



Heart rate variability as an objective biomarker for work-related musculoskeletal disorder risk: a cross-sectional study of Hong Kong (China) professionals

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Abstract

Aim: To examine whether heart rate variability (HRV) parameters predict work-related musculoskeletal disorder (WMSD) risk profiles in Hong Kong (China) professionals and provide incremental predictive validity beyond self-reported perceived stress.

Methods: A cross-sectional study recruited 105 full-time office workers from Hong Kong's financial, legal, healthcare, technology sectors, and other professionals across five corporate sites between December 2025 and February 2026. Participants completed HRV assessment using a photoplethysmography device (5-minute resting protocol plus 1-minute deep breathing protocol), the Perceived Stress Scale-14 (PSS-14), a musculoskeletal pain questionnaire, postural assessment (forward head posture index, thoracic kyphosis angle), and a sedentary behavior inventory. Pearson correlation, hierarchical multiple regression, mediation analysis (PROCESS Model 4), and moderation analysis (PROCESS Model 1) examined associations between HRV parameters, perceived stress, postural variables, and pain outcomes. Statistical significance was set at $p < 0.05$.

Results: HRV parameters were significantly negatively correlated with pain intensity ($r = -0.31, p < 0.001$) and multi-site pain burden ($r = -0.38, p < 0.001$). Normalized coherence emerged as the strongest HRV predictor of pain severity ($\beta = -0.29, p < 0.001$), explaining 11.4% additional variance beyond PSS-14 alone. Forward head posture and thoracic kyphosis statistically mediated the coherence-neck/shoulder pain association. Daily sedentary hours moderated the HRV-pain association, with workers exceeding 8 hours of seated work showing the strongest autonomic-musculoskeletal risk profiles.

Conclusions: HRV parameters, particularly normalized coherence, are associated with WMSD-relevant pain outcomes in Hong Kong office workers and capture variance not explained by self-reported stress alone. These findings support HRV as a potentially useful objective complement to existing WMSD risk-screening approaches in sedentary professional populations, although longitudinal validation is required before clinical application.



Keywords

heart rate variability, work-related musculoskeletal disorders, perceived stress, ergonomic risk, autonomic nervous system, sedentary behavior, occupational health, Hong Kong (China)

Introduction

Work-related musculoskeletal disorders (WMSDs) constitute one of the most prevalent and economically burdensome categories of occupational health conditions worldwide. A systematic analysis for the Global Burden of Disease Study 2019 estimated that 1.71 billion people globally are affected by musculoskeletal conditions, representing the leading contributor to years lived with disability across all health conditions [1]. In occupational contexts, WMSDs account for a disproportionate share of work absenteeism, presenteeism, reduced productivity, and long-term disability claims, with annual economic costs running into hundreds of billions of dollars across developed economies [2].

Prevalence estimates vary substantially across occupational sectors. Among healthcare workers, systematic reviews report 12-month prevalence rates of low back pain ranging from 40% to 77% in nurses, with shoulder and neck pain affecting 35–55% of clinical staff [3, 4]. Industrial and manufacturing workers similarly show elevated rates of upper-limb WMSDs, with repetitive manual tasks recognized as a substantial risk factor for shoulder, wrist, and elbow disorders [5]. Agricultural workers face the highest burden of low back and lower-limb disorders, with prevalence estimates exceeding 60% in several large international cohorts due to combined exposure to heavy lifting, awkward postures, and prolonged standing [6]. Office and computer-based workers, the population of focus in the present study, demonstrate distinct WMSD patterns dominated by neck (42–63%), shoulder (35–55%), and upper-back pain (30–45%), reflecting the biomechanical and psychophysiological consequences of prolonged sedentary computer use [7, 8]. These sector-specific patterns underscore that WMSD etiology is shaped by the interaction of occupation-specific exposures with individual physiological vulnerability.

The etiology of WMSDs is multifactorial, encompassing biomechanical, ergonomic, psychosocial, and physiological risk factors that interact in complex, often synergistic ways. While ergonomic risk factors—including repetitive motion, awkward postures, and prolonged static loading—have historically dominated WMSD research and intervention design, there is growing recognition that psychosocial factors, particularly occupational stress, play an equally significant role in WMSD onset, severity, and chronification [9]. The mechanisms through which psychological stress may translate into musculoskeletal pathology include neuromuscular tension, altered pain sensitivity, increased inflammatory markers, and disrupted autonomic nervous system regulation—pathways that converge on cardiovascular and musculoskeletal systems simultaneously [10].

Hong Kong (China) presents a particularly compelling context for WMSD research. As one of the world's most densely populated and economically competitive cities, Hong Kong's professional workforce is characterized by extended working hours, high performance expectations, and a pervasive sedentary work culture driven by the dominance of financial services, legal, and technology sectors. Wing et al. [11] documented that Hong Kong's working and sedentary lifestyle constitutes a significant risk factor for musculoskeletal pain, particularly in the neck, shoulder, upper back, and wrist regions, with perceived stress correlating significantly with combinations of musculoskeletal pain ($r = 0.333$ – 0.620 , $p < 0.010$) and posture emerging as a critical variable in the stress-pain relationship.

Complementing this, Low and McCraty [12] demonstrated in a large Hong Kong organizational study that the average employee experiences near-high stress levels as a baseline condition [mean Perceived Stress Scale (PSS) = 17.69], with emotional depletion, relational tension, and autonomic dysregulation as prevalent features of the occupational landscape. Together, these two bodies of evidence raise a critical unanswered question: if occupational stress is physiologically expressed through autonomic dysregulation, and autonomic dysregulation is associated with musculoskeletal vulnerability, then HRV—as the most

accessible and validated index of autonomic function—may predict WMSD risk profiles in occupational populations.

Heart rate variability (HRV) refers to the beat-to-beat variation in cardiac inter-beat interval timing, reflecting the dynamic interplay between sympathetic and parasympathetic branches of the autonomic nervous system [13]. Higher HRV indicates greater autonomic flexibility and self-regulatory capacity, while chronically reduced HRV is associated with elevated cardiovascular risk, impaired emotional regulation, and increased vulnerability to stress-related health outcomes [14]. A meta-analysis encompassing 21,988 participants found that low HRV is associated with a 32–45% increased risk of a first cardiovascular event [15].

In occupational settings, Low and McCraty [16] established that HRV provides a reliable objective measurement of workplace stress that complements self-reported stress measures. Their correlational study of 85 Hong Kong employees found significant negative relationships between perceived stress and both standard deviation of normal-to-normal intervals (SDNN; $r = -0.255$, $p < 0.05$) and root mean square of successive differences (RMSSD; $r = -0.282$, $p < 0.01$). They also identified that HRV parameters captured stress-related physiological dynamics that self-report measures alone could not detect.

The theoretical and empirical basis for a relationship between HRV and musculoskeletal pain is substantial. Autonomic dysregulation, indexed by reduced HRV, has been associated with altered pain processing, reduced pain inhibition capacity, and heightened central sensitization, all of which contribute to musculoskeletal pain chronification [17]. The neurovisceral integration model [18] positions HRV as an index of prefrontal cortical regulation that governs both emotional and nociceptive processing, suggesting that autonomic dysregulation and pain vulnerability share common neurobiological substrates. Internationally, reduced HRV has been documented in patients with chronic neck pain, fibromyalgia, low back pain, and tension-type headache [17, 19].

Despite this growing literature, no prior study has directly examined whether HRV parameters predict musculoskeletal pain profiles in occupational samples or provide incremental predictive validity over self-reported stress measures for WMSD risk. This represents the central gap that the present study addresses.

This study pursues three primary objectives:

1. To examine the relationships between HRV parameters and musculoskeletal pain intensity, pain site multiplicity, and pain-related functional impairment in Hong Kong office workers.
2. To determine whether HRV parameters provide incremental predictive validity for WMSD outcomes beyond self-reported stress measures.
3. To examine postural variables and sedentary work behavior as mediators and moderators of the HRV-musculoskeletal pain relationship.

The following hypotheses were tested:

- **H1:** Lower HRV parameters (SDNN, RMSSD, normalized coherence) will be significantly associated with greater musculoskeletal pain intensity and multi-site pain burden.
- **H2:** HRV parameters will explain significant additional variance in musculoskeletal pain outcomes beyond PSS-14 scores.
- **H3:** Postural variables will statistically mediate the relationship between HRV coherence and neck/shoulder pain.
- **H4:** Daily sedentary work hours will moderate the HRV-musculoskeletal pain relationship.

Psychosocial factors have been increasingly recognized as significant contributors to WMSD risk. Buscemi et al. [9] established through a systematic review that psychosocial stress is an independent risk factor for chronic musculoskeletal pain, operating through both direct physiological pathways (elevated cortisol, increased muscle tension, autonomic dysregulation) and indirect behavioral pathways (reduced physical activity, poor sleep, maladaptive pain coping). Chen et al. [20] demonstrated that occupational stress among Chinese workers was associated with musculoskeletal pain through neuromuscular tension

and ergonomic factors, although their study lacked objective physiological measurement of these mechanisms.

Wing et al. [11] provided the first empirical investigation of the perceived stress-musculoskeletal pain relationship in a Hong Kong population, finding that perceived stress correlated more strongly with combinations of musculoskeletal pain than with single-site pain—a pattern consistent with central sensitization mechanisms. Their finding that the PSS item “difficulties are piling up so high that you couldn’t overcome them” was associated with both pain intensity ($r = 0.232, p < 0.010$) and pain impact on lifestyle ($r = 0.270, p < 0.001$) underscores the bidirectional nature of the stress-pain relationship in this population.

HRV has been applied as an occupational health biomarker across diverse professional populations and research contexts. Järvelin-Pasanen et al. [21] reviewed HRV as an indicator of work-related stress, concluding that occupational HRV measurement provides unique physiological information that self-report instruments cannot capture. Internationally, HRV has been investigated as a marker of stress and recovery in healthcare workers [22], shift workers [23], and high-demand professional populations [24], with consistent findings of reduced HRV during work periods and incomplete recovery during non-work hours among workers reporting high job strain.

In the Hong Kong context, Low and McCraty [16] established photoplethysmography (PPG)-based HRV assessment as a feasible occupational research tool, demonstrating significant correlations between HRV parameters and both PSS and Personal and Organizational Quality Assessment scores. Their finding that normalized coherence was negatively correlated with relational tension ($r = -0.222, p < 0.05$) suggests that coherence metrics capture dimensions of occupational stress that extend beyond simple sympathovagal balance.

Postural variables occupy a critical position in the WMSD risk landscape, particularly for sedentary office workers. Forward head posture (FHP)—anterior translation of the head relative to the thoracic spine—has been associated with increased mechanical loading on cervical musculature [25]. Thoracic kyphosis, commonly associated with prolonged computer use, similarly increases compressive loading on thoracic and lumbar structures.

International literature consistently links these postural variables to upper-quadrant pain. A meta-analysis of office workers found that FHP was associated with a 1.5- to 2.0-fold increase in odds of chronic neck pain [26]. Wing et al. [11] identified posture as a significant variable in the Hong Kong stress-pain relationship, with the sedentary work culture creating conditions in which postural dysfunction and musculoskeletal pain may reinforce each other. The present study formally tests postural variables as statistical mediators in the HRV-pain relationship.

Cultural factors shape both the experience and expression of occupational stress and musculoskeletal pain in ways that have important implications for WMSD risk assessment in Asian professional populations. Several interrelated cultural dynamics warrant consideration.

Collectivist values and group harmony. East Asian workplaces, including Hong Kong, are shaped by collectivist values that prioritize group cohesion over individual expression of discomfort [27]. Workers may be reluctant to report pain or stress for fear of burdening colleagues, disrupting team dynamics, or being perceived as unreliable. This norm can systematically depress pain reporting in occupational health surveys.

Face-maintenance (mianzi). The concept of “face”—the social standing maintained through composure and competence—discourages open acknowledgment of physical or psychological vulnerability, particularly in professional contexts where weakness may be perceived as career-limiting [28]. Face-maintenance norms may lead workers to downplay symptoms or delay help-seeking until impairment is severe.

Endurance norms (chī kǔ, “to eat bitterness”). The Confucian-rooted value of chī kǔ—the capacity to endure hardship without complaint—is widely internalized in Chinese professional culture as a marker of moral character and work ethic [29]. While adaptive in moderation, this norm can normalize chronic pain and stress as expected aspects of working life rather than signals warranting intervention.

Somatization tendencies. Cross-cultural psychiatric literature has documented that East Asian populations more frequently express psychological distress through somatic symptoms—including musculoskeletal pain, fatigue, and headache—than through explicit emotional language [30]. This somatization tendency creates an additional layer of complexity in disentangling psychological and physical components of WMSD presentation.

Help-seeking behavior. Traditional reliance on family and informal networks, combined with stigma surrounding professional psychological services, reduces uptake of occupational health interventions targeting stress [31]. This pattern may delay early intervention and allow autonomic dysregulation to progress toward overt musculoskeletal pathology.

Taken together, these cultural dynamics suggest that objective physiological measures such as HRV may provide more accurate WMSD risk assessment than self-report instruments alone in Asian professional populations, as they are not subject to the suppression, endurance, and underreporting biases that characterize subjective stress and pain measurement in this cultural context. We acknowledge, however, that cultural framings should be applied cautiously and not as deterministic explanations; substantial individual variation exists within any cultural group.

Materials and methods

Study design

This study employed a cross-sectional correlational design. Quantitative data were collected at a single time point from each participant, comprising HRV assessment, self-reported perceived stress, a musculoskeletal pain questionnaire, postural assessment, and a sedentary behavior inventory. Data collection was conducted across five corporate locations in Hong Kong between December 8, 2025 and February 27, 2026, spanning 12 weeks of active data collection. Data collection was paused for two weeks over the Christmas and New Year period (December 22, 2025–January 4, 2026) to accommodate reduced corporate staffing, with active recruitment resuming on January 5, 2026. All data collection was completed prior to data analysis, which commenced on March 3, 2026.

Participants

Sampling strategy and recruitment

A multi-site purposive convenience sampling approach was used. Five corporate organizations operating in Hong Kong’s financial services, legal, healthcare, technology sectors, and other professionals were approached through professional networks of the Hong Kong Association of Psychology and agreed to host the study at their premises. Within each participating organization, recruitment proceeded as follows:

1. The research team distributed a study information sheet and recruitment poster via the organization’s internal communications channel (email, intranet, or staff notice board).
2. Interested employees self-referred to the research team by email, indicating availability for a one-hour assessment slot.
3. Eligibility was confirmed via a brief telephone or email screening against the inclusion and exclusion criteria.
4. Eligible participants were scheduled for an on-site assessment.

This sampling approach was selected for feasibility within the corporate access constraints typical of Hong Kong’s professional sector, while purposive sector targeting ensured representation of the four

occupational groups of interest. We acknowledge that purposive convenience sampling limits generalizability beyond white-collar sedentary occupations, and this is addressed in the [Limitations](#).

Sample size and power analysis

A power analysis was conducted using G*Power 3.1 to determine the required sample size for detecting medium effect sizes ($f^2 = 0.15$) in multiple regression analyses with up to six predictors, at power = 0.80 and $\alpha = 0.05$. This yielded a minimum required sample of 98 participants. To account for anticipated data exclusions due to HRV measurement artifacts (conservatively estimated at 5–8% based on typical PPG-based occupational HRV study attrition rates), 115 participants were recruited, of whom 105 provided complete, artifact-free datasets and were included in final analyses.

Inclusion and exclusion criteria

1. Inclusion criteria:

- Full-time employed adults aged 25–55 years.
- Working a minimum of 40 hours per week in a sedentary office environment.
- Employed in Hong Kong for at least 12 consecutive months.
- Able to read and respond in English or Cantonese.

2. Exclusion criteria:

- Current use of medications known to influence HRV, including beta-blockers, diuretics, angiotensin-converting enzyme (ACE) inhibitors, selective serotonin reuptake inhibitors (SSRIs), or serotonin-norepinephrine reuptake inhibitors (SNRIs) [13].
- Diagnosed cardiovascular arrhythmia or pacemaker implantation.
- Consumption of caffeinated or alcoholic beverages within 2 hours of assessment.
- Current acute musculoskeletal injury (within 4 weeks).
- Pregnancy.

Participant characteristics

Participant demographic and occupational characteristics are presented in [Table 1](#).

Table 1. Participant demographic and occupational characteristics (N = 105).

Characteristic	<i>n</i>	%
Gender		
Female	61	58.1
Male	44	41.9
Age group		
25–34 years	38	36.2
35–44 years	47	44.8
45–55 years	20	19.0
Industry sector		
Financial services	32	30.5
Legal	18	17.1
Healthcare	22	21.0
Technology	21	20.0
Other professional	12	11.4
Weekly work hours		
40–50 hours	41	39.0

Table 1. Participant demographic and occupational characteristics (N = 105). (continued)

Characteristic	n	%
51–60 hours	38	36.2
61–70 hours	18	17.1
> 70 hours	8	7.6
Daily seated hours		
< 6 hours	12	11.4
6–8 hours	39	37.1
> 8 hours	54	51.4

The mean age was 38.4 years (SD = 7.2). The majority of participants (51.4%) reported more than 8 hours of daily seated work, consistent with the sedentary work culture documented in prior Hong Kong research [11].

Instruments and measures

HRV assessment

HRV was assessed using the emWave Pro Plus device (HeartMath Institute, Boulder Creek, CA, USA), following the standardized protocol established in prior occupational research [16]. The device uses PPG to capture pulse data via a sensor placed on the participant’s earlobe, translating cardiac rhythm data into real-time HRV metrics.

Validity considerations. PPG-based HRV measurement has been compared against the gold-standard electrocardiography (ECG) in multiple validation studies. Schäfer and Vagedes [32] reviewed the agreement between PPG-derived and ECG-derived HRV indices and reported strong agreement for time-domain measures (SDNN, RMSSD) under resting conditions, with intraclass correlations typically exceeding 0.85. Agreement is generally weaker under conditions of movement, irregular rhythm, or low signal quality. To minimize these sources of error, the present study employed: (a) a controlled seated resting condition, (b) artifact rejection by the device’s proprietary algorithm, and (c) visual inspection of all tachograms by a HeartMath-certified practitioner, with rejection of recordings containing > 5% ectopic beats or signal interruption. We acknowledge that PPG-derived HRV cannot fully substitute for clinical-grade ECG, and this is addressed in the [Limitations](#).

Assessment protocol. The HRV assessment comprised two phases:

- Phase 1—5-minute resting HRV assessment: Participant seated upright, breathing normally, with no instruction on breathing rate.
- Phase 2—1-minute deep breathing protocol: Six complete breath cycles (5 seconds inhalation, 5 seconds exhalation), providing a physiological challenge assessment of maximum HRV range.

HRV parameters extracted. Four HRV parameters were extracted, as defined in [Table 2](#).

Table 2. HRV parameters extracted and their clinical significance.

Parameter	Definition	Clinical significance
SDNN (ms)	Standard deviation of normal-to-normal inter-beat intervals	Overall autonomic variability; reflects total HRV
RMSSD (ms)	RMSSD	Parasympathetic/vagal tone; short-term HRV
MHRR (beats/min)	MHRR during paced breathing cycles	Respiratory sinus arrhythmia amplitude
Normalized coherence (%)	Coherence peak power/total power within 0.04–0.26 Hz	Autonomic synchronization and psychophysiological coherence

HRV: heart rate variability; MHRR: mean heart rate range; RMSSD: root mean square of successive differences; SDNN: standard deviation of normal-to-normal intervals.

Normalized coherence is a metric specific to the HeartMath analytic framework, computed as the ratio of peak spectral power within the coherence band (0.04–0.26 Hz) to total spectral power [33]. It is interpreted as an index of autonomic order and respiratory–cardiovascular synchronization rather than as a Task Force (1996) standard parameter. Reference ranges applied in this study were: SDNN 35–141.8 ms; RMSSD 19.1–133.2 ms [34]; MHRR 8.6–37.2 beats/min; normalized coherence 50–100% (derived from the emWave analytic framework).

PSS-14

The PSS-14 [35] is a 14-item self-report instrument assessing the degree to which respondents perceive their lives as unpredictable, uncontrollable, and overloaded over the preceding month. Items are rated on a 5-point Likert scale (0 = never to 4 = very often), with seven positively worded items reverse-scored prior to summation. The PSS-14 has demonstrated strong internal reliability across cultural contexts [36, 37] and has been applied in prior Hong Kong occupational stress research [11, 16]. In the present sample, internal consistency was acceptable (Cronbach's $\alpha = 0.84$).

Musculoskeletal pain questionnaire

For consistency and direct comparability with the prior Hong Kong perceived-stress and musculoskeletal-pain study by Wing et al. [11], we administered the Low and Ho musculoskeletal pain questionnaire as used in that study, rather than the Nordic Musculoskeletal Questionnaire (NMQ). This choice was made for three reasons:

1. **Comparability with the only existing Hong Kong-specific stress-pain dataset.** Direct continuity with Wing et al. [11] permits replication and extension of findings within the same cultural and occupational context.
2. **Inclusion of pain intensity and functional impact dimensions.** The standard NMQ collects 7-day and 12-month pain prevalence by anatomical site but does not provide continuous measures of pain intensity (0–10) or functional impact on daily activities (0–5), which were central dependent variables in the present analyses.
3. **Cultural and language adaptation.** The Low and Ho instrument has been administered in English and Cantonese in Hong Kong professional populations.

We acknowledge, however, that the NMQ is widely regarded as the standard WMSD prevalence instrument internationally, and we list this as a [Limitations](#), with a recommendation that future research employ the NMQ in parallel to enhance international comparability.

The questionnaire assessed pain presence, location, intensity, duration, and functional impact. Participants rated pain intensity on a 0–10 scale and frequency of impact on daily activities on a 0–5 scale. Pain sites assessed were: neck, upper back, lower back, shoulder, wrist, knee, hip, head, and chest/abdomen. A multi-site pain burden score was computed as the sum of pain sites rated $\geq 4/10$ in intensity, providing a composite index of pain distribution. The full questionnaire is provided as [Supplementary material](#).

Postural assessment

Postural variables were assessed using a standardized clinical postural screening protocol:

- **FHP index:** Horizontal distance (cm) between the tragus of the ear and the acromion process, measured with a calibrated craniovertebral measurement tool with the participant in standardized standing posture. Greater distance indicated more severe anterior head translation.
- **Thoracic kyphosis angle:** Assessed using a flexible ruler (flexicurve) placed along the thoracic spine from T1 to T12, with the resulting curve digitized to calculate the kyphosis index in degrees.
- **Self-reported postural awareness score:** 5-item scale assessing habitual awareness of sitting posture during work (1 = never aware to 5 = always aware).

Inter-rater reliability. All postural assessments were performed by two trained assessors (both registered allied health professionals) who completed a 4-hour standardized training protocol prior to data collection. To establish inter-rater reliability, both assessors independently measured FHP index and kyphosis angle in 20 randomly selected participants during the first month of data collection. Inter-rater reliability was high for both measures: FHP index intraclass correlation coefficient ($ICC_{2,1}$) = 0.91 (95% CI [0.79, 0.96]); thoracic kyphosis angle $ICC_{2,1}$ = 0.87 (95% CI [0.71, 0.94]). Assessors were blinded to participants' HRV and PSS-14 results at the time of postural assessment.

Sedentary behavior inventory

A brief 8-item inventory assessed daily sedentary work behavior, including: total daily seated hours, frequency of postural breaks, screen time, use of ergonomic equipment (standing desk, ergonomic chair, monitor height adjustment), and frequency of physical exercise outside work hours. The full inventory is provided as [Supplementary material](#).

Procedure

A dedicated assessment room was arranged at each corporate site with controlled temperature (22–26°C) and minimal external noise, consistent with the environmental standardization protocol established in prior research [16]. The assessment sequence for each participant was:

1. Informed consent and eligibility screening (10 minutes).
2. PSS-14 and musculoskeletal pain questionnaire completion (15 minutes).
3. Sedentary behavior inventory completion (5 minutes).
4. 10-minute seated rest period prior to HRV assessment.
5. 5-minute resting HRV assessment (emWave Pro Plus).
6. 1-minute deep breathing HRV protocol.
7. Postural assessment by trained assessor (10 minutes).

Total session duration was approximately 55 minutes per participant. All HRV assessments were administered by a HeartMath-certified practitioner, consistent with prior research protocols [16, 38].

Data analysis

All statistical analyses were performed using SPSS Version 27.0 (IBM Corp., Armonk, NY, USA) [39]. Statistical significance was set at $\alpha = 0.05$ for all primary analyses (two-tailed), and $\alpha = 0.10$ for exploratory moderation analyses. Effect sizes are reported as r for correlations and f^2 for regression models, with the following interpretation thresholds: $r = 0.10$ (small), 0.30 (medium), 0.50 (large); $f^2 = 0.02$ (small), 0.15 (medium), 0.35 (large) [40]. p -value reporting follows the convention: $p < 0.05$, $p < 0.01$, $p < 0.001$, with exact values reported where $0.001 < p < 0.10$.

The analytical sequence was as follows:

1. Descriptive statistics for all continuous variables, with normality tested via Shapiro-Wilk.
2. Pearson correlation analysis examining bivariate relationships between HRV parameters, PSS-14, pain outcomes, postural variables, and sedentary behavior indices. To control the false discovery rate (FDR) across the multiple correlations reported in the Results section, the Benjamini-Hochberg procedure was applied (FDR-adjusted $q < 0.05$). At each step, the change in R^2 (ΔR^2) and its associated F -statistic were calculated to test whether the newly entered block significantly improved the model beyond the preceding block.
3. Hierarchical multiple regression with pain intensity as the primary dependent variable:
 - Block 1: Demographic covariates (age, gender, work hours).
 - Block 2: PSS-14 score.

- Block 3: HRV parameters (SDNN, RMSSD, MHRR, normalized coherence).
 - Block 4: Postural variables (FHP index, kyphosis angle).
4. **Regression diagnostic checks**, conducted on the final model:
 - **Multicollinearity:** Variance inflation factors (VIFs) and tolerance values examined; threshold for concern set at VIF > 5.0.
 - **Linearity:** Examined via partial regression plots and component-plus-residual plots.
 - **Homoscedasticity:** Assessed via plots of standardized residuals against standardized predicted values, supplemented by the Breusch-Pagan test.
 - **Independence of residuals:** Assessed via the Durbin-Watson statistic (acceptable range 1.5–2.5).
 - **Normality of residuals:** Assessed via Shapiro-Wilk test on standardized residuals and visual inspection of P-P plots.
 5. Mediation analysis (PROCESS macro v4.0, Model 4 [41]) testing postural variables as statistical mediators of the HRV coherence → neck/shoulder pain relationship, with bias-corrected bootstrapped confidence intervals (5,000 iterations).
 6. Moderation analysis (PROCESS macro v4.0, Model 1) testing daily sedentary hours as a moderator of the HRV-pain intensity relationship, with continuous moderator probed at the 16th, 50th, and 84th percentiles.

Frequency-domain HRV variables were natural-log transformed prior to analysis to correct for positive skew, consistent with standard HRV analytic practice [16].

Ethical considerations

This study was conducted in accordance with the Declaration of Helsinki. Ethics approval was obtained from the Ethics Committee of the Hong Kong Association of Psychology prior to any participant recruitment or data collection (Approval No. HKAP-20251015-001, approved October 15, 2025). Participant recruitment commenced on November 17, 2025, following a two-week pilot protocol testing phase (November 3–14, 2025). All participants provided written informed consent prior to participation, including consent for publication of de-identified aggregated data. Participant confidentiality was maintained throughout, with all identifying information replaced by anonymized participant codes. No animal subjects were involved in this research.

Results

Descriptive statistics

Descriptive statistics for all primary study variables are presented in Table 3. Shapiro-Wilk tests confirmed approximate normality for all continuous variables of interest after log-transformation of frequency-domain HRV measures (all $W > 0.96$, $p > 0.05$).

Table 3. Descriptive statistics for primary study variables (N = 105).

Variable	Mean	SD	Min	Max	Reference range
HRV parameters					
SDNN (ms)	72.4	18.6	31.2	128.7	35–141.8
RMSSD (ms)	48.3	14.2	18.9	97.4	19.1–133.2
MHRR (beats/min)	16.8	5.4	7.2	31.6	8.6–37.2
Normalized coherence (%)	58.4	16.3	22.1	91.7	50–100
Stress and pain					
PSS-14 total	22.6	5.8	9	38	0–56

Table 3. Descriptive statistics for primary study variables (N = 105). (continued)

Variable	Mean	SD	Min	Max	Reference range
Pain intensity (0–10)	5.8	2.1	0	10	—
Multi-site pain burden	2.9	1.6	0	7	—
Pain impact on lifestyle (0–5)	3.1	1.2	0	5	—
Postural variables					
FHP index (cm)	4.2	1.8	0.5	9.1	< 2.5 cm normal
Thoracic kyphosis angle (°)	48.6	9.3	28.4	71.2	< 40° normal
Postural awareness score	2.4	0.9	1	5	—
Sedentary behavior					
Daily seated hours	8.6	1.9	4.5	13.2	—
Weekly exercise hours	2.1	1.8	0	9.5	—

FHP: forward head posture; HRV: heart rate variability; PSS-14: Perceived Stress Scale-14; RMSSD: root mean square of successive differences; SDNN: standard deviation of normal-to-normal intervals.

The mean PSS-14 score of 22.6 exceeded the high-stress threshold of 20, consistent with the near-high stress baseline documented in prior Hong Kong organizational research [12]. Mean SDNN (72.4 ms) and normalized coherence (58.4%) fell within but toward the lower end of reference ranges, suggesting subclinical autonomic dysregulation consistent with chronic occupational stress. The mean FHP index of 4.2 cm substantially exceeded the normal threshold of 2.5 cm, indicating widespread postural dysfunction in this sample.

Bivariate correlations: HRV parameters and musculoskeletal pain

Pearson correlations between HRV parameters, PSS-14, and pain outcomes are presented in Table 4. All reported correlations remained statistically significant after Benjamini-Hochberg FDR correction ($q < 0.05$).

Table 4. Pearson correlations between HRV parameters, PSS-14, and musculoskeletal pain outcomes (N = 105).

Variable	SDNN	RMSSD	MHRR	Coherence	PSS-14	Pain intensity	Multi-site burden	Pain impact
SDNN	—							
RMSSD	0.71**	—						
MHRR	0.58**	0.62**	—					
Coherence	0.64**	0.59**	0.51**	—				
PSS-14	-0.27**	-0.31**	-0.19*	-0.34**	—			
Pain intensity	-0.28**	-0.26**	-0.17*	-0.31**	0.41**	—		
Multi-site burden	-0.35**	-0.33**	-0.21*	-0.38**	0.46**	0.67**	—	
Pain impact	-0.24*	-0.28**	-0.16	-0.29**	0.44**	0.71**	0.63**	—

* $p < 0.05$; ** $p < 0.01$. HRV: heart rate variability; MHRR: mean heart rate range; PSS-14: Perceived Stress Scale-14; RMSSD: root mean square of successive differences; SDNN: standard deviation of normal-to-normal intervals.

Three of the four HRV parameters—SDNN, RMSSD, and normalized coherence—demonstrated significant negative correlations with pain intensity, multi-site pain burden, and pain impact on lifestyle, largely supporting H1. MHRR was significantly correlated with pain intensity and multi-site pain burden, but its correlation with pain impact did not reach significance ($r = -0.16$, $p \approx 0.10$). Normalized coherence showed the strongest associations across pain outcomes ($r = -0.29$ to -0.38), followed by RMSSD ($r = -0.26$ to -0.33). PSS-14 showed stronger correlations with pain outcomes ($r = 0.41$ to 0.46) than individual HRV parameters, although the two predictor sets were only moderately correlated with each other ($r = -0.19$ to -0.34), suggesting they capture partially independent dimensions of WMSD risk.

Table 5. Correlations between normalized coherence and pain by anatomical site (N = 105).

Pain site	<i>r</i> with coherence	<i>p</i>	FDR-adjusted <i>q</i>	<i>n</i> with site pain
Neck	−0.38	< 0.001	< 0.001	74 (70.5%)
Upper back	−0.34	< 0.001	0.002	68 (64.8%)
Shoulder	−0.36	< 0.001	< 0.001	71 (67.6%)
Lower back	−0.29	0.003	0.007	62 (59.0%)
Wrist	−0.24	0.013	0.023	48 (45.7%)
Head	−0.31	0.001	0.003	52 (49.5%)
Knee	−0.18	0.066	0.085 (n.s.)	31 (29.5%)
Hip	−0.14	0.152	0.171 (n.s.)	24 (22.9%)
Chest/abdomen	−0.09	0.362	0.362 (n.s.)	18 (17.1%)

FDR: false discovery rate; n.s.: non-significant.

HRV parameters and pain site specificity

Site-specific correlations between normalized coherence and pain are presented in Table 5. After Benjamini-Hochberg FDR correction, correlations for neck, upper back, shoulder, lower back, head, and wrist remained significant ($q < 0.05$); knee, hip, and chest/abdomen correlations did not survive correction.

HRV coherence showed the strongest and most consistent associations with upper-body pain sites—neck, shoulder, and upper back—which are the regions most directly implicated in sedentary postural dysfunction. This pattern is consistent with prior findings in Hong Kong workers [11] and supports the mechanistic interpretation that autonomic dysregulation and postural loading converge on upper-body musculoskeletal structures in sedentary office workers.

Hierarchical multiple regression: predicting pain intensity

Hierarchical regression results are presented in Table 6, with the final model standardized coefficients in Table 7.

Table 6. Hierarchical multiple regression predicting pain intensity.

Block	Predictors added	<i>R</i> ²	ΔR^2	<i>F</i> for ΔR^2	<i>p</i>
1	Age, gender, work hours	0.08	0.08	2.94	0.037
2	+ PSS-14	0.24	0.16	21.38	< 0.001
3	+ SDNN, RMSSD, MHRR, coherence	0.35	0.11	4.27	< 0.001
4	+ FHP index, kyphosis angle	0.44	0.09	8.31	< 0.001

FHP: forward head posture; MHRR: mean heart rate range; PSS-14: Perceived Stress Scale-14; RMSSD: root mean square of successive differences; SDNN: standard deviation of normal-to-normal intervals.

Table 7. Final model standardized coefficients (block 4) predicting pain intensity.

Predictor	β	95% CI	<i>t</i>	<i>p</i>	VIF
Age	0.14	[−0.01, 0.29]	1.82	0.072	1.31
Gender (female)	0.11	[−0.04, 0.26]	1.44	0.153	1.18
Weekly work hours	0.16	[0.01, 0.31]	2.11	0.037	1.42
PSS-14	0.31	[0.15, 0.47]	3.94	< 0.001	1.67
SDNN	−0.12	[−0.29, 0.05]	−1.38	0.170	2.84
RMSSD	−0.16	[−0.33, 0.01]	−1.87	0.064	2.91
MHRR	−0.08	[−0.23, 0.07]	−1.02	0.310	1.96
Normalized coherence	−0.29	[−0.45, −0.13]	−3.61	< 0.001	2.11
FHP index	0.24	[0.09, 0.39]	3.18	0.002	1.78
Kyphosis angle	0.19	[0.04, 0.34]	2.47	0.015	1.62

FHP: forward head posture; MHRR: mean heart rate range; PSS-14: Perceived Stress Scale-14; RMSSD: root mean square of successive differences; SDNN: standard deviation of normal-to-normal intervals; VIF: variance inflation factor.

The final model explained 44% of variance in pain intensity [$R^2 = 0.44$, $F(10, 94) = 7.38$, $p < 0.001$, $f^2 = 0.79$, large effect]. HRV parameters as a block explained an additional 11% of variance beyond PSS-14 alone ($\Delta R^2 = 0.11$, $p < 0.001$), supporting H2. Normalized coherence was the only individually significant HRV predictor in the final model ($\beta = -0.29$, 95% CI $[-0.45, -0.13]$, $p < 0.001$), with PSS-14 ($\beta = 0.31$), FHP index ($\beta = 0.24$), and kyphosis angle ($\beta = 0.19$) also emerging as significant independent predictors.

Regression diagnostic checks

Diagnostic checks confirmed that all standard regression assumptions were adequately met:

- **Multicollinearity:** All VIF values for the final model were below the conventional threshold of 5.0 (range: 1.18–2.91; tolerance range: 0.34–0.85), indicating that the moderate intercorrelation among HRV parameters did not produce problematic multicollinearity.
- **Linearity:** Partial regression plots and component-plus-residual plots showed approximately linear relationships between each predictor and pain intensity.
- **Homoscedasticity:** The plot of standardized residuals against standardized predicted values showed no clear funnel or systematic pattern. The Breusch-Pagan test was non-significant [$\chi^2(10) = 12.41$, $p = 0.258$], supporting the homoscedasticity assumption.
- **Independence of residuals:** The Durbin-Watson statistic was 1.94, within the acceptable range of 1.5–2.5, indicating no problematic autocorrelation.
- **Normality of residuals:** Standardized residuals were approximately normally distributed (Shapiro-Wilk $W = 0.987$, $p = 0.423$), with the P-P plot showing close adherence to the diagonal line.

These diagnostic results support the validity of the regression-based inferences reported.

Mediation analysis: postural variables as statistical mediators

A statistical mediation analysis using PROCESS Model 4 [41] with 5,000 bootstrap iterations examined whether FHP index mediated the association between normalized coherence and neck/shoulder pain intensity. The conceptual model is presented in Figure 1.

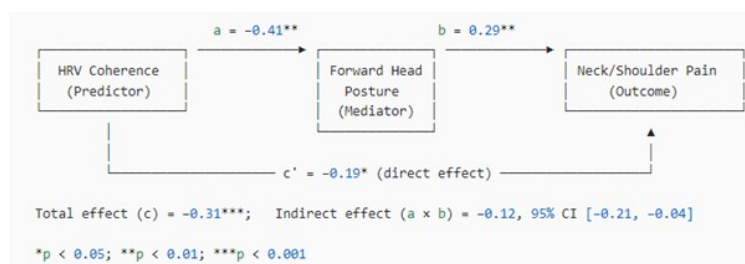


Figure 1. Statistical mediation model: HRV coherence → forward head posture → neck/shoulder pain. Coefficients are standardized betas. The indirect effect was estimated using 5,000 bias-corrected bootstrap samples.

The analysis yielded the following results:

- **Direct effect** of coherence on neck/shoulder pain (path c'): $\beta = -0.19$, $p = 0.028$.
- **Indirect effect** via FHP index (path $a \times b$): $\beta = -0.12$, 95% bootstrap CI $[-0.21, -0.04]$ (significant; CI excludes zero).
- **Total effect** of coherence on neck/shoulder pain (path c): $\beta = -0.31$, $p < 0.001$.

These results support H3: FHP index partially mediated the association between HRV coherence and neck/shoulder pain, accounting for approximately 39% of the total effect. Workers with lower autonomic coherence showed greater FHP displacement, which in turn predicted greater neck/shoulder pain intensity. A parallel mediation model with thoracic kyphosis angle as mediator yielded a significant indirect effect ($\beta = -0.09$, 95% CI $[-0.17, -0.02]$), suggesting both postural variables independently carry part of the coherence–pain pathway.

We emphasize that, given the cross-sectional design, these results constitute statistical mediation rather than confirmation of causal mechanism. Maxwell and Cole [42] have shown that cross-sectional mediation estimates can substantially diverge from longitudinal estimates of true causal mediation. The present findings are best interpreted as evidence consistent with—but not confirmation of—a coherence → posture → pain causal pathway.

Moderation analysis: sedentary hours as moderator

A moderation analysis using PROCESS Model 1 examined whether daily seated hours moderated the association between normalized coherence and pain intensity. The coherence × sedentary hours interaction term was statistically significant ($\beta = -0.22$, $p = 0.008$), supporting H4. Simple slopes are presented in Table 8.

Table 8. Simple slopes: effect of heart rate variability (HRV) coherence on pain intensity at different levels of daily seated hours.

Daily seated hours	Slope (β)	<i>t</i>	<i>p</i>	Interpretation
Low (< 6 hours/day)	-0.14	-1.42	0.159	Non-significant
Moderate (6–8 hours/day)	-0.26	-2.88	0.005	Significant
High (> 8 hours/day)	-0.41	-4.63	< 0.001	Strongly significant

The protective association between higher HRV coherence and lower musculoskeletal pain was substantially stronger among workers with the highest sedentary exposure. Among workers seated more than 8 hours daily—the majority of this sample (51.4%)—each standard deviation increase in normalized coherence was associated with a 0.87-point reduction in pain intensity on the 0–10 scale. This interaction is consistent with the interpretation that HRV coherence may function as a physiological buffer against the musculoskeletal consequences of prolonged sedentary work, although this causal framing requires longitudinal confirmation.

Subgroup analysis: HRV coherence tertiles

To provide clinically interpretable findings, participants were divided into tertiles based on normalized coherence scores: low coherence (< 47%), moderate coherence (47–68%), and high coherence (> 68%). Group comparisons are presented in Table 9.

Table 9. Pain and stress outcomes by HRV coherence tertile.

Outcome	Low coherence (<i>n</i> = 35)	Moderate coherence (<i>n</i> = 35)	High coherence (<i>n</i> = 35)	<i>F</i>	<i>p</i>
Pain intensity (0–10)	7.1 (1.6)	5.8 (1.9)	4.4 (2.0)	14.82	< 0.001
Multi-site pain burden	3.9 (1.4)	2.9 (1.5)	1.9 (1.3)	17.63	< 0.001
Pain impact (0–5)	3.9 (1.0)	3.1 (1.1)	2.3 (1.2)	16.41	< 0.001
PSS-14	26.4 (4.9)	22.8 (5.2)	18.6 (5.6)	16.28	< 0.001
FHP index (cm)	5.4 (1.7)	4.2 (1.6)	3.1 (1.5)	13.97	< 0.001
Daily seated hours	9.4 (1.7)	8.7 (1.8)	7.7 (1.9)	6.84	0.002

Values are means (SD). Post-hoc Bonferroni comparisons were significant at $p < 0.05$ between all tertile pairs for pain intensity, multi-site burden, and PSS-14. FHP: forward head posture; HRV: heart rate variability; PSS-14: Perceived Stress Scale-14.

Workers in the low coherence tertile reported pain intensity scores averaging 7.1 of 10—consistent with moderate-to-severe pain—compared to 4.4 of 10 in the high coherence group, a difference of 2.7 points exceeding the established minimal clinically important difference of 2.0 points for pain intensity scales [43]. The low coherence group also showed the greatest postural dysfunction (FHP = 5.4 cm vs. 3.1 cm) and longest daily seated exposure (9.4 vs. 7.7 hours), illustrating the convergent risk profile of autonomic dysregulation, postural dysfunction, and sedentary behavior in the highest-risk workers.

Discussion

HRV as a potential biomarker for WMSD risk

The primary finding of this study—that HRV parameters, particularly normalized coherence, are significantly and independently associated with musculoskeletal pain outcomes in Hong Kong office workers—provides empirical evidence consistent with a link between autonomic nervous system function and WMSD-relevant pain profiles in this population. The incremental predictive validity of HRV beyond PSS-14 ($\Delta R^2 = 0.11, p < 0.001$) is particularly noteworthy, as it suggests that HRV may capture physiological dimensions of WMSD risk that self-report instruments alone do not fully detect.

These findings are consistent with the broader international literature on autonomic dysregulation and chronic pain, including studies in fibromyalgia [17], chronic neck pain, and chronic low back pain populations, where reduced HRV has been documented across diverse clinical samples. The present study extends this literature by demonstrating analogous associations in a non-clinical occupational sample, suggesting that subclinical autonomic dysregulation may be detectable in working populations before progression to chronic pain syndromes. They also extend the foundational occupational HRV work of Low and McCraty [16], who established HRV as a valid objective complement to self-reported stress measures in Hong Kong professionals, into the specific domain of musculoskeletal health.

The emergence of normalized coherence as the strongest individual HRV predictor ($\beta = -0.29$) is consistent with the neurovisceral integration model [18], which positions coherence-related synchronization as a sensitive index of self-regulatory capacity. Workers with lower coherence may have reduced capacity to modulate both emotional stress responses and nociceptive processing, although the cross-sectional design of the present study cannot directly test this mechanistic interpretation.

The posture-autonomic-pain pathway

The mediation findings provide statistical evidence consistent with a pathway in which autonomic regulation, postural function, and musculoskeletal pain are interrelated in sedentary office workers. The significant indirect association of HRV coherence with neck/shoulder pain via FHP ($\beta = -0.12, 95\% \text{ CI } [-0.21, -0.04]$) is consistent with the interpretation that chronic autonomic dysregulation—characterized by sustained sympathetic activation and elevated muscle tension—may contribute to postural dysfunction, which in turn may generate mechanical loading on cervical and upper-thoracic structures. We note that the cross-sectional nature of the data precludes definitive causal inference [42], and alternative directional interpretations (e.g., that postural dysfunction itself contributes to autonomic dysregulation) cannot be ruled out without longitudinal data.

This statistical pattern is theoretically consistent with the trapezius muscle tension model proposed by Lundberg [10], in which psychosocial stress activates low-threshold motor units in the upper trapezius through cortical and subcortical pathways, generating sustained low-level muscle contraction that, over time, may produce tissue damage and pain. The present findings raise the possibility that HRV coherence could serve as an upstream marker of this process—potentially detectable before structural tissue damage occurs—although this hypothesis requires longitudinal investigation.

Sedentary work as a moderator of autonomic-pain associations

The moderation finding—that the HRV-pain association was substantially stronger among workers with the highest sedentary exposure (> 8 hours/day)—has potential practical implications. It is consistent with the interpretation that HRV coherence may function as a physiological buffer against the musculoskeletal correlates of sedentary work, with the strongest statistical association observed precisely among the most sedentary workers.

This finding aligns with prior identification of Hong Kong's sedentary work culture as a significant risk factor for musculoskeletal pain [11], and extends it by suggesting that autonomic regulation may play an important moderating role in this risk landscape. The finding that 51.4% of participants reported more than 8 hours of daily seated work—and that this group showed the strongest HRV-pain associations—

underscores the relevance of addressing sedentary behavior as part of comprehensive WMSD prevention in office-based professional populations, a concern that extends beyond Hong Kong to office workers in Western, Asian, and global contexts where sedentary work is increasingly the norm.

Cultural context and objective risk assessment

The present findings carry particular significance in the cultural context of Hong Kong's professional workforce. As discussed in [Introduction](#), multiple cultural dynamics—including collectivist values, face-maintenance, endurance norms, somatization, and reduced help-seeking—may systematically bias self-report measures of stress and pain in this population. The mean PSS-14 score of 22.6 in the present sample, while indicating high stress, may itself underestimate true physiological stress burden if cultural suppression effects are operative.

Objective physiological measurement may therefore provide a useful complement to self-report instruments in Asian professional populations. The finding that HRV explained 11% additional variance in pain outcomes beyond PSS-14 is consistent with this interpretation, although it does not directly demonstrate suppression bias and could reflect simply that HRV and PSS-14 capture partially distinct constructs. Future research employing experimental manipulation of disclosure conditions or comparison of objective and self-report measures across cultural samples would be needed to test the cultural suppression hypothesis directly.

Clinical and organizational implications

The present findings suggest several considerations for WMSD risk assessment and prevention in sedentary professional settings. We emphasize that these are tentative implications, given the cross-sectional design, and should be regarded as hypotheses for future testing rather than evidence-based recommendations for clinical practice.

For occupational health screening. HRV assessment may provide a feasible, non-invasive, and time-efficient (approximately 7 minutes per assessment) objective complement to standard self-report screening tools. Workers identified with consistently low coherence scores may represent a subgroup that could be prioritized for further ergonomic and psychophysiological assessment. We frame this in general terms of HRV assessment rather than in reference to any specific commercial device; methodological details for the present study are reported in [Instruments and measures](#).

For ergonomic intervention design. The mediation findings raise the possibility that interventions targeting postural dysfunction—including workstation ergonomic adjustment, postural awareness training, and movement break protocols—may yield additional benefit for workers with low HRV coherence, by potentially interrupting the autonomic–postural–pain pathway suggested by these data.

For psychophysiological intervention. HRV biofeedback, which has shown effectiveness in improving coherence and reducing perceived stress in prior Hong Kong professional samples [38, 44], represents a logical candidate intervention for workers identified as higher-risk through HRV screening. The present findings are consistent with—but do not establish—the possibility that coherence improvements achievable through HRV biofeedback training may translate into musculoskeletal pain reduction. Randomized controlled intervention trials are required to test this directly.

For organizational policy. The finding that workers exceeding 8 hours of daily seated work showed the strongest HRV-pain associations is consistent with the rationale for organizational policies promoting regular movement breaks, height-adjustable workstations, and integration of physical activity into the workday as structural WMSD prevention measures. These policies are supported by independent ergonomic evidence and need not depend on the present findings for their justification.

Limitations

Several limitations warrant acknowledgement.

Cross-sectional design. The cross-sectional design precludes causal inference. The mediation and moderation analyses presented should be interpreted as describing patterns of statistical association rather than confirmed causal pathways [42]. Longitudinal or experimental designs are required to establish directionality.

Selection bias and sampling. Participants were recruited via purposive convenience sampling across five corporate sites, drawn from the financial, legal, healthcare, technology sectors, and other professionals. This approach was feasible within Hong Kong's corporate access constraints but introduces potential selection bias: participants who self-referred to the study may differ systematically from non-volunteers in stress level, pain experience, or health-consciousness. The sample does not represent Hong Kong's full occupational landscape, including manual labor, service, manufacturing, and small-enterprise sectors. Generalizability beyond white-collar sedentary occupations is therefore limited.

HRV measurement device. HRV was measured via PPG (emWave Pro Plus), which is a non-gold-standard method relative to clinical-grade ECG. While PPG-derived time-domain HRV measures show strong agreement with ECG under controlled resting conditions [32], PPG cannot fully substitute for ECG, particularly for fine-grained spectral analyses. Future research should validate the present findings using ECG-based HRV measurement.

Self-report bias in pain and sedentary behavior measures. Pain intensity, multi-site pain burden, pain impact, and daily sedentary hours were all assessed via self-report, and are therefore subject to recall bias, social desirability, and the cultural reporting biases discussed in [Introduction](#). Objective measurement of sedentary behavior (e.g., accelerometry) and of pain-related disability (e.g., functional task performance) would strengthen future studies.

Pain instrument selection. The Low and Ho musculoskeletal pain questionnaire was selected for direct comparability with prior Hong Kong research [11] and for its inclusion of pain intensity and functional impact measures not available in the standard NMQ. However, the NMQ remains the internationally established standard for WMSD prevalence assessment, and its use in future research would enhance comparability with the broader international WMSD literature. We recommend that future studies in this area employ the NMQ in parallel with intensity-based measures.

Postural assessment precision. While inter-rater reliability for the FHP and kyphosis measures was high (ICC > 0.85), flexicurve and clinical anthropometric methods lack the precision of three-dimensional motion capture systems. Future research employing motion capture or inertial measurement units could provide more refined postural data.

Cultural framing. While we discuss cultural dynamics that may shape stress and pain reporting in Hong Kong, the present study did not directly measure these cultural variables. Cultural interpretations should be regarded as theoretically motivated context rather than empirically tested mechanisms within this study.

Conclusions and future directions

This study provides cross-sectional empirical evidence that HRV parameters—particularly normalized coherence—are significantly associated with musculoskeletal pain outcomes in Hong Kong office workers, and explain additional variance in pain intensity ($\Delta R^2 = 0.11$) beyond self-reported perceived stress. The mediation analysis is consistent with a pathway involving postural dysfunction, and the moderation analysis suggests that HRV-pain associations are strongest among the most sedentary workers.

These findings should be interpreted within the constraints of a cross-sectional, single-site (Hong Kong), white-collar sample. The data support HRV as a promising objective complement to self-reported stress in WMSD risk research, but do not establish HRV as a clinically validated screening tool. Definitive claims regarding clinical application require longitudinal validation and intervention trial evidence, which are beyond the scope of this study.

Future research priorities include: longitudinal cohort studies tracking HRV trajectories and WMSD onset over 12–24 months to establish temporal precedence and test causal pathways suggested by the present cross-sectional patterns; randomized intervention trials testing whether HRV biofeedback-mediated improvements in coherence produce measurable reductions in musculoskeletal pain burden, building on the clinical case evidence in Hong Kong professional samples [38, 44]; multi-modal wearable studies combining HRV monitoring with inertial measurement units and surface electromyography to capture real-time autonomic–postural–muscular dynamics during the workday; cross-cultural comparative studies examining whether the HRV-WMSD association documented in Hong Kong generalizes to other Asian professional contexts (e.g., Singapore, Japan, South Korea) and to Western professional populations, to test whether the patterns observed here are culturally specific or reflect more general autonomic–musculoskeletal dynamics in sedentary work; dose-response investigations examining the relationship between magnitude of HRV coherence improvement and magnitude of musculoskeletal pain reduction, to inform optimal HRV biofeedback intervention protocols for WMSD prevention; and replication using the NMQ as the primary musculoskeletal pain instrument, to enhance comparability with the broader international WMSD literature.

Abbreviations

ECG: electrocardiography

FDR: false discovery rate

FHP: forward head posture

HRV: heart rate variability

ICC: intraclass correlation coefficient

MHRR: mean heart rate range

NMQ: Nordic Musculoskeletal Questionnaire

PPG: photoplethysmography

PSS-14: Perceived Stress Scale-14

RMSSD: root mean square of successive differences

SDNN: standard deviation of normal-to-normal intervals

SNRIs: serotonin-norepinephrine reuptake inhibitors

SSRIs: selective serotonin reuptake inhibitors

VIFs: variance inflation factors

WMSD: work-related musculoskeletal disorder

Supplementary materials

The supplementary materials for this article are available at: https://www.explorationpub.com/uploads/Article/file/1007128_sup_1.pdf.

Declarations

Author contributions

AL: Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Visualization, Writing—original draft, Writing—review & editing, Supervision, Project administration. BL: Investigation, Data curation, Formal analysis, Writing—review & editing. Both authors read and approved the submitted version.

Conflicts of interest

The authors declare that they have no conflicts of interest related to this research. Adrian Low is a HeartMath-certified practitioner; this certification did not influence the design, conduct, analysis, or interpretation of the study. The HeartMath Institute had no involvement in this research.

Ethical approval

The Heart Rate Variability and Work-Related Musculoskeletal Disorder Risk study was approved by the Ethics Committee of the Hong Kong Association of Psychology (Approval No. HKAP-20251015-001, approved October 15, 2025). The study was conducted in accordance with the Declaration of Helsinki.

Consent to participate

Informed consent to participate in the study was obtained from all participants.

Consent to publication

Informed consent to publication was obtained from relevant participants. All participants provided written informed consent for the publication of de-identified aggregated data derived from their participation in the study. No individually identifiable information is included in this manuscript.

Availability of data and materials

The datasets generated and analyzed during the current study are not publicly available due to participant confidentiality terms stipulated in the ethics approval but are available from the corresponding author on reasonable request, subject to the participant consent terms.

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