observed covertly to minimize the Hawthorne Effect. Postures were recorded through pencil sketches at three time periods during the flight: T1 (12:38-12:58 IST), T2 (13:13-13:50 IST), and T3 (13:54-14:22 IST). Emphasis was placed on precisely noting and illustrating deviations, changes, twisting, and bending in body positions. Each posture was allowed to stabilise for 3-5 minutes during the sitting activity before recording to avoid capturing transitional movements. The visual observation, having time-dependent postural adaptations, had entries vector-outlined to produce a dataset for further analysis.

The marked joint coordinates were converted into numerical values and measured joint angles for the upper arm, lower arm, wrist, neck, trunk, and leg in the body configurations. Furthermore, using the RULA, risk scores were calculated to determine the prevalence and distribution of musculoskeletal discomfort across anatomical regions. Postural scoring included a −1 adjustment when the participant was leaning on an armrest, food tray, or handbag. An additional +1 was applied to all postures that were maintained beyond the defined time threshold. No load was assigned when the participant was holding a phone or not holding any object, while holding a book, tablet, or purse unsupported added +1, assuming a heavier load. For the lower body, a cross-legged posture or feet extended under the seat at a slanted angle added +2, whereas a V-shaped leg position with both feet on the ground added +1.

In this study, a modified version of the Nordic Musculoskeletal Questionnaire (NMQ) with images of sitting positions was circulated to the nine individuals to record their discomfort after the flight as our primary data. The RULA scores were compared with the discomfort reported from the circulated questionnaire to identify potential relationships between posture and perceived pain. The combined dataset was synthesized and analysed to identify the anatomical regions most significantly affected by discomfort and pain intensity. In addition, a Google Form based on the NMQ was distributed to frequent flyers to gain a broader understanding of postural duration, frequency of positional changes, and sustained non-neutral joint angles over defined time intervals in economy class. After data cleaning, responses from 24 participants were included in the analysis. The questionnaire collected information on the intensity of discomfort, the time of pain onset during the flight, and difficulty with movement after disembarking throughout the journey. The data were categorised by anatomical region, including the neck, shoulder, upper back, lower back, hip, thigh, and lower limb. Descriptive statistical frequency analysis and graphical representation were used to convert subjective perceptions into quantifiable indicators.

4. Data Collection

An observational shadowing method was used on a total of nine passengers (P1–P9) in their natural travel environment, without interaction. Each participant was recorded at three time points during the flight (T1, T2, and T3), resulting in 27 vector-outlined illustrations (Figure 1). At each interval, the posture was pencil-sketched and accompanied by written annotations describing head orientation, neck twists and bends, torso alignment, weight distribution between legs, and interaction with seat components such as the backrest, armrest, and footrest.

The sample consisted of five males (55.6%) and four females (44.4%) seated across the aisle, at the window, and in the middle seats. Participants ranged in age from approximately 14 to 50 years, encompassing adolescent, young adult, and middle-aged travellers. Most participants were in the working-age group (25–50 years), reflecting the frequent-flyer demographic. Flying frequency varied among first-time travellers and very frequent flyers, highlighting a comparison between habitual and non-habitual seating behaviour.

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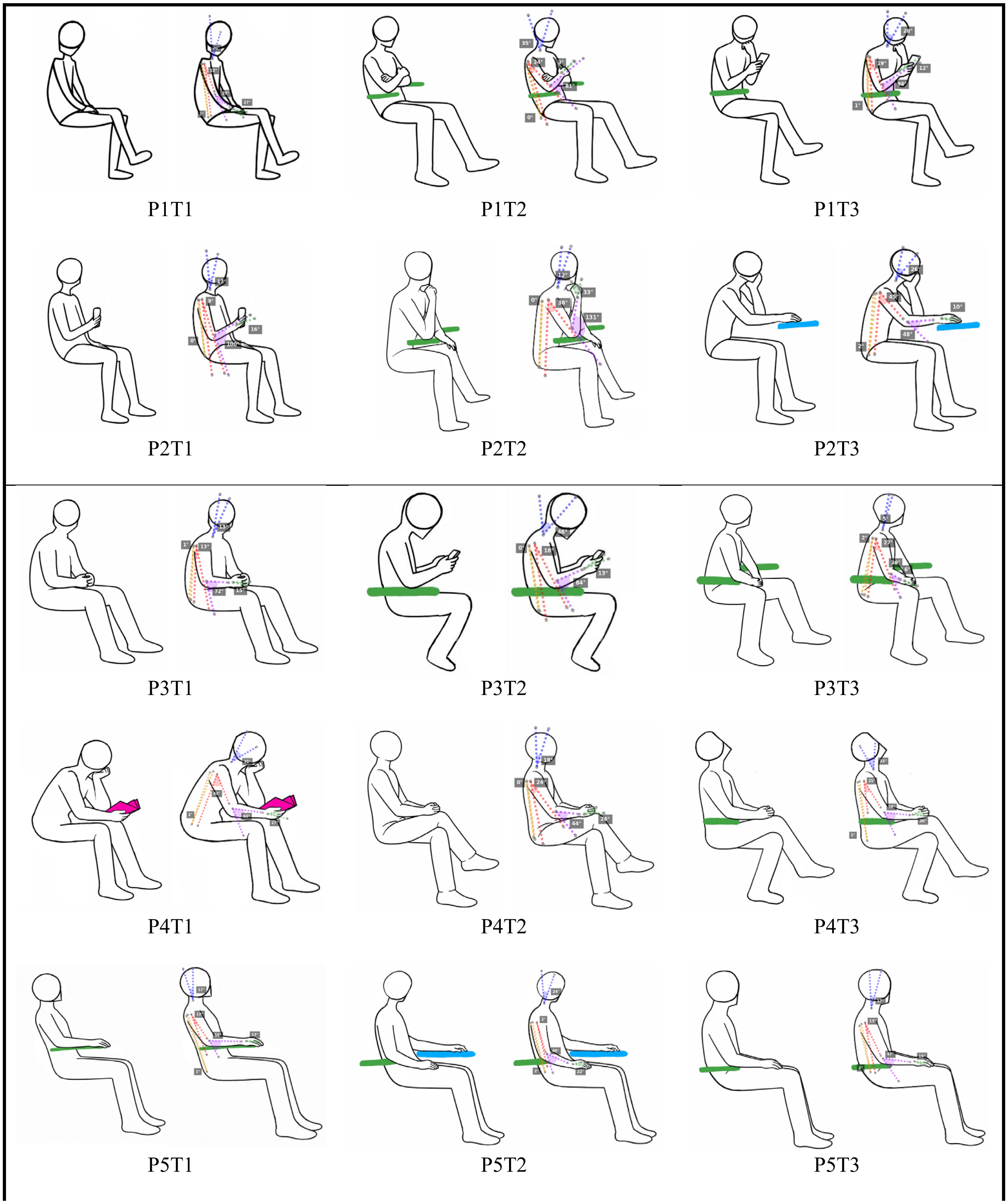
P1T1
P1T2
P1T3
P2T1
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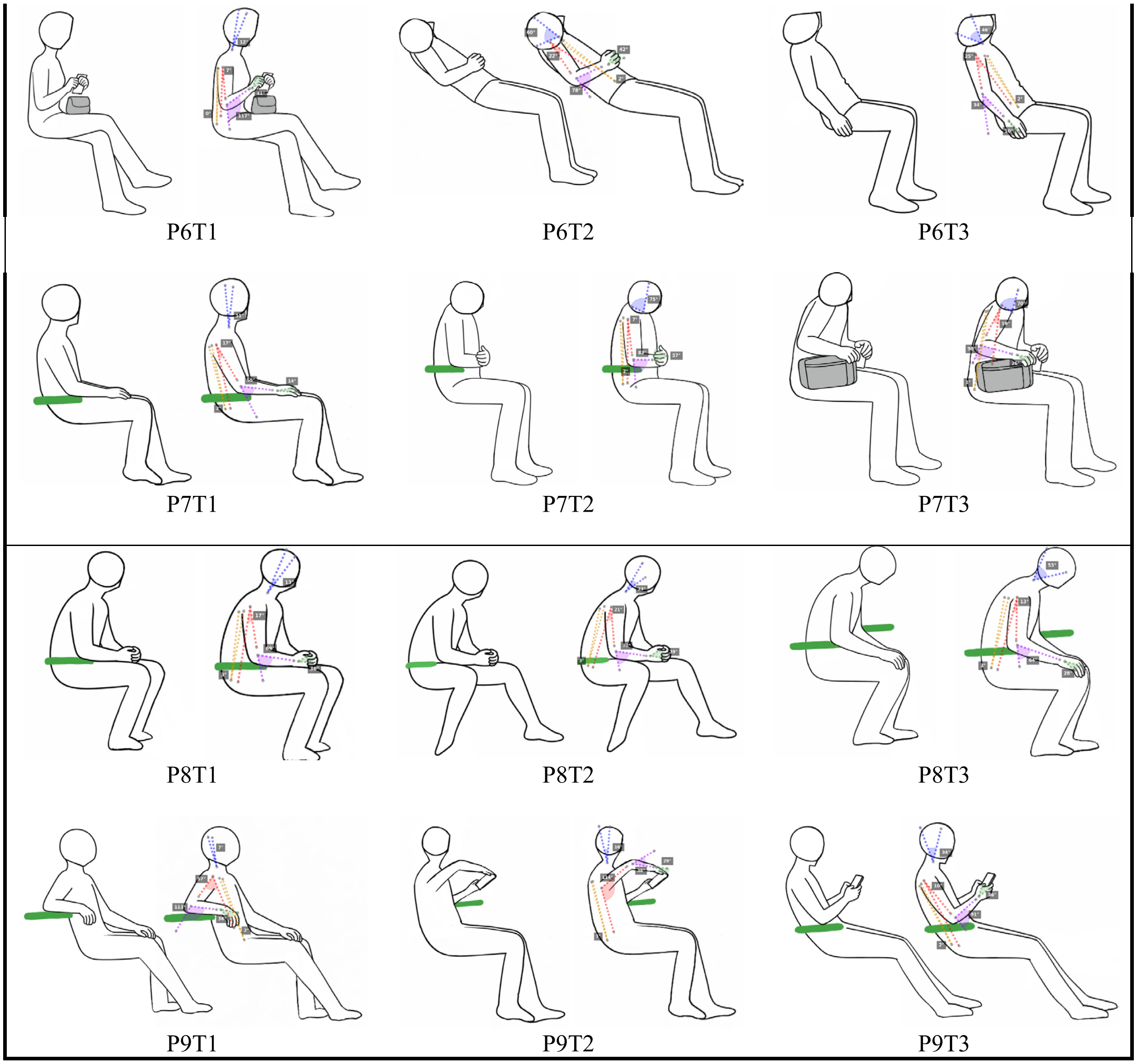

Figure 1. Ergonomic issues during in-flight activities and design parameters

Colour coding: Green represents the armrest, blue the food tray, pink the book (reading activity), grey the handbag/carry-on luggage, and a rectangle symbol represents the phone.

In the Google Forms questionnaire, 24 participants took part; the sample was dominated by females (62.5%, n = 15), with males (37.5%, n = 9). Most respondents were young adults with a mean age of 28.2 years (SD = 12.18), a median age of 24 years and the majority of the participants belonged to the 18-25 years age group (62.5%, n = 15), followed by the 26-35 years age group (16.7%, n = 4). Participants in the 36-50 years age group accounted for 8.3% (n = 2); those above 50 years also accounted for 8.3% (n = 2), while only 4.2% (n = 1) were below 18 years.

Flight frequency responses indicated a mixed level of travel exposure, with approximately 37.5% (n = 9) of the respondents flying once a year, 20.8% (n = 5) flying twice a year, and another 20.8% (n = 5) flying three times a year. A smaller proportion flew four times a year (12.5%, n = 3), and only 8.3% (n = 2) flew five or more times a year. With respect to departure times, morning flights were the most frequent, at 45.8% (n = 11); afternoon and night flights accounted for 16.7% (n = 4 each); evening flights comprised 12.5% (n = 3), and 8.3% (n = 2) of the respondents did not remember the departure times.

5. Results and Discussion

This section reports the key empirical findings linking observed in-flight posture exposure to post-flight discomfort. Results are presented in two stages: (i) time-sampled joint-angle exposure and self-reported in-flight behaviours, followed by (ii) regional discomfort prevalence (NMQ) and ergonomic risk screening (RULA).

5.1 In-Flight Posture Behaviour

This section combines objective posture data with subjective behavioural data to describe in-flight sitting exposure and its possible musculoskeletal consequences.

Figure 2 shows the distribution of joint angles (neck, shoulder, elbow, wrist, back) for the nine passengers at three time points (T1, T2, T3), with box plots indicating the median, quartiles, and range, and individual data points. Neck flexion angles showed a temporal trend, with median angles increasing from 8° at T1 to 30° at T2, and wider ranges (interquartile range: 5-15° at T1 to 30-50° at T3). It suggests a progressive drift away from the neutral position. Shoulder and elbow angles were temporally consistent (medians: 13-24° and 58-76°, respectively), although individual ranges were large (elbow range: 25-131°). Wrist deviation angles increased moderately over time (T1: 26° vs. T2: 28°), while back flexion remained small and constant (median: 1-2°) for all time windows. There was substantial inter-passenger variability in neck, shoulder, and elbow flexion angles among individual passengers within a single time window, indicating clear high- and low-exposure groups.

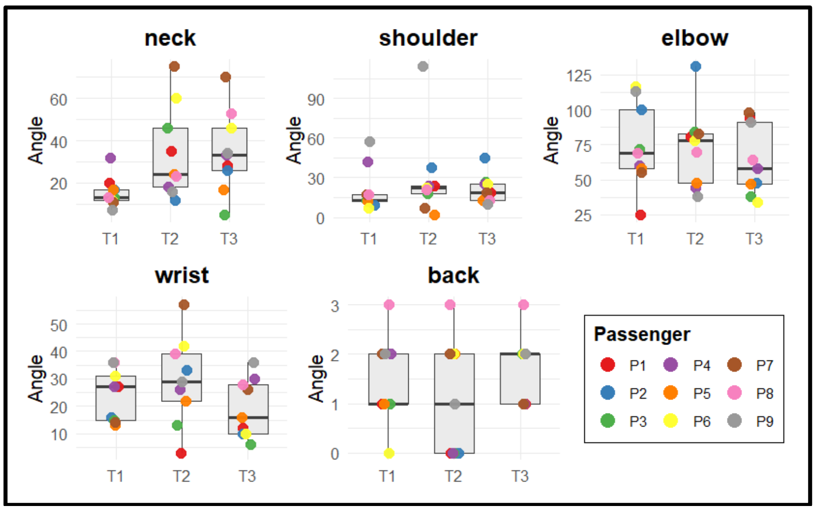

Figure 2. Boxplots illustrate the joint angles of the neck, shoulder, elbow, wrist, and back at three observation timepoints (T1–T3), demonstrating postural variability among passengers during the flight.

The exposure levels for each passenger (Table 2) summarize the three time points (T1, T2, T3) into individualized values, showing inter-individual variability. Each exposure level is characterized by a mean angle value, a standard deviation and minimum-maximum values (observed range).

Neck flexion had the largest variability (18.3-52.0° mean). Passenger P7 had the largest mean value (52.0 ± 35.6°, range 11-75°), reflecting a strong postural instability, while P2 and P5 kept a posture close to neutral. Five passengers (P1, P4, P6, P7, P8) had a mean neck flexion angle above 27°, reflecting high cervical loading exposure. Shoulder angles presented different patterns. Passenger P9 had the largest variability (60.3 ± 52.1°, range 10-114°), probably due to device handling, whereas P5 maintained low values, probably because the arms were close to the body during sitting in an idle position. Elbow flexion varied from 51.0° (P5) to 93.0° (P2). Passenger P2 had the largest flexion (93.0 ± 41.9°, max 131°), probably due to device handling. Five passengers had maximum flexion angles above 98°, indicating acute flexion during specific tasks. Wrist deviation had alarming trends in P7, P8, and P9 (mean > 32°). Passenger P8 had the highest mean value (34.3 ± 5.7°) with the least variability, indicating static wrist posture, a significant risk factor for carpal tunnel pressure. Low back flexion values were maintained. With P8 at 3.0° without variability, it indicates reliance on passive seatback support.

The three-window protocol captures posture at fixed time points rather than continuously, so peak joint angles between observations may have been missed. Even so, two patterns stand out: P5 and P8 maintained largely static, non-neutral postures with little variation, whereas P7 and P9 showed greater variability, suggesting more frequent adjustments, possibly due to discomfort or in-flight tasks.

The measured joint angles presented in Section 4 are complemented by survey data on self-reported posture and in-flight activities from a larger group of passengers (N = 24). These responses provide useful context for interpreting the observational findings but do not constitute direct measurement and may be influenced by recall bias.

The main activities (Figure 3) were sleeping (50%, n = 12), followed by phone, laptop, or tablet use (29%, n = 7), and sitting idle (21%, n = 5). Sleeping often required asymmetric neck positioning due to limited lateral head support, likely contributing to the high cervical variability observed in P6, P7, and P8. Device use encouraged forward head posture and cervical flexion, increasing posterior neck muscle demand and disc compression. This aligns with the elevated elbow angles (>90°) seen in P2, P6, P7, P8, P9, and P10, as well as the sustained wrist deviation in P8 (34.3°). Although sitting idle appears passive, it promoted static trunk positioning against the seatback, consistent with the low but steady back angles recorded (0.7–3.0°). Postural preferences (Figure 3) were mainly forward-leaning (50%, n = 12) and backwards-leaning (28%, n = 7). Forward-leaning increases anterior lumbar shear and requires erector spinae activation, supporting the repeated neck flexion (>27°) observed in five recordings. Backwards-leaning demands less muscle activity but promotes lumbar kyphosis and posterior loading, consistent with the measured low trunk angles. Together, the activity and posture data help explain the exposure patterns: device use was associated with neck, shoulder, and wrist loading; sleeping with asymmetric cervical strain; and idle sitting with sustained static trunk posture.

Table 2. Participant-specific joint angles, including mean, standard deviation, and range, are reported for neck, shoulder, elbow, wrist, and back postures observed during flight.

Passenger	Neck	Shoulder	Elbow	Wrist	Back
P1	27.7 ± 7.5 (20.0–35.0)	18.3 ± 6.0 (12.0–24.0)	66.7 ± 36.7 (25.0–94.0)	14.0 ± 12.1 (3.0–27.0)	0.7 ± 0.6 (0.0–1.0)
P2	18.3 ± 7.1 (12.0–26.0)	30.7 ± 19.1 (9.0–45.0)	93.0 ± 41.9 (48.0–131.0)	19.7 ± 11.9 (10.0–33.0)	0.7 ± 1.2 (0.0–2.0)
P3	21.3 ± 21.7 (5.0–46.0)	19.3 ± 7.1 (13.0–27.0)	64.7 ± 23.9 (38.0–84.0)	11.3 ± 4.7 (6.0–15.0)	1.0 ± 1.0 (0.0–2.0)
P4	27.7 ± 8.4 (18.0–33.0)	30.3 ± 10.1 (24.0–42.0)	54.0 ± 8.7 (44.0–60.0)	27.7 ± 2.1 (26.0–30.0)	1.0 ± 1.0 (0.0–2.0)
P5	19.3 ± 4.0 (17.0–24.0)	9.0 ± 6.1 (2.0–13.0)	51.0 ± 6.1 (47.0–58.0)	17.0 ± 4.6 (13.0–22.0)	1.7 ± 0.6 (1.0–2.0)
P6	39.3 ± 24.7 (12.0–60.0)	18.0 ± 9.6 (7.0–25.0)	76.3 ± 41.5 (34.0–117.0)	27.7 ± 16.3 (10.0–42.0)	1.3 ± 1.2 (0.0–2.0)
P7	52.0 ± 35.6 (11.0–75.0)	14.3 ± 6.4 (7.0–19.0)	78.7 ± 21.8 (55.0–98.0)	32.3 ± 22.2 (14.0–57.0)	1.7 ± 0.6 (1.0–2.0)
P8	29.7 ± 20.8 (13.0–53.0)	17.0 ± 4.0 (13.0–21.0)	67.7 ± 3.2 (64.0–70.0)	34.3 ± 5.7 (28.0–39.0)	3.0 ± 0.0 (3.0–3.0)
P9	19.0 ± 13.7 (7.0–34.0)	60.3 ± 52.1 (10.0–114.0)	80.7 ± 38.6 (38.0–113.0)	33.7 ± 4.0 (29.0–36.0)	1.7 ± 0.6 (1.0–2.0)

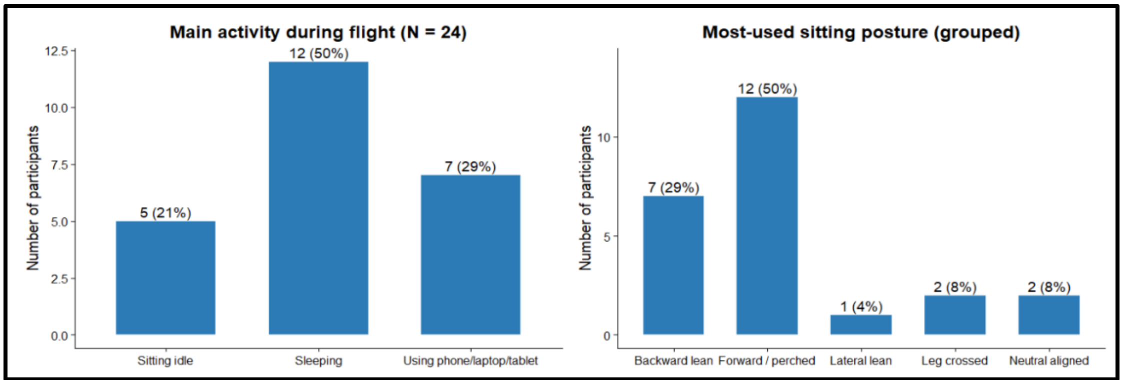

Figure 3. Primary in-flight activities and most commonly adopted sitting postures among economy-class passengers (N = 24).

5.2 Pain prevalence and ergonomic risk assessment

For the evaluation of post-flight musculoskeletal discomfort, the Nordic Musculoskeletal Questionnaire (NMQ) was used for the nine body regions. Pain reactions were recorded on a 4-point scale (0 = no pain, 1 = slight, 2 = moderate, 3 = severe). Figure 4 shows the prevalence (percentage of passengers with at least some pain) and the intensity (mean pain score for those with pain) for each body region. The bubble colours indicate the intensity.

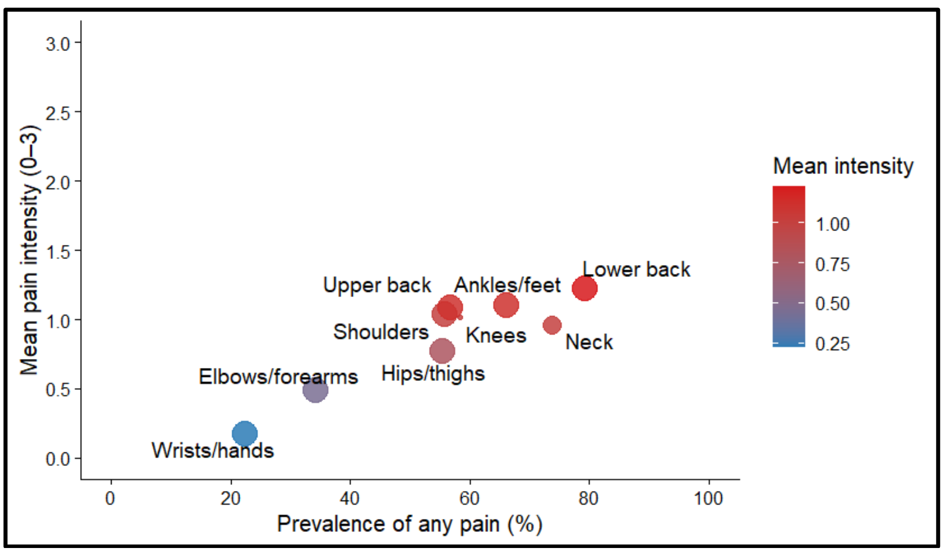

Figure 4. The prevalence and mean intensity of musculoskeletal discomfort were reported by passengers, with the lower back and neck exhibiting the highest levels of discomfort during the flight.

On the one hand, the prevalence data indicated that the axial and lower-extremity body regions were most affected. Lower back (80% prevalence), ankles/feet (65%), and neck (75%) had the highest prevalence of pain, while wrists/hands (22%) and elbows/forearms (35%) had the lowest. The prevalence of lower back and neck pain corresponds to the biomechanical exposure described in Section 5.1, where five passengers exhibited a mean neck flexion angle greater than 27° and the entire seatback was used in static trunk postures. Lower limb pain (ankles/feet and knees) is probably a result of prolonged static positioning of the lower extremities, with restricted movement of the knees/ankles due to limited leg space.

On the other hand, the intensity distribution showed a considerable deviation from the prevalence ranking. The lower back had both a high prevalence and the highest mean intensity (1.25), thus making it the foremost priority area. Ankles/feet had a high prevalence but a moderate intensity of 1.00, whereas neck had a lower intensity of 0.89. On the contrary, the upper back had a relatively lower prevalence but a higher intensity of 1.17, and the knees had a moderate prevalence with a higher intensity of 1.17. This discrepancy in prevalence and intensity indicates that although lower body pain was quite prevalent, the axial (lower back and upper back) and knee areas had more intense pain among the affected population.

This pattern of pain suggests a variety of biomechanical factors: axial pain (neck, lower back, upper back) is probably due to non-neutral trunk and neck posture, as described in Section 5.1, specifically, static seatback positioning (minimal back angle variability) leading to lumbar kyphosis and posterior element loading, in combination with progressive neck flexion (T1-T2 increase). Lower extremity pain (ankles/feet, knees) is due to static positioning, poor circulation, and joint fixation resulting from economy seating requirements, rather than active postural loading. The moderate prevalence of shoulder and hip/thigh pain corresponds to intermittent upper-extremity positioning requirements (device use) and pelvic pressure from seat-pan contact.

Lower back, upper back, and knees are identified as primary regions of discomfort; it can be investigated whether the ergonomic risk scores (RULA) indicate any temporal change during the flight and whether they correspond behaviourally to the observed pain patterns. The RULA risk scores were calculated at each time point for all nine passengers. Higher scores indicate notable postural deviation from neutral and increased musculoskeletal risk. Figure 5 illustrates the individual passenger RULA risk trajectories over the flight duration, indicating a high degree of inter-individual variability in both baseline risk levels and risk evolution patterns.

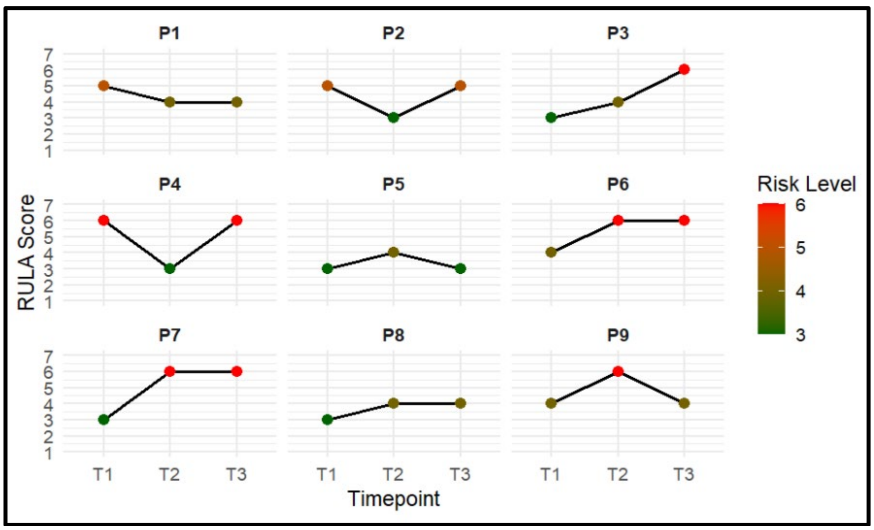

Figure 5. RULA score changes for individual participants (P1–P9) across three observation timepoints (T1–T3), demonstrating variations in ergonomic risk throughout the flight.

Three different patterns can be identified in the figure 5:
(1) Risk escalators (P3, P6, P7) demonstrated progressive increases (P3: 3-4-6, P6: 4-6-6), suggesting cumulative postural strain, likely due to fatigue-induced cervical flexion and trunk slumping, as indicated by the temporal neck angle increments identified in Section 5.1;
(2) Risk fluctuators (P2, P4, P9) demonstrated non-linear patterns with peaks during the middle flight window (P2: 5-3-5), suggesting task-related postural compensations;
(3) Risk stabilizers (P1, P5, P8) demonstrated stable scores (±1 point), indicating stable postural behaviour. The degree of inter-individual variability was large: T2 scores varied between 3-6, with P6 and P7 maintaining RULA ≥ 6 at T2-T3 ("investigate and implement change" threshold), while P5 kept RULA ≤4 throughout.
Escalating patterns represent processes of postural deterioration during prolonged sitting, while steady-state high scores represent risk constrained by these processes. RULA being an ordinal assessment method, the small sample size (n = 9) does not allow confirmatory inference but yields hypothesis-generating patterns. Passengers with high RULA (above 5) are at an increased risk for neck, shoulder, and upper back pain.

5.3 Proposed Improvements and Validation

Three interventions are highlighted. Firstly, cervical support must be optimized, given the progressive flexion of the neck and the 75% prevalence of neck pain. This points to the need to optimize headrests in economy class seats, which could be designed to be adjustable in the lateral direction to avoid asymmetric loading during sleep, which makes up 50% of all passenger activity. Secondly, the lumbar support must be optimized given the small angles observed in the trunk (0.7–3.0°), coupled with the 80% prevalence of lower back pain. The current seats promote kyphosis rather than lordosis, and a dynamic system could be designed to optimize the load. Thirdly, the constraints in the lower limbs must be re-evaluated, given the 65% prevalence of ankle/foot pain and 60% knee pain, which could be a contributory factor to compromised circulation. A 5–8 cm increase in legroom could be achieved without a substantial compromise in capacity.

This triangulation of angles, RULA, and NMQ also demonstrated good internal consistency. Passengers with high, sustained neck flexion were found to have high RULA scores, as expected. There was also good consistency in body angles identified as high risk by RULA and NMQ (neck, upper back, and lower back) and in pain areas (also neck, upper back, and lower back). The consistency of results between the observational study (sample size of 9) and the survey study (sample size of 24) provides good support for our findings. The activity patterns (50 per cent sleeping, 29 per cent using a device) and the posture preference (50 per cent preferring a forward-leaning posture) also provide good mechanistic consistency with our findings, as they indicate that the population size embodies archetypes of behaviour.

The observed increase in neck flexion during rest, sleep, reading, and use of electronic devices indicates insufficient head and cervical support in current economy-class seating. This evidence supports the integration of adjustable headrests designed to accommodate diverse anthropometric characteristics and preferred postures. Additionally, the high prevalence of lower back discomfort (80%) underscores the need for improved lumbar support systems and greater seat adjustability. Implementing these design modifications could reduce prolonged static loading and enhance overall passenger comfort during flights.

The present study utilized a limited sample of passengers during a single two-hour economy-class flight. While this sample size allowed for the identification of common postural behaviours and discomfort patterns, the findings may not be fully representative of all passenger demographics, aircraft configurations, seating layouts, or flight durations. Future research should include larger and more diverse passenger populations across multiple flights to improve the generalizability of the results.

However, there were three major shortcomings of this research, which might limit its generalization. They include:

(1) The research was conducted only for a short-haul flight, which took only about two hours. It might not be generalizable to long-haul flights, as passengers might be exposed for extended periods.

(2) The online survey might be prone to self-selection bias, as respondents were not randomly selected. Those who are highly sensitive to pain or discomfort may be motivated enough to participate in the survey, leading to an overestimation of the prevalence of back pain.

(3) The retrospective nature of the data might be prone to recall bias, as it is not directly measured. The data might not be as precise as using direct observation, as it might be prone to measurement bias. Further research is needed to build on this finding, preferably through a prospective cohort study. The results of this research may not be conclusive, as further research is needed, but they may be useful as a hypothesis generator.

6. Conclusion

By employing a behavioural, subjective, and computational analysis method to study passengers' in-flight activities on a short-haul domestic flight, a generalized comfort-level study was conducted. The major activities observed during the flight were sleeping, using electronic devices, and reading. An elliptic structural diagram was used to relate the postures, and a clear description of the neck, torso, upper arm, lower arm, wrist, and leg positions was achieved. Based on the results, neck flexion worsened over time, particularly during use of electronic devices and while sleeping. There was a high prevalence of neck pain (75%) and lower back pain (80%). In addition, the results from the joint angles, RULA, and NMQ were consistent.

To translate the above outcomes into practice, the following recommendations for seat design and passenger behaviour are made, with operational and financial constraints for economy-class seats in mind. First, design-based solutions to alleviate the strain on the neck and lower back region of the body. Second, to alleviate neck strain, passengers are advised to change position occasionally and keep electronic devices at eye level. The need for a balanced cabin system in terms of design, enhancing the comfort of the passengers, and providing a competitive advantage to the aviation industry through the modification of the characteristics of the seats based on the possible activities in a restricted cabin space is of paramount importance.

Acknowledgements

The authors are thankful to the passengers of Air India Express Flight IX2152 from Indira Gandhi International Airport to Navi Mumbai, who willingly participated and cooperated with us during the process. Their patience and cooperation made this study possible and helped form the basis of the research findings. A special thanks to Mr. Swattvik Som, Ph.D student in the Department of Design, Indian Institute of Technology Roorkee, for his constant guidance, constructive suggestions, and encouragement throughout the study. The efforts of Ms. Gunjan Varshney, Ph.D student in the Department of Applied Chemistry, Delhi Technological University, India are appreciated for reviewing this work and providing thoughtful feedback.

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