Work xx (20xx) x–xx
DOI:10.3233/WOR-230659
IOS Press
CORRECTED PROOF

Research Article

Musculoskeletal disorders prediagnosis by infrared thermography in CNC machinery operators: Regression models approaches

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Received 14 November 2023
Accepted 12 July 2024

Abstract.

BACKGROUND: Musculoskeletal System Disorders (MSDs) are a group of injuries that represent common occupational diseases and should be evaluated for prevention purposes because an increase has been observed due to the repetitive movements performed in the industry. This research was carried out in a manufacturing industry where metal parts are manufactured, and workers experience back and wrist pain.

OBJECTIVE: To prediagnose Musculoskeletal System Disorders (MSDs) and examine the relationship between temperature, demographic, and physiological factors in workers through predictive models, contributing to MSD prevention.

METHODS: Information from 36 operators was used to obtain vital signs and somatometry data, and thermograms of their hands in the dorsal, palmar, and back areas were collected and analyzed to determine the relationship between temperature and demographic and physiological factors.

RESULTS: The ergonomic evaluations proved that the operators were at high risk owing to repetitive movements and postures adopted during work. Eighty-six percent of cases with injuries were identified using infrared thermograms, proving their high level of effectiveness. When studying the relationship between temperature behavior during recovery from repetitive activities and demographic and physiological factors, it was determined that age, dominant hand, respiratory frequency, and BMI were the most significant.

CONCLUSIONS: Nine regression models were obtained, with coefficients of determination between 0.17 and 0.71. The significant factors for worker injuries were age, dominant hand, respiratory rate, and BMI. However, the sample size and variability in work activities should be extended to generalize the findings.

Keywords: Thermography, occupational illness, risk factors

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1. Introduction

Musculoskeletal System Disorders (MSDs) are associated with health problems in the locomotor system, including the muscles, bones, tendons, cartilage, joints, ligaments, blood vessels, and blood [1]. MSDs are a set of injuries (inflammatory or degenerative), and symptoms of the musculoskeletal system are mostly related to the neck, back, and upper extremities, that is, fingers, hands, wrists, elbows, shoulders, arms, and neck [2], as their origin is related to activities that require repetitive or long-lasting static force. The most common MSDs are tendonitis and carpal tunnel syndrome (CTS) [3].

MSDs represent one of the most common occupational illnesses in our present day. Tarik Ghailan, Nadia Manar [4] recommend taking the following measures to prevent them: prior detection of occupational hazards, early medical diagnoses, ergonomic intervention and identification of postures that generate greater muscle tension, both in the lower back and in the hands and wrists.

An increase in MSDs has been observed; therefore, it is necessary to perform assessments and control the related risk factors, as they are associated with repetitive movements [5], which are always performed in the industry. With MSDs, workers can present with severe pain, impairment in productivity and quality of work, and even, in extreme cases, generate disability, which increases costs for companies and the public social security system [1].

For example, in England, during 2017–2018, 469,000 employees were recorded with MSDs, causing losses of $6.6 million, while in the United States of America, losses were counted at $54.9 billion in 2017 [6]. In contrast, the U.S. Bureau of Labor Statistics in 2018 indicated that MSDs were associated with 30% of workplace absenteeism [7]. According to the Liberty Mutual Workplace Safety Index estimates [8], each time MSDs become chronic conditions or permanent disabilities, they can generate direct and indirect costs for companies, reaching $13.3 billion in the United States in 2021.

Among the factors associated with MSDs are strength, posture, task repetitiveness, recovery time, duration of repetitive work activities, and isometric contraction intensity; however, this list has been debated for years [9]. Other authors have estimated that factors such as low temperature, gloves, and tools that generate vibrations increase the risk of MSDs in the operator. Consequently, several occupational risk assessment methods have been developed, such as the Occupational Repetitive Action (OCRA) method and the Rapid Upper Limb Assessment (RULA) method.

However, studies of MSDs and predictive models vary in the literature; for example, only the following studies are available in Mexico. Campillo and De la Vega [10] developed a predictive model for MSDs using sensory thermography as the primary tool to determine the relationship between temperature variability and MSDs diagnosis and the gender difference concerning MSDs; however, the model does not explain the variation in time.

On the other hand, Márquez Gómez [1] in Venezuela used traditional methods such as RULA (Rapid Upper Limb Assessment) and OCRA (Occupational Repetitive Action) in combination with statistical techniques for the selection of significant predictor variables for the development of predictive models. In Italy, Grieco [11] reported a logarithmic conversion of relative exposure (OCRA) and injury indices, with which he built a simple linear regression model for the risk prediction of MSDs. In Spain, Alvarez Tello, Casado Mejía [12] developed a predictive model using binary logistic regression and stress index questionnaire items as the predictor variables. Thus, it should be noted that there is limited research on developing predictive models for MSD in countries such as Mexico.

The industrial sectors in which MSDs occur are varied, such as automotive and aerospace, because they involve polishing parts to give them a final finish to the metal surface, eliminating marks, scratches, scuffs, and any other flaws originating from previous processes. Thus, the objective is to prediagnose MSDs and study the relationship between temperature and demographic and physiological factors of workers using predictive models that contribute to the effective formation of MSDs.

2. Methods

This research was conducted in a manufacturing industry in the State of Baja California (Mexico), where metal parts for automobiles and airplanes are manufactured using computer numerical control (CNC) machines, and the final finishing process involves portable polishing machines. Workers have reported problems with wrist inflammation and back pain in this area owing to the repetitive movements and forced postures they adopt when adjusting the machinery and processing the parts.

Information from the industry is required to generate predictive models; therefore, the following activities were carried out.

2.1. Selection of participants

The project's research objectives, procedures, and duration were presented to the companies of interest for approval. This study was based on the clinical procedures established by the Occupational Health Department of the participating company, in which it is evident that MSD exist.

The operations analyzed were cutting parts, adjusting CNC machinery, and CNC machining. The activities they perform involve repetitive movements when handling machinery and tools and the handling of levers above the elbow; therefore, workers have presented problems in the back and wrists. The machinery is adjusted each time a new order is processed. After finishing the piece, it was polished to obtain a final finish. The operators work a 10-hour workday, and the frequency and severity of their work depend on their assigned production schedule.

On the other hand, adjusting CNC machinery involves more significant effort and adopting forced postures. Finally, machining activities are performed at the end of the process, including polishing parts where various wrist discomforts arise. Owing to the type of tool used to polish the part, its design is not ergonomic and is very heavy, thus contributing to wrist discomfort.

Afterward, company tours were conducted to learn about the product's production process, and surveys were conducted to select participants from whom sociodemographic data and vital signs were obtained. This phase lasted approximately three weeks, since the company worked from Monday to Thursday. Operators who consumed medications for the peripheral nervous system (vasodilators, antihypertensives) were discarded because their consumption affects the sympathetic vasoconstrictor response, which affects their body temperature [13].

Before obtaining the thermograms and eliminating uncertainties in temperature measurements, the following restrictions were imposed on participants based on the protocols of Ammer [14], Standard Procedures for Infrared Imaging in Medicine [15] and the Design and Application of a Protocol for Acquiring and Processing Infrared Images from the Hands [16]. The inclusion criteria were as follows.

- Do not smoke before capturing the images (12 h).
- Do not drink alcoholic beverages in the hours before the exam (12 h).
- Do not drink coffee or tea for several hours before the study (12 h).
- Preferably, they did not eat fatty foods before analysis.

2.2. Somatometry and vital signs

This study was conducted with written consent granted by the company, which was verbally provided to all participants. The protocol was reviewed and approved by the Ethics and Bioethics Committee of the Postgraduate Department of the Faculty of Engineering, Architecture, and Design of the Autonomous University of Baja, California, according to the NOM-035-STPS-2018 Standard.

The vital signs and somatometries of the study subjects were recorded. Data included weight, height, body mass index (BMI), blood pressure, heart rate, respiratory rate, age, sex, and the dominant hand. The operator was also asked if they had presented with or had any injuries. Finally, the Tinel and Phalen tests were performed to detect hand inflammation. In-house data collection and thermograms began in January 2022 and ended in June 2022. A diagram of the measurement methodology is shown in Fig. 1.

2.3. Preparation of the area

The following is a description of the conditions that the area in which the thermograms were taken must meet to guarantee the accuracy of the temperature values collected according to the protocol determined.

2.3.1. Environmental conditions of the study

An ambient temperature between 22 and 24°C (±1°C) is maintained in the workplace, with a humidity percentage between 45–60%. When the upper limits of humidity are exceeded, the dehumidifier is used to lower its level to an optimal state because, through these controlled factors, vasomotion is avoided, which affects the accuracy of the temperature values in the subject. However, it is essential to avoid air currents, lamps under the study subject, or domes during thermal imaging. Before taking the images, the participants were asked to wash their hands with water and neutral soap, keep the wrist and forearm area uncovered, and keep their hands free of rings, bracelets, gloves, and tape.

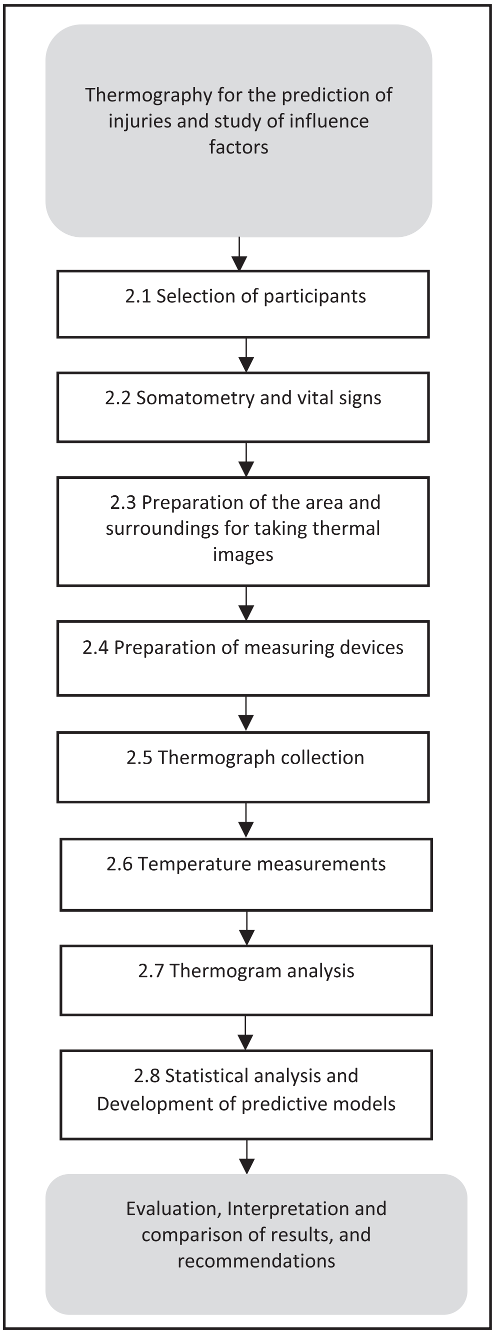

Fig. 1. Measurement methodology flowchart.

2.4. *Preparation of measuring devices*

2.4.1. *Thermographic infrared camera implementation*

The infrared thermography (IT) camera used in this study was a FLIR ThermaCAM^{TM} E25 model (FLIR Systems, Boston, Massachusetts, USA)

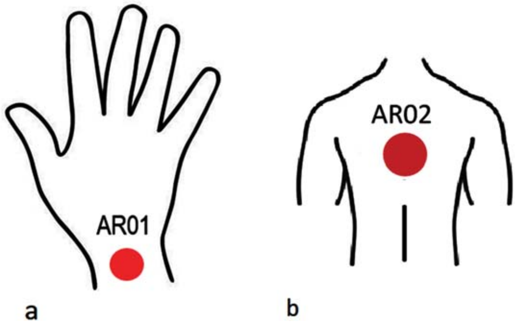

Fig. 2. ROIs (region of interest) were taken for temperature analysis on the palms and back of the hand (a) and the back (b) of the study subjects.

with a resolution of 160×120 pixels, an accuracy of $\pm 2°C/\pm 3.6°C$ for $\pm 2\%$ of reading, and a spectral range of 7.5–13 µm. The camera was mounted on a tripod for better handling, with an emissivity of 0.98, which is the average emissivity of human skin, thus avoiding temperature measurement errors. The emissivity was set to this value each time the infrared camera was used. The chosen region (Fig. 2) was selected for all participants. Before each shot, the camera was turned on for 15 min to maintain thermal equilibrium with the surroundings. The camera was placed perpendicular to the subject's hand at a minimum distance of 601 m [17]. In this study, a distance of 1.60 meters was considered. It is worth mentioning that a black surface was used as a background for the image, contributing to improving the reading of the thermograms and reducing the surrounding noise.

2.4.2. *Participant management*

Before starting the images, the participants were checked to ensure that they complied with the established restrictions to continue the process. Menstrual cycle was also considered in women; if the participant was in her period, thermal imaging did not continue. No cases were reported. The images were taken on a black chair to which a black laminated wooden board was attached, and the participant had to place her hands on it.

In each session, the subject was asked to stand behind the chair and avoid touching the board because the marks on the board caused noise in the thermal images. The board was marked with tape to guide the subjects to place their hands, as shown in Fig. 3. The first shot was taken at the back of the hand and then on the palms. A series of thermal images were taken for 5-minute spacing (see Fig. 4), starting at times 5, 10, 15, and 20, as recommended by Vardasca, Ring [18],

Fig. 3. Experimental setup diagram. Source: Own elaboration.

and García [19]. Once the capture was completed, the operator waited in another chair while the 5-minute pause elapsed until four pairs of shots were obtained. Thermal imaging was performed from 10 AM to 1 PM on Monday to Thursday. Thus, three participants were obtained per day.

2.5. Thermograph collection

The thermal images were then downloaded and analyzed using ThermaCAM™ Researcher Pro 2.10 software, FLIR Systems, Boston, MA, USA. In total, 324 images were reviewed. When analyzing each IT image, the color palette was configured in the rain option, and the emissivity (0.98) was adjusted during the shots.

2.6. Temperature measurements

The IR image was delimited according to the region of interest (ROI) to measure the temperature in that area. Then, the results option was activated to display the maximum, minimum, max-min, and average temperature values (Fig. 4).

2.7. Thermogram analysis

Next, the data were exported to Microsoft® Excel for organization and grouping according to the times the temperatures were recorded (5′, 10′, 15′, and 20′). Subsequently, the temperature differences were calculated for the minimum and maximum values of temperature captured by the thermographic camera. Subsequently, the thermal asymmetries that could represent a possible injury were identified and classified according to their alarm levels and severity, as established by Sillero-Quintana, Arnaiz-Lastras [20], as shown in Table 1.

Table 1
The scale of the level of attention given according to differences of temperatures between the body ROI (body region of interest) against laterals or between two shots of the same ROI (20)

Temperature Differences	Level of Attention
≤0.4	Normal
0.5–0.7°C	Follow-up
0.8–1°C	Prevention
1.1–1.5°C	Warning
≥1.6°C	Seriousness

Previously, Occupational Repetitive Action (OCRA), an ergonomic method to determine the risk to workers due to repetitive movements in their work activities, and rapid upper limb assessment (RULA), which is an [21–23] ergonomic evaluation method for posture adopted by the operator in the workplace for the upper limbs [24, 25]. Evaluations were performed to diagnose surgeries.

2.8. Statistical analysis and development of predictive models

The study factors were grouped for analysis of the acquired data. The variables to be considered are organized in the codebook listed in Table 2.

Statistical analyses were carried out using IBM® SPSS® V.25 software, Armonk, NY, USA IBM Corp, with the data normality tests performed using the Shapiro-Wilk test. Once normal and non-normal data were identified, non-parametric tests were performed (Mann-Whitney), which were applied to all data due to the small sample size [26]. The relationship between the factors' influences and temperature differences was determined, and an analysis of variance was used to identify significant factors. Regression models were generated using Minitab® 17.

Nine types of regression models were constructed using (a) study factors (age, sex, antiquity, dominant hand, injury, BMI, blood pressure (BP), respiratory rate (RR), heart rate, and Phalen/Tinel tests) and the temperature differences obtained by infrared thermography. Differences were considered statistically significant at $p < 0.05$, with a 95% confidence interval.

Fig. 4. ThermaCAM Researcher Pro 2.10 software display. Source: Own elaboration.

Table 2
Codebook of the studied variables

No.	Variable Name	Values
1	Age	1: <40 years
		2: ≥40 years
2	Sex	1: Male
		2: Female
3	Antiquity	1: ≤12 months
		2: >1 year <6 years
		3: ≥6 years
4	Dominant hand	1: right-handed
		2: ambidextrous
5	Injury	1: Yes
		2: No
6	BMI	1: normal (18.5–24.9 kg/m)^2
		2: overweight (25–29.9 kg/m)^2
		3: obese (≥30 kg/m)^2
7	BP (blood pressure)	1: normal
		2: low
		3: high
8	Heart rate	1: normal
		2: low
		3: high
9	RR (respiratory rate)	1: normal
		2: low
		3: high
10	Phalen/Tinel tests	0: approved
		1: not approved

3. Results

3.1. Demographic characteristics of the participants

Table 3 shows the vital signs and somatometric data of the participants.

Table 4 shows the results of the OCRA and RULA evaluations to measure the risk of repetitive activities in the study areas. All participants were identified as having an unacceptably high risk for OCRA and a level of action 4 in the RULA evaluation.

3.2. Thermal imaging

A total of 324 thermal images of the palmar and dorsal regions of the hand were analyzed. Figures 5 and 6 show examples of images captured from the palmar and dorsal regions of the hands, respectively. The thermograms were from moments 5′, 10′, 15′, and 20′.

The first thermogram was obtained after 5 min of rest and after the participant's highly repetitive activity. The thermogram sequences corresponded to a single participant.

Table 5 shows the minimum and maximum temperature differences in the dorsal area between the right and left wrists, calculated for each period.

Regarding the diagnoses of injuries utilizing IT, Table 6 summarizes the participants who reported having symptoms of suspected CTD or a confirmed

Table 3
Demographic characteristics

No.	Variable Name	Values	Qty	Percentage
1	Age	1: <40 years	25	69%
		2: ≥40 years	11	31%
2	Sex	1: Male	32	89%
		2: Female	4	11%
3	Antiquity	1: ≤12 months	15	42%
		2: >1 year <6 years	12	33.33%
		3: ≥6 years	9	24.67%
4	Dominant hand	1: right-handed	33	92%
		2: ambidextrous	3	8%
5	Injury	1: Yes	20	56%
		2: No	16	44%
6	BMI	1: normal (18.5–24.9 kg/m)^2	8	22%
		2: overweight (25–29.9 kg/m)^2	16	44.67%
		3: obese (≥30 kg/m)^2	12	33.33%
7	BP (blood pressure)	1: normal	22	61%
		2: low	9	24.67%
		3: high	5	14.33%
8	Heart rate	1: normal	21	58%
		2: low	4	11%
		3: high	11	31%
9	RR (respiratory rate)	1: normal	31	86%
		2: low	3	8%
		3: high	2	6%
10	Phalen/Tinel tests	0: approved	30	83%
		1: not approved	6	17%

Table 4
Results of the OCRA and RULA assessment conducted in the study areas

AREA	Assessment method	Rating	Results	Recommendations
Cutting	OCRA	91	Unacceptable high risk	Job upgrading, medical supervision and training
Cutting	RULA	7	Level of action 4	Immediate changes in the design of the task or workstation are necessary.
CNC	OCRA	122	Unacceptable high risk	Job upgrading, medical supervision and training
CNC	RULA	7	Level of action 4	Immediate changes in the design of the task and/or workstation are necessary.

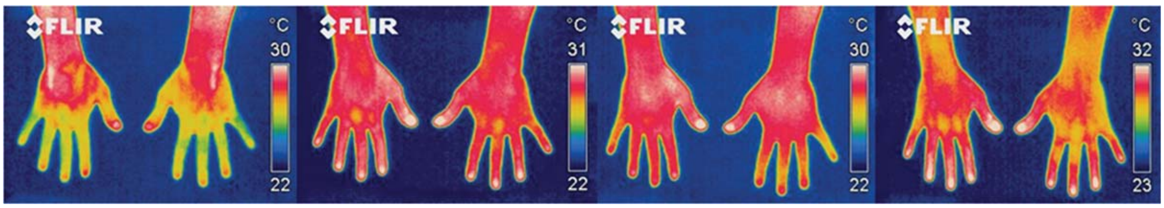

Fig. 5. Thermogram from the back of the hand of one of the participants at moments 5′, 10′, 15′, and 20′.

diagnosis of tendinitis, as well as the asymmetries obtained, their levels of attention, and the diagnoses obtained by thermal imaging. It is worth pointing out that twelve subjects were successfully classified.

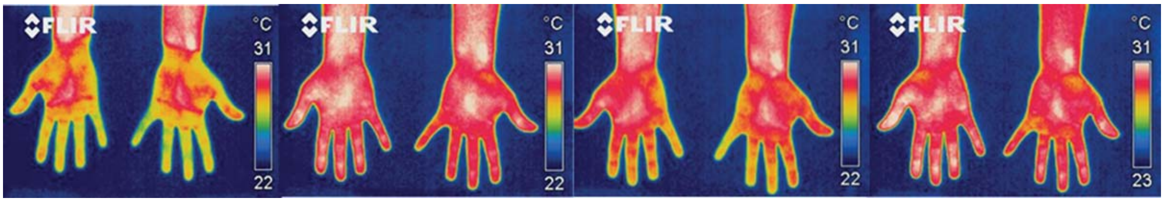

Fig. 6. Example of thermogram taken from the front area of the palm at times 5′, 10′, 15′, and 20′.

Table 5
Values of the minimum and maximum temperature differences from the back of the hand were obtained from the participants by time

Participant	ΔT5 Min	ΔT5 Max	ΔT10 Min	ΔT10 Max	ΔT15 Min	ΔT15 Max	ΔT20 Min	ΔT20 Max
Subject 1 with an injury	4.2	0.3	1	0.7	2.6	0.2	1.2	0.2
Subject 2 with an injury	0.7	0.8	0.6	0.1	4.4	0.4	1.8	0.7
Healthy Subject 1	5.6	0.1	0.9	0.5	1.9	0	3	0.2
Healthy Subject 2	0.4	0.5	0.7	0.7	0.3	0.3	0.9	0.1
Healthy Subject 3	0.1	0.8	0.9	0	0.6	0.3	1	0.7

ΔT = The temperature (minimum or maximum) of the back of the right hand and the temperature (minimum or maximum) of the back of the left hand.

Table 6
Diagnostic results of asymmetric wrist injuries in the palmar and dorsal region of the hand and back

Subject with Injuries	Maximum Asymmetry (°C)	ROI (region of interest)	Level of Attention	Injury Diagnosis (Warning/ Seriousness)
1	5.2	Back	Serious	Yes
2	3.5	Back	Serious	Yes
3	1.1	Back of the hand	Warning	Yes
4	1.6	Back of the hand	Serious	Yes
5	1.5	palm of the hand	Warning	Yes
6	4.4	back	Serious	Yes
7	2.8	back	Serious	Yes
8	3.1	palm of the hand	Serious	Yes
9	2	palm and back of the hand	Serious	Yes
10	2.3	palm of the hand	Serious	Yes
11	3.7	back of the hand	Serious	Yes
12	3.1	palm of the hand	Serious	Yes

The Shapiro-Wilk normality test yielded both normal and non-normal data. Because the two samples were small, the Mann-Whitney U test was performed for all data [26]. Table 7 shows a summary where age, dominant hand, test, respiratory rate, and BMI were determined to be statistically significant for temperature differences according to the non-parametric tests performed. Table 8 shows the results of the analysis of, where the series of significant factors for each ROI used in this research can be seen, among which the most important are age, dominant hand, and test. Table 9 briefly shows the quadratic regression models generated according to the influencing factors generated for each of the body regions of interest, which, as can be seen, were for average temperatures and, at times, 20 with maximum temperature values.

4. Discussions

In collecting demographic data from the participants, 69% were under 40 years of age and 89% were male. Fifteen of the 36 people had been with the company for one year or less, and 12 had been with the company for up to six years. Ninety-two percent of participants were right-handed. It was found that 44% of the participants presented with injury or discomfort, 67% were overweight, and regarding vital signs, 61% had normal blood pressure, 58% had normal heart rate, and 86% had normal respiratory rate. When the Phalen and Tinel tests were performed, 83% of the participants passed the tests.

When ergonomic evaluations were performed in the cutting and CNC areas, both areas showed an

Table 7
Mann-Whitney U-test of study factors for temperature differences

ROI (region of interest)	Factor	Time (minutes)	Temperature Differences	*p*-Value
Palm-left hand	Age	15	Average	0.049
Palm-right hand	Age	15	Maximum	0.012
Palm-left hand	Age	15	Average	0.026
Palm-left hand	Age	20	Minimum	0.035
Palm- right hand	Age	20	Maximum	0.018
Palm- right hand	Age	20	Average	0.009
Palm- right hand	Age	20	Maximum	0.012
Palm-left hand	Age	20	Average	0.016
Palm- right hand	Dominant hand	15	Minimum	0.009
Palm- right hand	Dominant hand	20	Average	0.041
Palm-left hand	Dominant hand	20	Maximum	0.049
Palm-left hand	Dominant hand	20	Average	0.023
Palm- right hand	Test	10	Maximum	0.029
Palm-left hand	Test	5	Average	0.033
Palm- right hand	Respiratory rate	20	Maximum	0.046
Back- right hand	Test	5	Maximum	0.002
Back- right hand	Test	10	Minimum	0.046
Back- right hand	Test	20	Maximum	0.016
Back- right hand	Age	10	Maximum	0.015
Back- right hand	Age	15	Maximum	0.009
Back- left hand	Age	15	Maximum	0.016
Back- right hand	Age	20	Maximum	0.03
Back- left hand	Age	10	Maximum	0.045
Back- left hand	Age	20	Maximum	0.002
Back- right hand	Dominant hand	10	Minimum	0.041
Back- left hand	Dominant hand	15	Minimum	0.049
Back- right hand	Dominant hand	15	Maximum	0.034
Back- left hand	Dominant hand	20	Maximum	0.049
Back- right hand	Injury	15	Minimum	0.049
Back- left hand	BMI	10	Maximum	0.018
Back- left hand	Test	10	Maximum	0.025
Back	Age	0	Average	0.026
Back	Age	0	Maximum	0.000
Back	Age	0	Average	0.032
Back	Age	0	Maximum	0.013
Back	Test	0	Maximum	0.023

unacceptably high risk when applying the OCRA method. The cutting area was 91, and the CNC was 122. The RULA method showed an action level of four in each area, indicating that immediate changes should be made. This proves the need for an in-depth study of work areas to reduce the risks due to repetitive movements and postures adopted while performing their work.

Ninety-two percent of the study subjects presented thermal asymmetries in the dorsal area, 39% of the participants presented a severity level of attention, and 34% had an alarm level. Finally, 27% of the participants showed both severity and alarm levels. In the palmar region of the hand, 83.3% of the study population manifested thermal asymmetries, of which 50% presented with severity and alarm levels of attention, 27% alarm levels, and 23% severity levels.

When analyzing the temperature differences between healthy and unhealthy subjects, high-

Table 8
Analysis of variance of the study factors for the corresponding ROI (region of interest)

ROI (region of interest)	Factor	Time (minutes)	Temperature Differences	*p*-Value
Back- left hand	Age	20	Maximum	0.000
Back- left hand	Dominant hand	20	Maximum	0.021
Palm-left hand	Age	20	Maximum	0.000
Palm-left hand	Test	20	Maximum	0.032
Back	Age	0	Maximum	0.000
Back	BMI	0	Maximum	0.016
Back- right hand	Respiratory rate	20	Maximum	0.040
Palm- right hand	Sex	20	Maximum	0.011
Back	Antiquity	0	Maximum	0.007
Back	Injury	0	Maximum	0.034
Back	Test	0	Maximum	0.023
Palm-left hand	Age	20	Average	0.001
Palm-left hand	Dominant hand	20	Average	0.036
Back- left hand	Age	20	Average	0.002
Back- left hand	Dominant hand	20	Average	0.037
Back	Antiquity	20	Average	0.027
Back	BMI	20	Average	0.004

Table 9
Summary of models by ROI (region of interest), hand section, back, and factors included

ROI (region of interest)	Regression models	R-sq	R-sq (Adj.)
Back of hand	MaxDIT20=25.22+2.044 Age+1.664 DH+0.295 RC+0.879 TEST	0.5171	0.4548
Palm	MaxPIT20= 26.411 + 1.656 Age + 1.189 DH + 0.427 BMI + 0.314 AT + 1.065 TEST	0.5607	0.4875
Back	EIMaxI=34.026 + 0.0176 No. - 0.928 Age + 0.342 Injury - 0.360 BMI	0.4601	0.3904
Back of hand	DΔT20 Max=0.181 + 0.2075 FR - 0.255 TEST	0.2294	0.1827
Palm	PΔT20 Max=–0.644 + 1.009 Gender	0.1741	0.1499
Back	EΔT Max=0.509 - 0.274 Sex + 0.1536 Length of service - 0.1982 Injury - 0.271 TEST	0.3929	0.3146
Palm	AvgPIT20=+ 1.607 Hand Dominant + 0.131 Injury - 1.647 TEMPERATURE - 0.0143 BMI + 0.124 TA+ 0.0375 RIT CARD + 0.0121 FRE RESP + 0.0017 No.*No. + 0.000039 No.*No.*No.*No.+ 0.961 TEST.	0.7112	0.5186
Back of hand	AvgDIT20=71.9 - 0.058 No. + 0.0978 AGE + 0.432 Sex - 0.00545 Seniority+ 1.676 Hand Dominant + 0.164 Injury - 1.390 TEMPERATURE - 0.0371 BMI + 0.234 TA+ 0.0375 RIT CARD + 0.0120 FRE RESP + 0.0016 No.*No. + 0.000016 No.*No.*No.*No.+ 0.835 TEST	0.6449	0.4081
Back	EIAvgI=43.3 + 0.275 No. - 0.0104 AGE + 0.999 Sex - 0.00790 Seniority+ 0.675 Hand Dominant + 0.613 Injury - 0.392 TEMPERATURE - 0.0815 BMI + 0.291 TA+ 0.0050 RIT CARD + 0.0147 FRE RESP - 0.01468 No.*No. + 0.000241 No.*No.*No.+ 0.279 TEST	0.655	0.4251

temperature differences were observed from the first shot at Time 5. The highest asymmetry was 5.6°C in healthy subjects at 5 min. His lesion and cyst formation were detected when the Tinel/Phalen test was performed. The subject was young, had worked in the company for five years, was right-handed, and presented with obesity. Regarding vital signs, only the heart rate was elevated.

In this study, 100% of the cases (12 out of 12 people) in which the operators' presented injuries were detected by IT with alarm (17% of the participants) or seriousness (83% of the participants) levels of attention. In comparison, Papež, Palfy [27] and Papež, Palfy [28] identified 72.2% of cases between patients with healthy hands and hands with CTS. On the other hand, based on the dorsal part of the hand and considering only severe and healthy cases, the effectiveness of IT diagnosis was raised to 80%.

Similarly, Palfy and Papez [29] obtained an effectiveness of approximately 80% through computer systems and intelligence using 44 thermograms of healthy and pathological hands to determine the effectiveness of IT as a method of diagnosing CTS.

Also Baic, Kucewicz [30, 31], determined the validity of IT for the diagnosis of CTS, reaching a success rate close to 80% in detecting healthy and pathological hands. Similarly, Tchou, Costich [32] obtained a similar result (effectiveness of approximately 80%) by registering 122 thermal images of healthy hands and hands with CTS.

Therefore, the effectiveness of infrared thermography in detecting hand pathologies has been demonstrated through the identification of thermal asymmetries, which are known indicators of disease [33]. In contrast to other studies that concluded that the dorsal region of the hand provides more effective results for the diagnosis of CTS than the palmar region [27–29, 32, 34], this investigation presented effective results in both regions.

Thirty-three percent of the participants presented significant asymmetries and 92% presented with minimal temperature increments. Asymmetries were present at each time point ($5'$, $10'$, $15'$, $20'$). Nine of the twelve participants were young. 58% of participants had injuries to their wrists. Fifty percent of the asymmetries were in the dorsal area of the hand. 92% of the study population were overweight or obese. Regarding vital signs, 75% had blood pressure outside the normal range, 50% had non-normal heart and respiratory rates, and 17% had a non-normal range.

Sex and respiratory rate factors showed a normal distribution. In contrast, the remaining study factors, age, seniority, dominant hand, injury, BMI, blood pressure, heart rate, and Tinel/Phalen test results, provided normal and non-normal data.

However, the parametric tests on the dorsum proved the influence of age on the maximum temperatures at times $10'$, $15'$, and $20'$. The dominant hand component was associated with the minimum temperatures at times $10'$ and $15'$ and with the maximum temperatures at times $15'$ and $20'$. The injury factor was related to the minimum temperature at time $15'$. Finally, BMI influenced the maximum temperature at time $10'$. Similarly, other studies have reported a relationship between CTS [35–41].

When analyzing the relationship between temperature differences and the study factors in the palmar region of the hand, significance was identified for age at times $10'$, $15'$, and $20'$ for the minimum, maximum, and average temperatures. Likewise, the dominant hand influenced the minimum, maximum, and average temperatures at times $15'$ and $20'$. For the Tinel and Phalen Tests, the association was in the average and maximum temperatures at $5'$ and $10'$, respectively. In addition, the respiratory frequency influences the maximum temperature at time $20'$.

Age and the Tinel/Phalen tests were influential factors in the back region and hand in the average and maximum temperatures. In our study, 69% of the participants were younger than 40, which contradicts the research results indicating that pathologies such as CTS increase with age [36, 37, 42]. In addition, several studies conclude that age is associated with the prevalence of CTS [35–37, 42].

For the dominant hand, Reinstein [43] indicated that this pathology occurs more frequently in the person's dominant hand since the most significant activity is exercised precisely in this hand, which is a significant factor that influences the development of CTS. In addition, Tang QY, Lai WH [44] found that patients with carpal tunnel surgery have a more rapid recovery in their non-dominant hand and suggested that this is because more significant activity is exerted in the dominant hand, which is a contributing factor in a slower rate of symptom resolution after surgery.

As for the analysis of variance, the significant factors in the palmar and dorsal regions of the hand were age, dominant hand, Tinel/Phalen tests, respiratory frequency, and sex, whereas age, BMI, and age were significant.

The most accurate regression models developed with the significant factors for each body region of interest were as follows: for the palmar area of the hand, a coefficient of determination of 0.7112 was reached, whereas for the dorsal region, a value of 0.6449 was reached. Finally, for the back, the coefficient of determination was 0.6550. These models were generated with average temperatures at time $20'$. The information provided by each equation is as follows.

Equation 1: The maximum temperature value on the back of the hand at 20 min of rest from work activity was obtained by considering the factors of age, dominant hand, heart rate, and Tinel/Phalen tests. A coefficient of determination of 0.5171 was obtained.

Equation 2: Maximum palm temperature value at 20 min of work break, with age, dominant hand, BMI, blood pressure, and Tnel/Phalen test. The coefficient of determination is 0.5607.

Equation 3: Maximum temperature value reached on the back considering age, injury, and BMI, with a determination coefficient of 0.4601.

Equation 4: Obtain the maximum temperature value at the back of the hand at 20 minutes rest, with the factors of respiratory frequency and Tinel/Phalen test. The coefficient of determination was 0.2294.

Equation 5: Equation for the palm of the hand to determine the maximum temperature reached at 20 min of rest, considering gender.

Equation 6: Maximum temperature reached on the back, with 20 min of rest. Factors considered: sex, seniority, injury, and Tinel/Phalen test. The coefficient of determination was 0.3929.

Equation 7: Average palm temperature after 20 min of rest. Factors such as dominant hand, injury, body mass index (BMI), blood pressure, heart rate, respiratory rate, and Tinel/Phalen test were considered. The model generated a determination coefficient of 0.7112.

Equation 8: Generate the average temperature on the back of the hand for 20 minutes of rest. It includes the following factors: age, sex, seniority, dominant hand, injury, BMI, blood pressure, heart rate, respiratory rate, and the Tinel/Phalen test. A coefficient of determination of 0.6449 was obtained.

Equation 9: Mean back temperature using age, sex, seniority, dominant hand, injury, BMI, blood pressure, heart rate, respiratory rate, and Tinel/Phalen test: coefficient of determination: 0.655.

According to Danko, Hudak [45], the optimal temperature value on the back of the hand is 30.3°C. The optimal temperature value on the palm is 35.2°C. Using the developed models to determine the highest temperature during a 20-minute break is possible, providing information to create active rest periods for workers. Using the developed models to determine the highest temperature during a 20-minute break is possible, providing information to create active rest periods for workers.

It is advisable to take short and frequent active breaks when work activities involve postural risks, repetitive movements, or great muscular effort, according to Mital et al. [46].

Castro et al. [47] found that taking active breaks increases work harmony, relaxation, and work performance and decreases stress and tension due to bad posture.

In turn, the research carried out by Gómez [48] achieved an accuracy of 83.91% and a kappa index of 63.14% in their statistical model for the prediction of MSD-related discomfort in hands/wrists, and considered six factors: postural overload, repetition of movements, gender, MSD-related medical history, frequency of housework, and job rotation. In another study, multiple regression models were developed to predict the combined frequency and severity of MSD pain, achieving an R-squared of 32.9%, [49]. In addition, Sasikumar and Binoosh [50] employed several machine learning algorithms in their model to predict MSDs among IT professionals, considering postural, physiological, and work-related factors, with an accuracy of 81.25%.

5. Conclusions and limitations

Ergonomic evaluations have proven that operators present a high risk owing to the repetitive movements and postures they adopt in their work performance. This shows that companies need to take action to solve and prevent occupational diseases.

Likewise, this study demonstrated IR's effectiveness in detecting suspicious CTS or tendinitis lesions through thermal asymmetries in the dorsal and palmar areas of the hand, which allows timely follow-up for workers' health care.

When statistically analyzing the data, significant differences were found between the study factors and hand temperature recovery times. Age, dominant hand, respiratory rate and BMI were identified as significant factors in the development of the regression models, whose coefficients of determination ranged from 0.17 to 0.71 (Table 9). Through these models, it was possible to determine the average and maximum temperatures reached on the back and palm according to the factors involved in each equation. This information will guide top management in planning active break programs during the workday that contribute to the well-being of the worker and fulfillment of the company's objectives. Therefore, it is essential to consider such factors in the healthcare of the operators.

However, the sample size in this study was small. However, this research is being expanded to other industries to increase the sample size and thus, generalize the conclusions.

This section is part of an extensive study to create a universal predictive model for various industries based on their respective operations. Although work-related factors greatly influence injuries, external factors such as worker health, lifestyle, and other activities can also contribute significantly to injuries.

Through the study of temperature behavior, it is possible to support companies in implementing active breaks during the workday and evaluate their benefits to workers' health and the company by measuring performance through production and quality aspects.

Institutional review board statement

The study was conducted in accordance with the guidelines of the Declaration of Helsinki and approved by the faculty postgraduate department according to the NOM-035-STPS-2018 Standard.

Informed consent statement

Informed consent was obtained from all the subjects involved in the study.

Data availability statement

The participants (s) provided written informed consent for publication of this paper.

Acknowledgments

The authors appreciate the postdoctoral stay granted to Melissa Cazares from the "POSTDOCTORAL STAYS IN MEXICO MODALITIES 1 AND 2", supported by CONAHCYT (Consejo Nacional de Humanidades, Ciencias y Tecnologías).

Conflicts of interest

The authors declare no conflicts of interest.

Funding

The research leading to these results has received funding from the PROJECT titled "DEVELOPMENT AND TESTING OF MODELS FOR PREDICTION OF WORK-RELATED MUSCULOSKELETAL DISORDERS (MSD) IN THE UPPER EXTREMITIES USING INFRARED THERMOGRAPHY under the Grant agreement number I1200/224/2021. This work was supported by CONAHCYT (Consejo Nacional de Humanidades, Ciencias y Tecnologías)"

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