Title: An observational method for Postural Ergonomic Risk Assessment (PERA)

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Highlights:

1. PERA is suitable for assessing postural risk factors in cyclic work.
2. PERA is based on the ISO 11226 and the EN 1005-4.
3. The method was tested on 9 work cycles, comprising 88 work tasks.
4. The results were verified by comparison of evaluations by EAWS.

Abstract:

Production lines are characterized by monotonous, repetitive work. Repetitive movements and awkward postures are the most prominent physical risk factors in the workplace. To ensure the safety of the operators, various legislations have been enacted along with technical standards for ergonomic risk evaluation.

There are numerous methods to assess the ergonomic risk at work. However, most methods are not meant to be used for assessing cyclic work. This paper proposes a method, PERA (Postural Ergonomic Risk Assessment), which is suitable to assess the postural ergonomic risk of short cyclic assembly work. Its key features are simplicity and compliance with standards. The added value of the method is that it provides an analysis of every work task in the work cycle, which facilitates in identification of sources of high risk to the operator.

The method has been verified on 9 work cycles, constituted by 88 work tasks, and it demonstrates accordance with the EAWS, which has been developed to comply with the relevant standards, and is one of the most comprehensive tool for ergonomic risk assessment.

Industrial relevance: The simplicity and the compliance with standards of the proposed method would allow for a quick check of every work task of the work cycle and identification of problem areas. With further work, it would be possible to integrate the method along with work design tools used in the industry.

Key words: Work related musculoskeletal disorders (WMSDs), posture, ergonomic risk assessment, observational method, assembly line, work cycle

1.0 Introduction:

The World Health Organization (Luttmann et al., 2003) defines musculoskeletal disorders (MSDs) as "health problems of the locomotor apparatus, that is, of muscles, tendons, skeleton, cartilage, ligaments and nerves. MSDs include all forms of ill-health ranging from light, transitory disorders to irreversible, disabling injuries. MSDs are considered work related when the musculoskeletal disorders are induced or aggravated by work and the circumstances of its performance. Such work related musculoskeletal disorders (WMSDs) are supposed to be caused or intensified by work, though often activities such as housework or sports may also be involved."

The impact of WMSDs on the health of the working population is quite significant. According to a report published by the European Agency for Safety and Health at Work (EASHW) in 2010, MSDs are the most common occupational disease among the recognised occupational diseases, accounting for 59% of the total (Schneider et al., 2010). The 5th European Working Conditions Survey (EWCS), 2012, reported that more than 40% of the workers suffered from backache and/or muscular pains. Repetitive hand or arm movements and tiring or painful positions (awkward postures) are the most common physical risks in the workplace, with about 63% and 46% of the workers being exposed to these risks, respectively, for at least a quarter of the time (Parent-Thirion et al., 2012). This data corresponds with the high incidence of backache and muscular pain and motivates the indications provided by the Machinery Directive 2006/42/EC (The European Parliament and the Council of the European Union, 2006), with reference to ISO 11226 and EN 1005-4, as well as the significant literature that is available on the assessment of postural ergonomic problems at the workplace.

Li and Buckle (1999), David (2005) and Takala et al. (2010) exhaustively reviewed literature methods for ergonomic risk assessment and, also, discussed the requirements of practitioners from these methods. Among occupational safety and health practitioners, observational techniques, either through pro forma sheets or computer software programmes, are still considered the most suitable methods (David, 2005).

OWAS (Karhu et al., 1977) describes the whole body posture using a 4 digit code, indicating the position of the back (4 options), arms (3 options), legs (7 options) and the load to be handled (3 options). The method provides a look up table to translate the 4 digit code into 4 action categories. OWAS is generally used to instantly analyse single snapshots of postures. A possible weakness is that the posture categories of OWAS could be quite broad to provide an accurate description of posture (Keyserling, 1986).

PLIBEL (Kemmlert, 1995) uses a checklist to rapidly identify ergonomic hazards in the workplace. The list of items consists of questions concerning awkward postures (including neck/shoulders, back, arms, hips and legs), tiring movements, poor design of tools or workplace, and stressful environmental or organizational conditions. The author of the tool advised against a quantitative measure after the completion of the checklist and recommended to conclude the assessment by short verbal description. Although, the method is general and simple to use, most of the questions in the checklist are subjective, requiring strong ergonomics knowledge from the user to assess the ergonomic conditions, especially in the presence of multiple hazards (Li and Buckle, 1999).

REBA (Hignett and McAtamney, 2000) is able to assess a variety of postures. The method allows to score 144 possible combinations of posture (including trunk, neck, legs, upper arms, lower arms and wrists). The additional factors considered are load, coupling and frequency. After the analysis, the method provides an overall score, which could be classified into one of the 5 action levels of ergonomic intervention. However, the user must identify the critical work activity to assess, which could be difficult, depending upon the body part and the risk being assessed (Takala et al., 2010).

The three methods, OWAS, PLIBEL and REBA lack indications for combining risks from multiple sources. Moreover, they do not take duration into account in their analyses. This makes their use for assessing cyclic work difficult.

EAWS (Schaub et al., 2013) is an ergonomic risk assessment method to holistically assess cyclic work. The method was developed based on the following 4 criteria:

- Physiological and biomechanical criteria
- Medical/epidemiological data
- Psychophysical factors
- Compliance with other internationally accepted methods and standards

The method assesses work cycles under 5 sections. 4 of these (general, postures, action forces and manual material handling) are combined to produce a whole body score. While, the fifth section (repetitive load of the upper limbs) is scored separately. Thus, the method allows for a holistic evaluation of the work cycle considering the combination of risks from different sections, along with their durations in a work cycle. The final score of the EAWS (higher of the whole body and upper limbs) can be classified into the 'traffic light' scheme of 3 levels (green, yellow and red), which is supplemented with recommendations for ergonomic intervention. Although, the authors of the method note that the application of EAWS is complex and requires intensive training, the EAWS is disseminated in several companies in Europe (Schaub et al., 2013).

The purpose of this work is to propose a simple method for Postural Ergonomic Risk Assessment (so called as PERA) of cyclic work. Apart from the EAWS, literature review revealed a gap in the existing methods for the ergonomic risk assessment of cyclic work. The EAWS has many strengths and was considered a benchmark tool for this work due to its widespread use in the industry (Schaub et al., 2013). The key target for the proposed method was usefulness for the industries. This was to be achieved by developing a simple method, which takes into account the relevant standards (ISO 11226 and EN 1005-4), and considers, simultaneously, the impact of posture, force applied by the operator and the duration of the tasks on the ergonomic risk to the operator. The method analyses every work task of the work cycle, which helps in the quick identification of high risk work tasks, along with providing an overall averaged score and corresponding recommendations for ergonomic intervention.

This paper describes the method and its development and validation, followed by discussion and conclusion.

2.0 Development of the method:

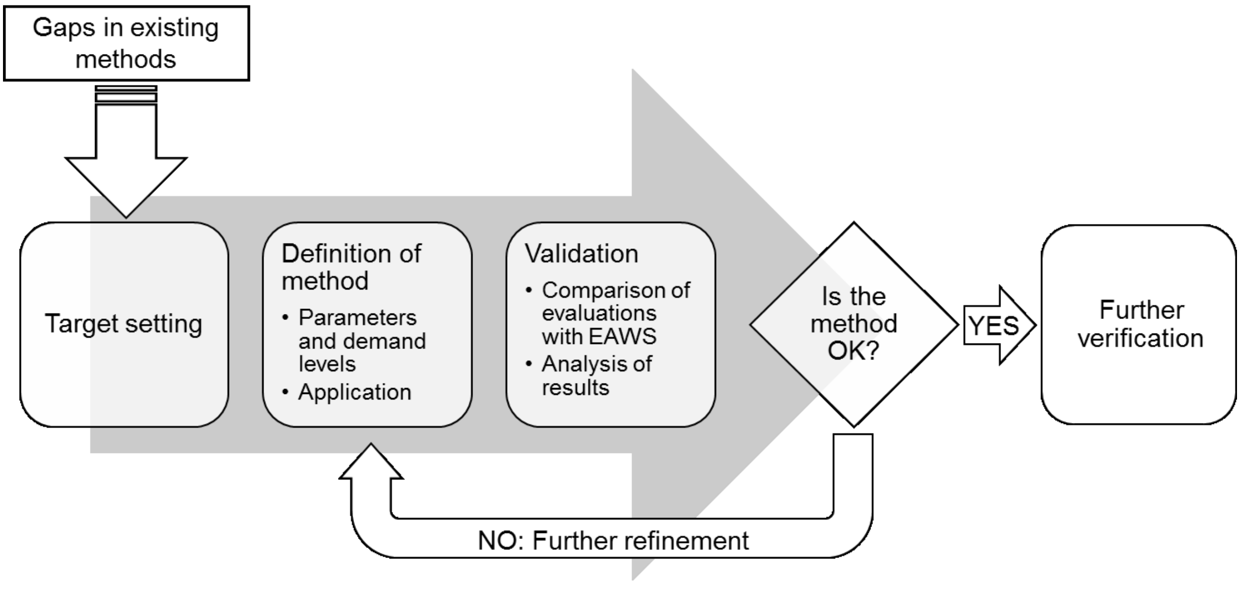

Figure 1: Iterative procedure to develop the method

A trial and error method was used to develop the method iteratively. Figure 1 shows the steps followed to develop the method, which are explained in this section.

2.1 Target setting

From the gaps in the existing methods, targets were set. The targets were:

- Ability to assess cyclic work. A procedure must be defined to combine the risks due to the different constituent work tasks of a work cycle.
- Compliance with the relevant standards (ISO 11226 and EN 1005-4) and the EAWS to ensure industrial relevance.
- A simple method which is easy to understand and apply, while providing enough details to assist decision making. A quantitative measure was considered essential to assist decision making (Saaty, 1990) and to understand the impact of modifications of the work cycle.
- False positive: The method must not underestimate the risk. A false positive is a safer error to have than a false negative. However, the method must not be too much conservative either.

2.2 Definition of method

The proposed method is an adaptation of the cube methods to evaluate risk due to work (Sperling et al., 1993; Kadefors, 1997, 1994). There are 2 versions of the cube methods, which are compared in Table 1. Conceptually, both the methods consider 3 parameters for assessment and divide them into 3 levels of demand, resulting in 27 possible combinations of demand levels. The key difference in the two methods is the way they evaluate a work situation. Sperling provided a classification for all the possible combinations of demand levels. Instead, Kadefors proposed a multiplicative model to evaluate the work. 1, 2 and 3 points were assigned for low, medium and high demand levels, respectively. The points from the three parameters were multiplied to give an overall score, which formed the basis for the evaluation of risk. Besides, the field of application of the two methods, and, thus, the parameters for assessment are different.

Table 1: Comparison of Sperling's and Kadefors' cube methods

	Sperling's method	**Kadefors' method**
Field of application	Work with hand tools	Evaluation of manual work at the workplace
Parameters	Force, Precision, Time	Force (F), Posture (P), Time (T)
Demand levels	Low, Medium, High	Low (1 point), Medium (2 points), High (3 points)
Method for classification	Individual classification of all possible combinations	Multiplicative model (F×P×T) with an acceptability criteria based on the score.

The cube methods present a simple model for assessing the ergonomic risks and, thus, they became a starting point for the development of the proposed method. They are easy to understand and apply as they consider three factors for the onset of WMSDs and divide them into three levels of demand each. While, the simultaneous consideration of three factors allows for a realistic evaluation for the risk of WMSDs, the use of only three levels of demands facilitates in the application of the method.

2.3 Validation of method

For the validation of PERA, its assessments of work were compared with those by the EAWS. The EAWS was considered as a benchmark due to its compliance with standards (including the ISO 11226 and the EN 1005-4) and its wide dissemination among industries.

As the proposed method is focussed on postural ergonomic risk assessment, only, the postures and general section of the EAWS were deployed. The general section of the EAWS allows to summarise the analysis and identify a few additional physical loads (extra points) which are not evaluated in other sections. The posture section is used to evaluate basic postures and movements of trunk and arms. Small forces (up to 30 – 40 N) are already included in its evaluation, while larger forces are evaluated using the action forces or manual material handling section (Schaub et al., 2013). The posture section considers the bending (flexion) of back and the position of arms in the standing (and walking), sitting and kneeling positions. It also considers lying and climbing, and, asymmetric postures of the trunk and far reach of the arms. The various symmetric postures are assigned scores depending on their duration. Whereas, for asymmetric postures, the intensity of the posture is multiplied by its duration score to obtain the asymmetry score. All the scores are finally summed up to provide the overall score for the posture section.

For the iterative development of the method, 5 "high risk" work cycles were considered. The definition of the threshold, beyond which work cycles are classified as "high risk", is a very critical aspect of the method. It was important to optimize the method using the high risk work cycles, so that it would be able to detect an ergonomically unsafe situation. For further verification, additional work cycles of lower risk were considered. After the optimization of the method using high risk work cycles, it was also important to verify that the method is not too much conservative, evaluating every work cycle as "high risk". The rationale behind the selection of the work cycles was to ensure that a substantial variety of work situations was considered. The work cycles ranged from low to high risks, with cycle times from 25s to 250s. The work cycles had postural risks to different body parts in different proportions. Table 2 and Figure 2 present an overview of all the work cycles analysed, highlighting their variety with respect to cycle times and sources of risks.

Table 2: Duration of stressful postures (posture score ≥ 2 points; Table 4) in different work cycles

Work Cycle		**No. of work tasks**	**Cycle Time (s)**	**Stressful postures duration (percentage of Cycle Time)**					
								Asymmetric Postures	
No.	Title			Trunk	Shoulder	Head / neck	Elbow	Trunk	Head/neck
1	Passenger seat installation	12	78.64	35	72	0	8	55	0
2	Driver Seat Installation	8	121.64	18	92	6	0	42	0
3	Engine compartment tubes installation	16	249.92	10	57	0	34	26	22
4	Fixture installation on chassis cross-member	5	76.08	92	92	0	8	0	0
5	Tubes installation on chassis cross-member	14	165.52	75	75	0	17	10	0
6	Right-rear door assembly with body	6	24.60	0	44	14	13	34	22
7	Transmission assembly 1	7	35.48	18	0	34	90	0	18
8	Transmission assembly 2	6	36.40	0	41	22	12	12	0
9	Trolley assembly	14	189.00	5	5	58	66	0	0

Note 1: Sum of percentage durations ≠ 100 due to the simultaneous presence of multiple stressful postures

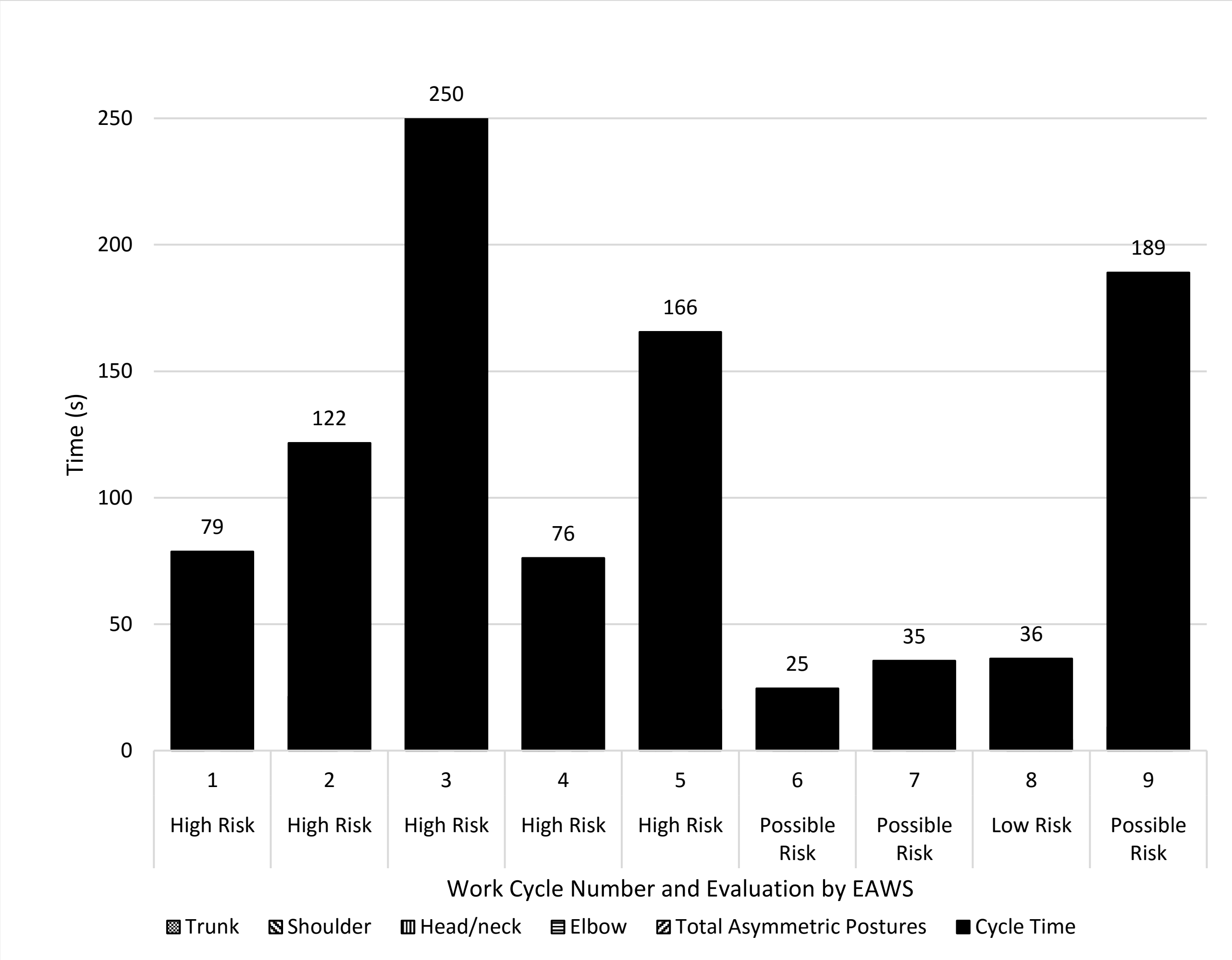

Figure 2: Overview of analysed work cycles and their evaluations by EAWS. The thick bar represents the Cycle Time of the work cycle. While, from left to right, the thinner bars within the thick bar represent the duration of stressful postures (posture point ≥ 2; Table 4) of trunk, shoulder, head/neck, elbow and total asymmetric postures (sum of asymmetric postures of trunk and head/neck), respectively, within the corresponding work cycles.

The work cycles were, first, assessed using Kadefors' cube method (Sperling's method was not applicable for these cycles). Only 1 of the 5 high risk work cycles matched with the evaluations of the EAWS. The method was underestimating the risk with respect to the EAWS, primarily, as its acceptability criterion was somewhat permissive. Thus, work cycles with lower risk were not verified. The results are summarized in Table 3. Moreover, the definition of the demand levels of time were based on number of hours per day, which is unintuitive for assessing cyclic work. After transforming these thresholds to percentage duration of time, they corresponded to 12.5% and 50% of the time. The threshold of 50% of the time turned out to be quite large as not even a single work task out of the 55 work tasks analysed in the 5 work cycles was found to have a duration of more than 50% of the cycle time.

Table 3: Comparison of evaluations by EAWS and Kadefors' cube method

		EAWS		
		Low Risk	Possible Risk	High Risk
Kadefors' cube method	Low Risk			x x
	Possible Risk			x x
	High Risk			x

However, one of the key strengths of the cube method is that it is a multiplicative model, which allows for the interaction of the parameters of the model. The interaction between parameters is an important aspect for ergonomic risk assessment, although, further investigation is needed in this field. Li and Buckle (1999) and David (2005) found a number of ergonomic assessment methods that acknowledged the presence of interaction between the risk factors of WMSD, however, there is very limited epidemiological data to quantify the interactions or weight the different factors. More recently, Gallagher and Heberger (2013) found evidence from existing literature suggesting the presence of an interaction between force and repetition on MSD risk. However, the evidence was not conclusive as the interaction was, often, not tested by the authors. Further research must be designed, specifically, to investigate the possible interactions.

The cube methods provided a starting point for the development of the method. However, it was realized that the method needed refinement as its evaluations were not corresponding with a more detailed method, such as the EAWS, often, leading to an underestimation of the postural risk. The definitions of posture, duration and the acceptability criteria were not related to the indications of the standard. The refined version of the method and its features are explained in the section 3.0.

3.0 Postural Ergonomic Risk Assessment (PERA):

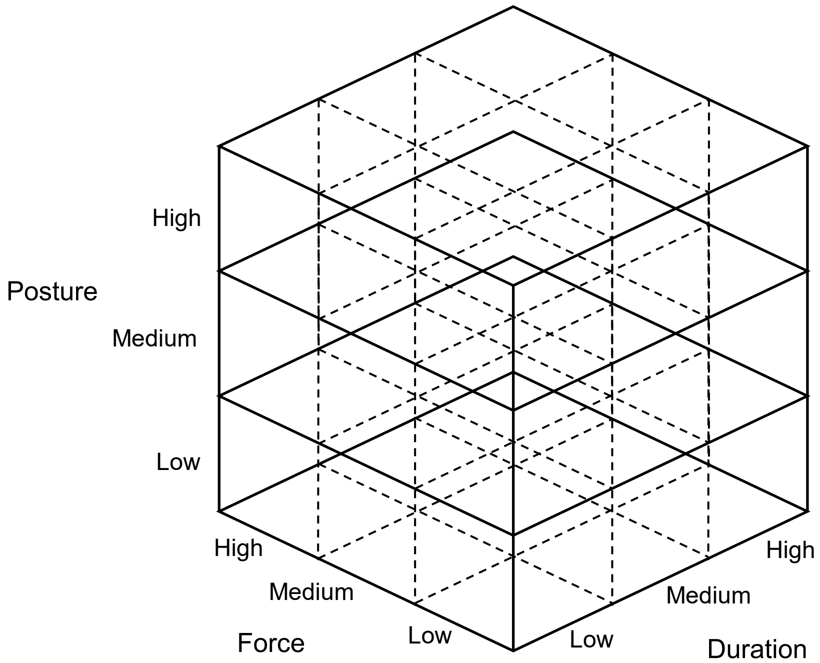

Figure 3: Graphical representation of the concept of the cube method

Just as in the cube method proposed by Kadefors, the 3 parameters considered in PERA are posture, force and duration, and they are divided into 3 demand levels of low risk, medium risk and high risk. Figure 3 represents a graphical representation of the cube method. The cube method was adapted to evaluate cyclic work, characterized by awkward static postures and light assembly work using hand tools or partners. PERA was tested for cycle times from 25 seconds to 250 seconds. For very short cycle times, attention should be posed on possible high frequency movements (refer to EN 1005-4). PERA is not applicable for finger intensive tasks and is not suitable for work cycles dominated by application of high forces. However, it can be used to evaluate occasional application of large forces.

Application of PERA requires to follow these general steps:

1. The work cycle must be divided into different tasks, which are characterized by different postures or different work content. These are called work tasks.
2. The percentage duration of the work tasks with respect to the cycle time should be calculated.
3. Each work task must be observed for the posture of the operator and the force applied by the operator.
4. The observations of posture, force and duration for each work task must be classified into one of the three demand levels (low risk, medium risk or high risk) for each parameter, as described in Table 4.
5. In general, for observations of posture, force and duration falling into low, medium and high risk, a score of 1, 2 and 3 points must be assigned, respectively. In case the risk level for posture changes during a work task, the score must be a time weighted average of the points corresponding to the different risk levels in the same work task.
6. Using these scores, the score for each work task must be computed by multiplying the scores of the three parameters for the corresponding work task.
$$Work\ Task\ score, T_i = (posture)_i \times (force)_i \times (duration)_i$$
7. The overall score for the work cycle must be computed as an average of the score obtained from all the constituting work tasks.
$$Overall\ work\ cycle\ score, A = (\Sigma\, T_i)/n_i$$
Where, n_i = number of work tasks considered for the final score

The steps to evaluate the overall score by the method are also illustrated in Figure 4.

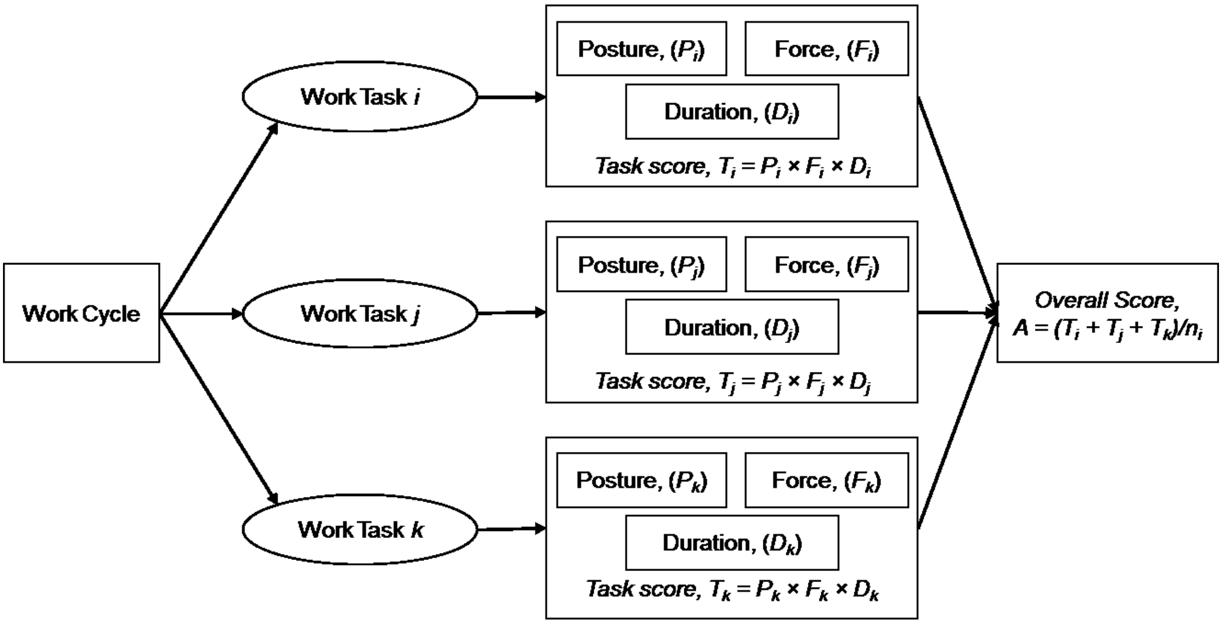

Figure 4: An illustration of calculation of the overall score of the work cycle by PERA.

3.1 Definition of demand levels

The criteria for the classification of the demands into low, medium or high risk for the three parameters are presented in Table 4.

Table 4: Criteria for classification of demands of posture, duration and force by PERA

			Low Risk (1 point)	**Medium Risk (2 points)**	**High Risk (3 points)**
Posture	Trunk	Forward bending	0° - 20° (Upright)	20° - 60°	Greater than 60°
			20° - 60° with trunk support	-	-
		Backward bending (extension)	With trunk support	-	Without trunk support
		Asymmetric postures	-	Rotation/lateral bending 0° - 10°	Rotation/lateral bending greater than 10°
		Other	-	-	Convex lumbar spine when sitting
	Shoulder	Flexion / abduction	0° - 20°	20° - 60°	Greater than 60°
			20° - 60° with full arm support	-	-
		Extension / adduction	-	-	Greater than 0°
	Head & neck	Forward bending	0° - 25°	25° - 40°	Greater than 40°
		Backward bending (extension)	-	With trunk support	Without trunk support
		Asymmetric postures	-	Sideways bending from 0° - 10°	Sideways bending greater than 10°
			-	Twisting (rotation) from 0° - 45°	Twisting (rotation) greater than 45°
	Other	#Elbow flexion / extension	0° - 20°	20° - 60°	Greater than 60°
		Knee angle while sitting	90° - 135°	-	Less than 90° or greater than 135°
	# Elbow must be observed only when work is being performed by hands. In this case, neutral position is considered as 90° angle of the elbow joint				
Duration		Percentage of cycle time	0% - 10%	10% - 20%	Greater than 20%
Force		Exertion of physical effort	Not visible. E.g.: Manipulation of light objects	Visible. E.g.: smooth and controlled motion, use of both the hands when the task does not seem very heavy	Clearly visible. E.g.: Low control over motion, bulging muscles, facial expressions, gestures
			-	-	Vibrations from powered hand tools
			-	-	Counter-shocks or impulses (such as from heavy hammering)

The definitions of the demand levels of PERA are based on the ISO 11226, EN 1005-4 standards and the EAWS. The idea behind the definition of the demand levels of posture was to make it comprehensive and robust. All the features from the standards and the EAWS were integrated to create a comprehensive set of definitions. For example, the ISO 11226 does not allow asymmetric postures, however, they are conditionally allowed in the EN 1005-4 and the EAWS. While, the EAWS does not consider the postures of head/neck, the ISO 11226 refers to them and the EN 1005-4 considers the asymmetric postures of head/neck as well. As also, the EAWS was used as an inspiration to deal with asymmetric postures with extra criticality (by the way of assigning an additional point to the base score; as described in section 3.2.2).

As regards the duration of postures, the ISO 11226 recommends the maximum acceptable holding times for trunk bending, head bending and upper arm elevation as 20% of the maximum holding times. As can be seen from Table 5, the maximum acceptable holding times depend on the body joint and its angle. However, the most critical value for maximum acceptable holding time is 1 minute for all 3: trunk, head and upper arm elevation. The thresholds for duration were set at 10% and 20% of the cycle time. For cycles longer than 5 minutes, attention should be given to the posture and actual duration as the 1 minute limit of maximum acceptable holding time could be exceeded (refer to ISO 11226). Whereas, for very short cycles, the risk factor could change from static posture to repetitive movements. Repetitive movements could be unacceptable if they are sustained for long durations (refer to EN 1005-4).

Table 5: Maximum acceptable holding times (ISO 11226)

	Trunk		**Head**		**Upper Arm elevation**	
Bending angle (degrees)	60	20	85	25	60	20
Maximum Acceptable Holding time (min)	1	4	1	8	1	4

As PERA is an observational method, the definition of the demand levels of forces are qualitative. Direct measurements of forces were not considered feasible. So, quantitative definitions of force would have been counterproductive. Besides, generally, there is an agreement that observational assessments of force yield better results than self-reports from operators (Wiktorin et al., 1996; Winkel and Mathiassen, 1994; Spielholz et al., 2001; Bao et al., 2009). The variability of observational assessment of force could be reduced significantly if some information about the tasks (such as forces or moments) is known, although, the observer's training and experience could compensate for lack of such information (Koppelaar and Wells, 2005).

For the definition of the demand levels of force, Latko's visual analogue rating scale for assessment of hand forces was referred (Spielholz et al., 2001). The scale was developed for observational assessment of hand force with qualitative descriptors. The scale provided a 10 point linear score from 0 (none) to 10 (greatest imaginable). The qualitative descriptors were taken to define the 3 demand levels of PERA. The use of hand-held power tools was considered a high risk as they could be a significant source of stress, leading to the inflammation of tendons (Armstrong et al., 1999).

3.2 Special cases

During the development of PERA, the following special cases were also defined:

3.2.1 Special case for duration:

- In case a stressful posture is maintained or worsened in subsequent tasks, the duration of the subsequent tasks must be cumulated prior to its classification into one of the three demand levels.

3.2.2 Special cases for posture:

- In case multiple body parts are involved, the worst affected part is considered for the assignment of posture score for the concerned work task.
- In case of simultaneous presence of asymmetric and symmetric postures from medium or high risk, an additional point must be added to the assigned posture score for the concerned work task. Thus, it is possible to obtain a maximum score of 4 points for posture in this case.

3.2.3 Special cases for force:

- In case a similar force is applied sporadically during the work task (such as hammering, multiple operations of a manual machine in a work task, etc.), then, the risk level due to the force will be considered as if it is present consistently for the duration of the task.
- In case there is substantial variation in the applied force during a work task (such as a high initial force followed by sustained lower force during pushing of a trolley), it is advisable to split the work task into separate tasks for a more accurate assessment.

3.2.4 Special case for low risk work tasks:

- Work tasks which have low risk levels for posture and force are called as low risk work tasks, that is, they have 1 point for both posture and force. As will be explained in section 3.3, low risk work tasks required special attention due to the calculation of the final score as an average. Such low risk work tasks with a duration of less than 10% of the cycle time are excluded from the computation of the final average score of the work cycle. Whereas, low risk work tasks with duration of 10% of the cycle time or more are included in the computation of the final average score of the work cycle, but, they are assigned 1 point for duration also, instead of 2 or 3. Consequently, the work task score is 1 point only.

3.3 Acceptability criteria

On the basis of the overall score of the work cycle (*A*), an overall classification of the work cycle is provided as shown in Table 6.

Table 6: Risk level classification by PERA

Overall Score (*A*)	Classification of risk level	Recommended Action
$A < 4$	Low risk	Acceptable; No action is necessary
$4 \le A < 7$	Possible risk	Further investigation by a more refined method (such as EAWS)
$A \ge 7$	High risk	Not acceptable; Corrective action is necessary

For the acceptability criteria, both of the original cube methods were referred. As Kadefors' cube method was underestimating the risk in our preliminary analysis, the acceptability criteria needed to be made more rigorous. While, PERA treats all the parameters equally, Sperling's cube method treated the parameters unequally. So, the combination of parameters affected the overall classification of the work cycle in Sperlings's method. For example, there are 6 possible combinations for a work situation having one parameter at High Risk, another at Medium Risk and the third at Low Risk. While, PERA would give the same score for all the combinations, instead, Sperling's method provides 6 classifications, corresponding to every possible combination. Table 7 shows a comparison of the scores provided by the multiplicative model used in Kadefor's method and PERA with the possible classifications by Sperling's method. While such a comparison is made, it must be emphasized here that Sperling's method was to evaluate work with hand tools and the parameters considered were different from PERA. The purpose of the comparison was to see how a mathematical model compares with a direct classification of the work.

Table 7: Comparison of work cycle classification by the multiplicative model and Sperling's cube method

Combination of parameters (irrespective of parameter) L=Low; M=Medium; H=High			**Score by multiplicative model (PERA)**	**Classifications as per Sperling's cube method** (number in brackets indicates number of possible combinations with corresponding classification)
L	L	L	*(1×1×1)* = 1	Acceptable (1)
L	L	M	*(1×1×2)* = 2	Acceptable (3)
L	L	H	*(1×1×3)* = 3	Acceptable (1); Further Investigation (2)
L	M	M	*(1×2×2)* = 4	Acceptable (3)
L	M	H	*(1×2×3)* = 6	Acceptable (1); Further Investigation (5)
M	M	M	*(2×2×2)* = 8	Acceptable (1)
L	H	H	*(1×3×3)* = 9	Further Investigation (1); Unacceptable (2)
M	M	H	*(2×2×3)* = 12	Further Investigation (3)
M	H	H	*(2×3×3)* = 18	Unacceptable (3)
H	H	H	*(3×3×3)* = 27	Unacceptable (1)

Considering the thresholds from Kadefors' method (which were at 5 and 10 points), the equality of parameters and the continuity of a point based overall score, it was decided to consider a maximum of two parameters at medium risk as Low Risk, which is up to 4 (=2×2×1) points. A combination of all the three parameters at medium risk or worse was considered as High risk, which is 8 (= 2×2×2) points or more. Finally, for the first try, the thresholds were set at 4 and 7 points. These thresholds were found quite suitable during subsequent trials of the method.

However, during the development of the method, it was noticed that, in case there were a substantial number of low risk work tasks, the method was underestimating the risk. The average is susceptible to the distribution of scores, and, the danger from a high risk work task could be missed due to the presence of other tasks. PERA was made robust enough to counter this problem. The special case for low risk work tasks (section 3.2.4) helps in differentiating between work tasks which offer a recovery period to the operator from work tasks which result in an unjustified reduction of the overall score.

On the contrary, PERA would result in a very high score if the work cycle is dominated by high risk work tasks. A score greater than 14 points would indicate such a work cycle, which would require immediate corrective action. The high score by the method, with respect to the threshold, helps in perceiving this severity of the situation. As shown in Figure 5, the distribution of scores by PERA approximates to a logarithmic distribution. This corresponds well with the logarithmic nature of the relationship between stress and the rate of damage to tissues (Gallagher and Heberger, 2013).

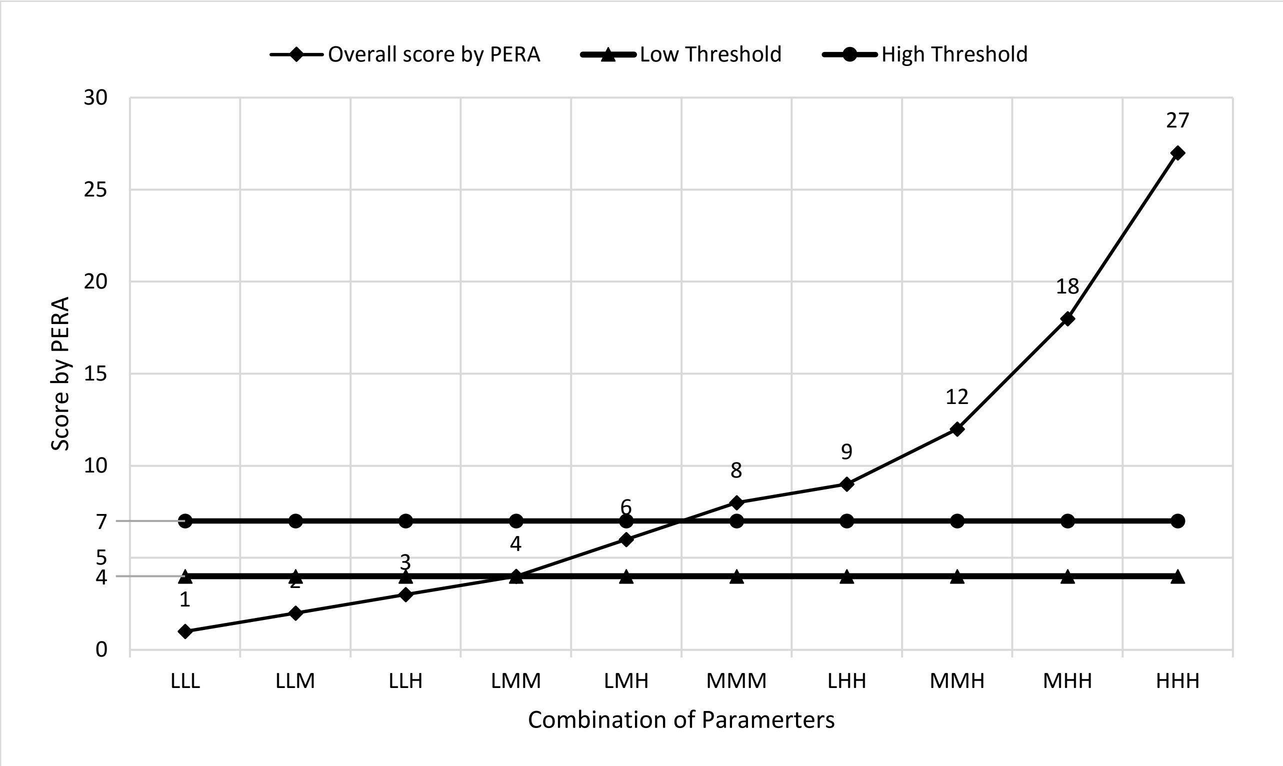

Figure 5: Distribution of score by PERA

To conclude the section on the definition and application of PERA, the key differences of PERA with the original cube methods are summarized as follows:

1. The definitions of the demand levels of PERA were defined based on the relevant standards ISO 11226 and EN 1005-4, and the EAWS and broadened with respect to the original cube methods.
2. The definitions of posture were made clearer. Terms, such as "optimal", which are subject to personal interpretation, were avoided.
3. Whereas, the definitions of force were made qualitative instead of fractions of Maximum Voluntary Contraction (MVC), to facilitate application as an observational method.
4. The duration demand levels were modified, as well as expressed as a percentage of cycle time instead of hours per day. It is more suitable for assessing cyclic work.
5. The final acceptability criteria for the work cycle was changed to ensure compliance of PERA with the reference method.

3.4 Validation

The refined version of PERA was able to deliver the same evaluations of the work cycles as the EAWS. The results are summarised in Table 8.

Table 8: Comparison of evaluations by EAWS and PERA

		EAWS		
		Low Risk	Possible Risk	High Risk
PERA	Low Risk	x		
	Possible Risk		x x x	
	High Risk			x x x x x

As an illustrative example of the method, Table 9 presents the detailed evaluation by PERA for one of the work cycles. It shows some of the special cases which were described earlier. In work task 5 and 6, the counting of time was continued as the posture of the same body part was maintained or worsened during the subsequent work tasks. In work task 11, an additional point was added to the posture score due to the presence of an asymmetric posture along with high shoulder abduction. From the individual work task scores, the overall work cycle score was evaluated as 8.58 points. This work cycle was classified as “High risk”.

Table 9: Detailed analysis of Work Cycle 1, Passenger seat installation, by PERA

CYCLE TIME, C.T. (s)		**78.64**						
Work Task			**Force**	**Posture**		**Duration**		**Task Score (F×P×D)**
No.	Description	**Duration (% of C.T)**	Score (F)	Score (P)	Comment	Score (D)	Comment	
1	Withdraw lift from vehicle	8.44	1	3	Elbow flexion >60deg. Shoulder flexion >60deg	1		3
2	Move lift to seat location	11.14	1	3	Trunk rotation >10deg	2		6
3	Position lift on seat	8.24	2	3	Trunk flexion 20-60deg. Shoulder flexion >60deg	1		6
4	Mount headrest	10.27	2	2	Shoulder flexion 20-60deg. Trunk flexion 0-20deg	2		8
5	Press button on lifting partner	3.10	1	3	Shoulder flexion >60deg. Trunk flexion 20-60deg	2	Time continued	6
6	Disengage seat stopper on the floor	4.12	3	3	Trunk flexion >60deg	2	Time continued	18
7	Withdraw seat and lift	4.88	1	2	Taking average value (from trunk bending >60deg to upright trunk)	1		2
8	Take rubber brackets from the floor	4.22	1	3	Trunk flexion >90deg	1		3
9	Attach rubber brackets on seat frame underside	4.12	2	3	Trunk lateral bending >15deg	1		6
10	Move seat and lift to vehicle	26.81	1	4	Trunk rotation >10deg and shoulder abduction >60deg	3		12
11	Position seat in vehicle	13.12	2	4	Shoulder abduction >60deg and trunk lateral bending <10deg	3	Time continued	24
12	Release seat from lift	1.53	1	3	Shoulder abduction >60deg	3	Time continued	9
						Average Score		8.58

4.0 Discussion and limitations:

1. All the evaluations had been performed on the basis of video recordings of the work cycles and the same data was used in analyses by all the methods. The videos were of real work cycles in the factories (or a part of the work cycle) and they were made by the company analyst, specifically for this work.

2. The key target of this work was to ensure compliance with the current standards. This compliance was to be achieved through a simple model for ergonomic risk assessment. A simple model compromises on the details and accuracy of the model. Not every aspect of postural risk

assessment could be included, and simplifications were made to facilitate its use. As PERA is focussed on posture, the definitions of posture were defined in detail. However, to keep the model simple, the force and duration aspects were simplified and defined in brief.

3. As a simple and quick method for postural ergonomic risk assessment, the overall risk level classification is of relevance. The purpose of the method is to check if the work cycle is ergonomically safe or not, for which the overall risk level classification would suffice. The absolute scores provided by PERA are not of significance by themselves or in relation with the scores provided by the EAWS, apart from their use for the overall risk level classification. However, the scores are of significance to understand how the changes in the work cycles affect ergonomic risk assessment. A quantitative measure assists in decision making as it is useful for assessing the impact of the modifications made to the single aspects of the work cycles.

5.0 Conclusions:

PERA is mainly focused on postural ergonomic risk assessment, but offers industrial relevance for work cycles dominated by such risk.

1. PERA achieved a 100% success rate with respect to the evaluations by the EAWS. The 9 work cycles, comprising 88 different work tasks, offered a substantial variety. The cycle time ranged from 25 seconds to 250 seconds. Although, most of the analysed work cycles were from the automotive sector, the work cycles included risks to the trunk, the shoulders, the elbows, the head and the neck, along with the occasional presence of asymmetric postures and application of large forces.
2. The key features of PERA are its simplicity and compliance with standards. With little efforts, the users can familiarize themselves with the working of this method and quickly assess industrial work cycles for postural ergonomic risks.
3. An added value of PERA is that it provides a task by task analysis of the work cycle along with an overall evaluation of the work cycle. This allows for quick identification of sources of high risks in the work cycle.

Further validation of PERA is needed, although, the current results are promising. The future work in this project could include a more detailed analysis and definition of the risk levels due to force and repetitive movements. Subsequently, an automated application of the method using computers and integrating with work design methods could also be worked upon. Promising results were achieved by Laring et al. (2002), when they integrated the cube method of Kadefors with SAM, an MTM based technique. This demonstrates, that, such a possibility is feasible.

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