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Development of Prolonged Standing Strain Index to Quantify Risk Levels of Standing Jobs

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Many occupations in industry such as metal stamping workers, electronics parts assembly operators, automotive industry welders, and lathe operators require working in a standing posture for a long time. Prolonged standing can contribute to discomfort and muscle fatigue particularly in the back and legs. This study developed the prolonged standing strain index (PSSI) to quantify the risk levels caused by standing jobs, and proposed recommendations to minimize the risk levels. Risk factors associated with standing jobs, such as working posture, muscles activity, standing duration, holding time, whole-body vibration, and indoor air quality, were the basis for developing the PSSI. All risk factors were assigned multipliers, and the PSSI was the product of those multipliers. Recommendations for improvement are based on the PSSI; however, extensive studies are required to validate their effectiveness.

prolonged standing strain index (PSSI)   standing jobs   muscle fatigue
comfort   control measures

1. INTRODUCTION

Almost all industrial jobs require a standing posture, especially when workers handle heavy equipment and products, reach for materials and goods, and push and pull excessive loads. These jobs are nearly impossible to do in a sitting posture. Tomei, Baccolo, Tomao, et al. pointed out that workers are exposed to prolonged standing if they spend over 50% of the total working hours during a full work shift in a standing posture [1]. Standing for a prolonged period has been recognized as a vital contributor to a decrease in performance in industry. It causes occupational injuries, decreased productivity, increased medical costs, and demoralization of workers.

Prolonged standing at workstations can cause muscle fatigue and mental stress. Furthermore, an insufficient rest period during the standing time coupled with improper footwear can lead to discomfort and fatigue in the lower extremities, causing occupational injuries in the long term. When workers work in a prolonged standing posture, static contraction occurs particularly in

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their back and legs, resulting in impaired functioning of calf muscles [2]. Prolonged standing transfers the weight of upper body parts to lower parts and results in lower back pain. Eighty-three percent of industrial workers in the USA experience foot or lower leg pain and discomfort associated with prolonged standing [3]. Reduced blood circulation in the lower legs and localized muscle fatigue are hypothetical reasons for increased discomfort and whole-body fatigue associated with prolonged standing [4]. Reduced blood circulation also results in blood pooling, manifested as foot and lower leg swelling [3]. Prolonged standing is a risk factor for preterm birth and spontaneous abortion among working pregnant women [5, 6]. Pregnant women who stand for over 8 h in a working day are liable to spontaneous abortion (preceded by a previous history of spontaneous abortion) [5].

Besides, employers risk losing the revenue expected from their employees' productivity, and incur the cost of workers' compensation and health treatment [3]. For example, pain in the lower back related to prolonged standing can affect workers' ability to bend or twist their body during their work. This may affect their productivity. In addition, workers who suffer from occupational injuries must be referred to physicians for treatment, which involves consultancy and medication costs.

This paper was prepared to develop the prolonged standing strain index (PSSI) to quantify risks standing jobs pose and to propose recommendations to minimize the risk of muscle fatigue and occupational injuries in industrial workplaces.

2. DEVELOPING PSSI—SCIENTIFIC BASES

The first stage of developing the PSSI consisted in identifying the risk factors that contributed significantly to discomfort, fatigue, and injuries related to prolonged standing. That is why, to begin with, we gathered information from literature, direct surveys in enterprises, interviews with management and production workers, guidelines, and experts. We reviewed magazines, journals, guidelines, and online databases. The review helped in defining methods and tools for assessing risk, and in obtaining alternative solutions that minimize the health risk prolonged standing poses.

Several workstations in three metal stamping companies were surveyed to identify risk factors associated with prolonged standing. The workers' postures, movements, and job cycles were recorded with a camcorder.

We used the prolonged standing questionnaire [7] during the interviews with management staff and production workers to obtain information on the discomfort and injuries workers experienced due to standing jobs, their history of pain and treatment, and suggestions on ways to improve workstations that require standing. The benefit of interview sessions is information not available from publications or indirect surveys.

The Department of Safety and Health of Malaysia (DOSH) and the International Organization for Standardization provide information on prolonged standing in the workplace. These institutions published a code of practice for indoor air quality (IAQ) [8], and guidelines on standing at work [9] and on comfort levels dependent on whole-body vibration (WBV) [10]. We referred to these documents to establish the PSSI.

As a significant input to the development of the PSSI, we obtained opinions and advice from ergonomics practitioners, medical doctors, physiotherapists, safety and health engineers, and academics, in formal and informal discussions during several seminars and conferences on ergonomics, safety, and health. The confirmation of risk factors that contribute significantly to discomfort and fatigue associated with prolonged standing was an outcome of this effort. We thus identified six risk factors in the human–machine–environment system which significantly contribute to discomfort and muscle fatigue associated with jobs that require prolonged standing:

- human: working posture (WP), muscle activity (MA), standing duration (SD), and holding time (HT);
- machine: WBV; and
- environment: IAQ.

2.1. WP

Awkward WP is recognized as a risk factor for discomfort, reduced efficiency, and occupational injuries [11, 12]. An awkward posture means various parts of the body are bent, extended, or flexed rather than in a straight or neutral position. This condition can lead to discomfort and fatigue in the lower back. Table 1 classifies the risk levels of WP, according to the rapid entire body assessment (REBA) score [13]. The lowest score in the REBA indicates the safest posture for the worker, whereas the highest score represents the most unsafe posture. An analysis of WP is useful in classifying a posture as either safe or unsafe. Action levels result from a WP analysis; they define the musculoskeletal load associated with a worker's posture. Action level 0 indicates that the current posture is good and this condition has to be maintained. Action level 1 means the current posture is of low risk, yet further action may be required. Action level 2 classifies the current posture as a medium risk for the health; hence, further action is necessary. Action level 3 means the current posture involves a high risk and further action is necessary soon. Action level 4 means that the current posture involves a very high risk; therefore, further action is required immediately.

TABLE 1. Classification of Posture Risk Levels [13]

Rating Criterion	REBA Score	Posture Risk
Very safe	1	action level 0 (negligible)
Safe	2–3	action level 1 (low)
Slightly unsafe	4–7	action level 2 (medium)
Unsafe	8–10	action level 3 (high)
Very unsafe	11–15	action level 4 (very high)

Notes. REBA—rapid entire body assessment.

2.2. MA

An analysis of MA is useful in determining muscle fatigue workers experience during their work. It considers the level, frequency, and duration of effort regarding the neck, shoulders, back, arms and elbows, wrists, hands and fingers, legs and knees, ankles, and feet and toes. The rationale behind including an analysis of MA in the PSSI is that continuous standing can lead to muscle fatigue. When workers experience slight fatigue while working, their muscles are at a low risk for muscle fatigue [14]. In contrast, they are at a very high risk for muscle fatigue if they are extremely strained (Table 2). Rodgers provides details on criteria of fatigue [14].

TABLE 2. Rating Criteria for Muscle Fatigue and Fatigue Risk Levels [14]

Rating Criterion	Fatigue Risk Level
Slight fatigue	low
Moderate fatigue	moderate
Fatigue	high
Extreme fatigue	very high

2.3. SD

SD can also determine workers' level of discomfort. Prolonged standing can lead to discomfort and pain in numerous body parts, especially legs, knees, and the lower back. When a job involves continuous standing, the muscles in the lower extremities and the back muscles are under constant stress. Due to the combination of body mass, workload, and duration of standing, the muscles are continuously under stress. As a short-term effect, the muscles can become fatigued. The PSSI was based on Meijsen and Knibbe's guidelines for standing in the workplace [15] (Table 3).

TABLE 3. Risk Levels With Respect to Standing Duration [15]

Rating Criterion	Risk Level	Description
Safe	low	≤1 h of continuous standing, and ≤4 h total
Slightly unsafe	moderate	>1 h of continuous standing, or >4 h total
Unsafe	high	>1 h of continuous standing, and >4 h total

2.4. HT

An analysis of HT is useful in identifying a recommended maximum holding time (MHT) for workers holding goods. The analysis considers shoulder height (SH) and arm reach (AR) with respect to workers' feet. A posture is considered comfortable if workers adopt a moderate working height (50, 75, 100, or 125% of SH) and a small working envelope (25 or 50% of AR); then the recommended MHT can be over 10 min. A posture is moderately comfortable if an object is held at a moderate working height (50, 75, 100, or 125% of SH) and a large envelope (75 or 100% of AR); then the recommended MHT is 5–10 min. Postures are uncomfortable if the working height is too low or too high, i.e., 25 or 150% of SH, respectively, and the envelope is 25, 50, or 100% of AR. Under these conditions the recommended MHT is under 5 min [17].

Working conditions which require holding loads in a static standing posture for several hours may result in discomfort. Examples of industrial tasks that involve long standing include welding plates with a shielded metal arc machine, assembling vehicle tires in the overhead posture, and holding a jig or clamp to drill holes with a drill machine. No movement during these tasks imposes very high static loads on the body and impedes the blood flow, thus resulting in rapid fatigue and slower recovery of tissues.

2.5. WBV

WBV is a risk factor for discomfort and occupational injuries. When a worker stands close to a vibrating machine, the machine transmits its vibration to the worker's legs via its frame and base. Excessive exposure to WBV can result in localized fatigue and pain in the lower back, neck, shoulders, and knees [16]. Limiting workers' exposure to WBV minimizes the risk of injury. According to Standard No. ISO 2631-1:1997, vibration should not exceed the weighted acceleration $a_{\text{we}} = 0.8$ m/s^2 (root-mean-square) for long-term exposure and daily exposure of 8 h. Table 4 summarizes the comfort levels related to the exposure to WBV [10].

TABLE 4. Comfort Criteria Corresponding to Acceleration of Vibration [10]

Rating Criteria	Acceleration (m/s^2)
Comfort	<0.32
Slight discomfort	0.32–0.63
Moderate discomfort	0.50–1.00
Discomfort	0.80–1.60
Considerable discomfort	1.25–2.50

2.6. IAQ

A safe workstation is one with good IAQ. Poor IAQ in the working environment can cause a variety of short- and long-term occupational health problems [9]. IAQ does not directly contribute to discomfort or fatigue at work; however, poor IAQ leads to severe health problems such as the sick-building syndrome, respiratory problems, bronchitis, and eye irritation. Moreover, poor IAQ brings about reduced productivity of the enterprise, increased absenteeism, and a loss of working time. Details of indoor air contaminants and maximum limits can be found in DOSH [9]. An analysis of IAQ is useful in determining the maximum limit of IAQ contaminants to ensure the workplace is safe. Indoor air is considered safe when the levels of air contaminants do not exceed the maximum limits.

2.7. Development of the PSSI

An analysis of each risk factor (WP, MA, SD, HT, WBV, and IAQ) produces a rating to reflect the effects of that risk factor on workers' comfort, fatigue, and safety. The ratings have numerical values of 1–5. WP and WBV have the maximum rating of 5, while the maximum rating for MA is 4, for SD and HT maximum ratings are 3, and for IAQ the maximum rating is 2. The lowest rating stands for comfort and safety, whereas the highest rating reflects hazardous conditions. Each rating is assigned a multiplier. The PSSI was developed on the basis of multiplicative interactions among the risk factors that corresponded to the six multipliers. It can be described with a linear relationship (Equation 1):

$$\text{PSSI} = \text{WP} \times \text{MA} \times \text{SD} \times \text{HT} \times \text{WBV} \times \text{IAQ}, \quad (1)$$

where PSSI—prolonged standing strain index, WP—working posture, MA—muscle activity, SD—standing duration, HT—holding time, WBV—whole-body vibration, and IAQ—indoor air quality.

Table 5 shows the rating criteria and multipliers representing the risk levels for each risk factor.

TABLE 5. Rating Criteria for Each Risk Factor

	Risk Factor (Multiplier)					
Rating	**WP**	**MA**	**SD**	**HT**	**WBV**	**IAQ**
1	very safe (1)	slight fatigue (1)	safe (1)	comfort (1)	comfort (1)	safe(1)
2	safe (2)	moderate fatigue (3)	slightly unsafe (3)	moderate discomfort (3)	slight discomfort (3)	unsafe (244)
3	slightly unsafe (3)	fatigue (244)	unsafe (244)	considerable discomfort (244)	moderate discomfort (3)	
4	unsafe (244)	extreme fatigue (244)			discomfort (244)	
5	very unsafe (244)					

Notes. WP—working posture, MA—muscle activity, SD—standing duration, HT—holding time, WBV—whole-body vibration, IAQ—indoor air quality.

TABLE 6. Risk Levels of Standing Jobs

	Multiplier						
Risk of Standing	**WP**	**MA**	**HT**	**SD**	**WBV**	**IAQ**	**PSSI**
Safe	1	1	1	1	1	1	1
	2	1	1	1	1	1	2
Slightly unsafe						1	3[a]
	3	3	3	3	3	1	243
Unsafe						1	244[b]
	244	244			244	244	>244

Notes. WP—working posture, MA—muscle activity, SD—standing duration, HT—holding time, WBV—whole-body vibration, IAQ—indoor air quality; a—if any factor is 3, b—if any factor is 244.

2.8. Definition of the PSSI and Recommendations

The risk of standing was divided into three categories, related to the effects of prolonged standing at the workstation, safe, slightly unsafe, and unsafe, which were derived from the values of the PSSI.

Workers are considered safe during standing work when they obtain a multiplier of 1 for each factor or a multiplier of 2 for WP. Generally, to obtain a safe level the PSSI should be 1–2. These conditions are the best and need to be maintained to ensure a worker is comfortable and safe.

The level is slightly unsafe if the PSSI is 3–243. The risk factors associated with prolonged standing indicate that the condition can harm the worker. Slightly unsafe can result from a slightly unsafe WP (multiplier of 3), moderate fatigue in muscles (MA—multiplier of 2), moderate discomfort due to HT (multiplier of 2), slightly unsafe SD (multiplier of 2), some discomfort due to machine vibration (WBV—multiplier of 2), while IAQ is still good (multiplier of 1). These conditions require further investigation and improvement because the existing workstation design and work practices can lead to health problems in the long term.

Standing jobs are considered unsafe if the PSSI equals or exceeds 244. The multipliers of WP are 4–5, the multipliers of MA are 3–4, HT causes substantial discomfort (multiplier of 3), SD is unsafe (multiplier of 3), WBV has a multiplier of 4–5, and either IAQ is safe (multiplier of 1) or unsafe (multiplier of 244). In these conditions the workstation design, the working environment, and the work practices are likely to cause health problems. Therefore, immediate investigation and improvement are required. Table 6 presents all levels of the risk of standing (safe, slightly unsafe, and unsafe) corresponding to the multipliers of each risk factor and the PSSI.

On the basis of the value of the PSSI, we proposed several recommendations to improve workers' comfort and occupational health. When the risk of standing generating the PSSI obtains the safe level, the workstation design and the work practices should be maintained. However, when it reaches the slightly unsafe or unsafe level, the proposed recommendations should be considered, based on the individual risk factor. In other words, WP, MA, SD, HT, WBV, and IAQ have their individual recommendations for reducing or eliminating the risk of discomfort and occupational injuries.

2.8.1. Recommendations for WP

The following recommendations apply to WP [13]:

- keep the trunk upright, at 0–20° flexion or 0–20° extension; avoid twisting or side-flexing;
- keep the neck flexed by 0–20°, without twisting or side flexing;
- keep the legs equally weight bearing; avoid flexion over 60°;
- keep the upper arms at 20° extension or 20° flexion; avoid raising the shoulders;
- maintain the lower arms at 60–100° flexion;
- maintain 0–15° flexion or extension of the wrists; avoid bending or twisting the wrists;
- ensure an appropriate table height;
- place the workpiece, materials, and tools within easy reach;
- reduce the workload to be handled, and avoid shocks or rapid forces during the handling; and
- use a well-designed handle to lift loads.

If it is not possible to follow those recommendations, administrative controls such as job rotation should be considered.

2.8.2. Recommendations for MA

To improve MA, the following recommendations can help [14]:

- put less effort into the movements of the main body parts;
- limit continuous MA to under 6 s; and
- limit the frequency of effort to one effort per minute.

2.8.3. Recommendations for SD

The following control measures can reduce discomfort related to continuous standing:

- interrupt continuous standing with a few microbreaks;
- install antifatigue mats on the floor;
- use soft shoe insoles;
- alternate standing–sitting posture; and
- rotate jobs.

2.8.4. Recommendations for HT

If workers experience moderate comfort due to their SH and AR when handling loads, the posture should be maintained for 1–2 min. If SH and AR cause discomfort, the posture should be maintained for under 1 min [17].

2.8.5. Recommendations for WBV

The following control measures can be useful in reducing the level of risk associated with exposure to WBV [18]:

- limit exposure to WBV by providing microbreaks;
- install dampers or vibration isolators to the machine;
- provide antivibration standing platforms;
- provide workers with thicker shoe insoles; and
- rotate jobs.

2.8.6. Recommendations for IAQ

The following control measures reduce the level of risk related to poor IAQ [8]:

- eliminate hazardous chemicals from the workplace;
- substitute a hazardous chemical with a less hazardous one;
- enclose the processing and handling of hazardous chemicals;
- isolate hazardous chemicals to control emission;
- modify the parameters of the process; and
- provide workers with personal protective equipment.

3. THE USE OF THE PSSI—AN EXAMPLE

To demonstrate the use of the PSSI, we did a case study in a metal stamping company situated in Shah Alam, Malaysia. Metal stamping and producing metal stamped parts for passenger vehicles was its main activity.

At the end of a metal stamping process line, a worker collected the stamped parts from an incoming conveyor and arranged them in a cage. The worker worked a 12-h shift. He had to stand throughout the working hours and do the following movements:

- 10–20º torso flexion while reaching for the products from the incoming conveyor;
- ~180º body rotation while transferring the products to a cage;
- 30–40º torso flexion while loading the products into the cage; and
- 45–90º torso flexion while arranging the products in the cage.

The worker did the job manually with the work cycle of over four times per minute. Furthermore, he was exposed to WBV due to a high cyclic impact between the plunger of the stamping machine and its die.

In these circumstances, the worker was exposed to prolonged standing because he had to stand continuously to do the job. So, the worker was identified as exposed to several risk factors leading to discomfort and muscle fatigue. All risk factors had to be analysed to determine the risk level. The following sections present the risk factors and their analysis.

3.1. WP

As described before, the worker did the job in extreme postures because he had to bend his trunk while arranging the products. The load was under 5 kg, and the handle was in a good condition. The worker's posture can be summarized as follows:

- trunk: over 20º extension and twisted;
- neck: over 20º flexion;
- upper arms: 45–90º flexion;
- lower arms: 60–100º flexion;
- wrists: 0–15º flexion; and
- posture changes: to carry products from the conveyor to the cage, the worker needs to change his posture significantly.

According to the REBA, the score for this posture was 6, so it was slightly unsafe [13]. The multiplier for WP was 3 (Table 5).

3.2. MA

In terms of MA, the level, duration, and frequency of the worker's muscle effort can be summarized as follows:

- level of neck effort: light—head turned partly to the side;
- duration of neck effort: under 6 s;
- frequency of neck effort: less than once per minute;
- level of shoulder effort: light—arms slightly away from the sides;
- duration of shoulder effort: under 6 s;
- frequency of shoulder effort: less than once per minute;
- level of back effort: light—leaning to the side;
- duration of back effort: under 6 s;
- frequency of back effort: less than once per minute;
- level of arm/elbow effort: light—arms away from body and light;
- duration of arm/elbow effort: under 6 s;
- frequency of arm/elbow effort: less than once per minute;
- level of wrist/hand/finger effort: light;
- duration of wrist/hand/finger effort: under 6 s;
- frequency of wrist/hand/finger effort: less than once per minute;
- level of leg/knee effort: effortless standing;
- duration of leg/knee effort: under 6 s;
- frequency of leg/knee effort: less than once per minute;
- level of ankle/foot/toe effort: standing with little force on both feet;
- duration of ankle/foot/toe effort: under 6 s; and
- frequency of ankle/foot/toe effort: less than once per minute.

According to Rodgers, those kinds of effort caused low risk for muscle fatigue [14], hence, the multiplier for MA was 1 (Table 5).

3.3. SD

The job processes required the worker to stand for over 1 h continuously, and over 4 h out of total working hours. This duration caused considerable discomfort to the worker [15]. The multiplier for SD was 244 (Table 5).

3.4. HT

On average, the worker's SH and AR while holding the products were SH—50% with respect to feet and AR—100% with respect to feet. Under these conditions, the worker was exposed to moderate discomfort [17]. Hence, HT obtained the multiplier of 3 (Table 5).

3.5. WBV

The worker worked near press machines that produced mechanical vibration. The machines transmitted vibration to the worker through the floor, causing exposure to WBV. A WBV measurement system (QUEST from Quest Technologies, USA) was used to measure the acceleration of vibration (in meters per square second) experienced by the worker while doing the task in standing posture. The acceleration of vibration measured in the foot–head direction (orthogonal axis in the vertical direction of a standing person) was 0.315–0.630 m/s^2. According to Standard No. ISO 2631-1:1997, the acceleration magnitude caused the worker some discomfort [10]. The multiplier for WBV was 3 (Table 5).

3.6. IAQ

The quantities of CO_2 and CO surrounding the workstation were measured to determine the level of contamination. Both quantities were measured with a Gray Wolf (USA) IAQ probe (IQ-410). The average quantities of CO_2 and CO were 7838 and 2.06 mg/m^3, respectively [19]. According to DOSH, the quantities of the contaminants were safe [8]. Table 5 indicates that the level of IAQ had the multiplier of 1.

3.7. PSSI and Recommendations

All obtained multipliers were supplied to Equation 1.

$$\begin{aligned} \text{PSSI} &= \text{WP} \times \text{MA} \times \text{SD} \times \text{HT} \times \text{WBV} \times \text{IAQ}, \\ \text{PSSI} &= 3 \times 1 \times 244 \times 3 \times 3 \times 1, \\ \text{PSSI} &= 6588. \end{aligned} \tag{2}$$

Table 7 summarizes the results of the analysis of risk factors, the value of the PSSI, and the risk of standing.

Based on the results, MA and IAQ should be maintained as they contribute to a low value of the PSSI. On the other hand, SD, WP, HT, and WBV contributed significantly to a high value of the PSSI. This indicates that improvements are necessary to reduce or eliminate discomfort and potential occupational injuries.

For the significant risk factors, the following recommendations should be considered:

- SD—provide the worker with a few microbreaks, install antifatigue mats on the floor, use soft shoe insoles, and rotate the job among workers with the same level of skills;
- WP—ensure the trunk is upright, up to 20º flexion, the neck should remain at 0–20º flexion; ensure appropriate working height,

TABLE 7. Summary of Risk Factors Analysis

Risk Factor	WP	MA	SD	HT	WBV	IAQ
Rating	slightly unsafe	slight fatigue	unsafe	moderate discomfort	slight discomfort	safe
Multiplier	3	1	244	3	3	1
PSSI				6588		
Risk of standing				unsafe		

Notes. WP—working posture, MA—muscle activity, SD—standing duration, HT—holding time, WBV—whole-body vibration, IAQ—indoor air quality.

make sure the products are within easy reach, and rotate jobs to avoid continuous exposure;
- HT—have the worker maintain his body posture for under 1 min while picking up the products from the conveyor; and
- WBV—limit continuous exposure of WBV by providing microbreaks, install dampers or vibration isolators in the press machine, and provide antivibration standing platforms and thicker shoe insoles.

4. DISCUSSION

Most industrial jobs have to be done in a standing posture. Standing has been associated with versatility because of the mobility of the posture and the degree of freedom. For example, the standing posture is common in manufacturing work such as metal stamping. It is preferred because the press machine does not allow workers to comfortably adjust their legs under the die platform. In addition, the design of the press machine does not provide adequate space for workers to sit.

Standing is considered versatile; however, this posture can lead to discomfort if it is maintained for a long time. A number of surveys found a significant association between continuous standing during working hours and pain in the back and legs [20, 21, 22]. Fatigue in the gastrocnemius muscles (back side of the legs) can be linked to working in prolonged standing [23, 24]. The latest literature identified work-related musculoskeletal disorders, chronic venous insufficiency, preterm birth and spontaneous abortion, and carotid atherosclerosis as prevalent health problems caused by prolonged standing [25]. In addition, observational and biomechanical studies found that prolonged standing is a potential contributor to disc degeneration as a result of intervertebral and vertebral endplate compression, and increased intradiscal pressure [26, 27].

Various control measures have been proposed to reduce discomfort associated with prolonged standing in the workplace. According to King [28] and Kim, Stuart-Buttle, and Marras [29], floor mats and shoe insoles are effective ways to improve body comfort during prolonged standing tasks. Floor mats, shoe insoles, or both, are more comfortable than standing on hard floor [28], and beneficial to the back [29]. Van Dieën and Oude Vrielink proposed a work–rest schedule to minimize the discomfort associated with prolonged standing. In addition, longer breaks would more effectively minimize the risk of leg swelling due to prolonged standing [30]. Alternating standing and sitting working postures during the working hours is also a possible solution to provide comfort in the lower extremities [24, 31].

Ergonomists, occupational safety and health officers, and management need methods of assessing the risk factors associated with prolonged standing to improve occupational health. During ergonomics studies, an observation method with video recording can be used [32]. Furthermore, the direct technical measurement method with surface electromyography is recognized as reliable for measuring muscle fatigue caused by prolonged standing [33, 34].

To date, measuring discomfort associated with prolonged standing jobs has relied on qualitative assessment such as questionnaire surveys. As an alternative, this study developed the PSSI to provide a semiquantitative analysis of prolonged standing jobs in industry. The PSSI represents the risk levels of standing with respect to physiological, psychophysical, machine, and environmental factors at industrial workstations.

According to literature, direct workplace surveys, interviews with industrial workers, expert opinions, and established guidelines, six risk factors can contribute significantly to discomfort associated with standing jobs. We used those risk factors, derived from the human–machine–environment system, as a foundation to develop the PSSI. WP, MA, SD, and HT belong to the human sphere, while WBV and IAQ belong to machine and environment spheres, respectively. All risk factors were analysed individually to measure their levels. Then, the levels for each risk factor were assigned multipliers representing their weight for discomfort and fatigue. The PSSI is their product. We recommended potential solutions to minimize the risk levels corresponding to the PSSI values.

The PSSI was validated through a real case study in a manufacturing company, during a metal stamping process. The working conditions in that case study caused discomfort to the worker because

- the job had to be done in a prolonged standing posture (12 h);
- the workstation design and the processes demanded awkward working postures;
- the process cycle frequency was high, thus limiting recovery time;
- the job required repetitive movements and the working space was restricted, leading to standing in one area (static standing) for a long time—impaired mobility;
- the stamping machines generated strong mechanical vibrations due to high and repetitive impact between the plunger and die of the machine. Due to cyclic loading the machine transferred vibrations to the workers' body through the machine foundation, causing exposure to WBV, and in consequence—muscle fatigue and increased risk of lower back pain [35, 36, 37, 38]; and
- the stamping and grinding processes produced small metal particles thus potentially impairing IAQ at the workstation.

Under these conditions, the PSSI was 6588. This value indicated that the worker was exposed to unsafe conditions due to a prolonged standing job. According to the value of the PSSI, we proposed a number of recommendations to minimize discomfort.

5. CONCLUSION

This study developed a new method, called the PSSI, to quantify the risk levels associated with standing jobs. The PSSI is based on the elements of the workplace; human (WP, MA, SD, and HT), machine (WBV), and environment (IAQ). All factors were critically analysed with the established ergonomics assessment techniques to determine their risk levels. The risk levels were assigned multipliers based on their importance for discomfort and fatigue, and the PSSI was calculated by multiplying the multipliers. To minimize the risk levels associated with standing jobs, alternative solutions were recommended depending on the value of the PSSI.

The PSSI is at an early stage of development; therefore, it requires improvement. For example, there are no empirical studies to verify the exact relationships between the risk factors and the corresponding multipliers. Furthermore, the proposed recommendations should be validated to determine their effectiveness.

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