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Original Article

Contribution of Situational Operational Leeway for Ergonomic Assessment in the Evaluation of Work Situations

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Contribution of Situational Operational Leeway for Ergonomic Assessment in the Evaluation of Work Situations

Abstract

This study investigates the problems related to identifying MSD risk factors using simple risk assessment tools. The purpose is to study the contribution of situational operational leeway (SOL) indicators as a complementary method to the information provided by simple MSD risk assessment tools and to show how SOL might be a supplement to these established tools.

Eight simple tools (OSHA, RULA, REBA, QEC, CE, EAWS, NIOSH, and MAC) were used to evaluate ten workstations in the metallurgy industry. The indicators of SOL, derived from the human-centred activity model, were also explored in the same workstations to define whether SOL is adequate. The results of these two approaches were compared to identify the difference between them.

Analysing the risk of MSD on ten workstations using eight simple tools showed the variability of exposure between tools for identical work situations. We analysed the same workstations with the SOL indicators, and disagreement was found in judgment between the two approaches of MSD risk identification. The SOL indicators estimated a lower risk of MSD than the simple tools. This study proposes that SOL indicators might improve the phase of MSD risk identification as a complement to the current simple tools.

Keywords: Critical situation, risk assessment tool, Musculoskeletal Disorders, Situational Operational Leeway

Introduction

Risk prevention approaches for musculoskeletal disorders (MSDs) aim to improve working situations (Aptel, Gerling, and Cail 2000; St-Vincent et al. 2011). In the majority of preventative models, risk evaluation is the first step in MSD risk prevention. This initial assessment phase determines the risk level using simple assessment tools and directs the prevention approach towards the most critical work situations. The most commonly used MSD risk assessment tools are paper-based observational methods, self-reported questionnaires, and in-house methods (G. C. David 2005; Malchaire et al. 2011; Takala et al. 2010). These simple tools identify MSD risk based on characteristics of the work activity. The majority of observational tools evaluate the worker's exposure to MSD risk factors using a checklist. These tools primarily consider a limited number of biomechanical and physiological parameters (G. C. David 2005; Denis, Lortie, and Rossignol 2000; Malchaire et al. 2011). The questionnaire/self-assessment tools gather information on the task and establish a risk level based on the perceptions and feelings of the workers (Descatha et al. 2009; Hansson et al. 2001; Roman-Liu 2014). Large industrial groups have created in-house tools compatible with their specific activity (Berlin et al. 2009; Hägg 2003; Törnström et al. 2008). In-house ergonomic methods often use a triangulation of data that is gathered by observations, questionnaires (asking for the perception of workers), and direct measurements to evaluate risk levels.

Previous studies have criticized the reliability and repeatability of simple tools (Barrero, Katz, and Dennerlein 2009; Chiasson et al. 2012; Zare et al. 2017). The results of these tools have been often questioned because of inter and intra-individual variability, the variations of the technical-organizational system (e.g., unexpected mishaps/incidents arising from machines and materials), and the diversification of products (Badets, Merlo, and Pilniere 2017; Koukoulaki 2014; Mathiassen 2006; Zare,

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3 Sagot, and Roquelaure 2018). Furthermore, scientific knowledge of the etiological
4 model of MSDs has been gradually expanded, leading to a consensus on the multi-
5 causality of MSD risk factors (J. Bodin et al. 2018; Julie Bodin et al. 2017; Karsh 2006;
6 Roquelaure 2018). The variability of activity (e.g., individual variability, production,
7 and organizational variations) and multi-causality of MSDs question the use of simple
8 assessment tools solely in MSD risk estimation. These tools might be little
9 representative of the non-ergonomic situation in a workplace and may not facilitate
10 monitoring and following the effects of changes/interventions on risk exposure.
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21 Following a systematic and developmental approach and focusing not only on
22 the constraints, which simple tools often evaluate, but also on the resources of the work
23 situation provide the possibility for activity regulation (despite the individual,
24 environmental, and organizational constraints). Thus, the activity of the operator is not
25 as simple as applying prescribed instructions but is a regulatory process aimed at the
26 achievement of objectives (either personal or set by the company) by managing the
27 system and individual variations (Hubault and Bourgeois 2013; Roquelaure 2018;
28 Snelwar and Hubault 2015; Daniellou * 2005). The notion of situational operational
29 leeway (SOL) arises from the convergence of the characteristics of a professional
30 environment and those of the worker (Coutarel et al. 2015; Vézina et al. 2016; Coutarel
31 2004). This merging is entirely situational, and it has been defined as follows:
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48 ‘Situational operational leeway constitutes the possibility for the operator to
49 develop an efficient mode of operation in a specific work situation (or work
50 strategy). “Efficient” meaning effective in the performance of tasks and protecting
51 oneself at work’ (Coutarel et al. 2015).
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55 This definition refers to the human-centred activity model (Vézina 2001). Figure
56 1 shows 46 representative indicators of this model, frequently used for ergonomics
57 interventions (Coutarel, Roquelaure, and Daniellou 2013; St-Vincent et al. 2011; Vézina
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2001). We suggest the possibility of using three components of this model for the risk assessment phase: the work strategies developed by individuals to overcome the work constraints, the effects of activity on health and the effects on performance. This approach might respond to the difficulties discussed above regarding the simple MSD risk assessment tools. We assume that using this model to assess MSD risk factors might improve the identification phase of critical situations. The previous study demonstrated that none of the simple tools currently used by companies for MSD risk assessment consider whether SOL is sufficient in a work situation (Norval et al. 2019). Furthermore, these tools do not evaluate the number of operational strategies available to the operator in dealing with a situation in a suitable manner.

This study aims to investigate the contribution of SOL indicators compared to the information provided by simple risk assessment tools and to show how SOL might be a supplement to these tools. The risk of MSDs was measured by eight simple tools and by three components of the SOL. The results were then compared to find the differences between these methodologies to estimate MSD risks.

Material and Methods

This study was carried out in a French company that produces and assembles diesel engines. The production lines consisted of the main engine parts (i.e., cylinder heads, engine blocks, and connecting rods), a complete engine assembly line, and a trim line. We used eight MSD risk assessment tools and SOL indicators on a sample of ten workstations. These workstations were selected in collaboration with the company's occupational health and safety experts based on the difficulties encountered by workers. Having worked with the company for three years, we had in-depth knowledge of the selected case studies. Before starting the experimentation, the research ergonomist and the operators defined the reference situation for each workstation. The reference

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2
3 situation represented the situation most exposed to MSD risks among all the scenarios
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5 encountered at the workstation. Each workstation in our sample was firstly evaluated
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7 using eight simple tools, and then, the reference situation selected on this workstation
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9 was examined by the SOL questionnaire. The ten cases studied correspond to the ten
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11 reference situations chosen from ten workstations (Table 1).
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14 The sample consisted of two workstations for rod machining (Connecting rod
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16 finishing and Connecting rod drafting), one workstation in the engine painting area
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18 (Pre-paintwork covering), four workstations for final engine assembly (Final engine
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20 assembly line, Engine wiring unit assembly, Engine injector kit preparation, and
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22 Manifold/turbo assembly preparation), one workstation in the engine preparation area
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24 before testing (Fixtures/equipment pre-testing), and two workstations in the engine kit
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26 preparation area (Preparation of small parts orders and Fixtures packaging). The ten
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28 selected workers were experienced operators (having worked at the workstations, at
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30 least, for more than six months), without any restriction (incapacity to perform the
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32 activity) and volunteered to participate in this study (Table 1). The written informed
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34 consent was obtained from all participants. We studied only one operator per
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36 workstation because of the industrial restrictions and the qualitative nature of this study.
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42 Each workstation was observed for 2 to 2.5 hours (nine identical cycles
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44 separately for each tool) during the evaluation by the simple tools. The first observed
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46 cycle on a workstation was recorded, and then the eight other cycles selected for
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48 assessments were verified to be as same as possible with the recorded film. SOL
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50 indicators were then investigated over 1.5 to 2 hours on ten identical cycles (the same
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52 cycles as for the simple tools) using an SOL checklist and interviews with the operators.
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55 The parameters for the study, such as the method for selecting the reference situation,
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3 the assessor, the evaluation tools (simple tools and the SOL questionnaire), and the
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5 methodology for approaching the operators were similar for ten workstations.
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8 9 ***MSD risk assessment tools***

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11 The following observational methods were used to evaluate MSD risk factors in this
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13 study: Occupational Safety and Health Administration (OSHA) checklist (Silverstein
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15 1997), an in-house tool called Ergonomic Criticality (CE), Quick Exposure Checklist
16
17 (QEC) (G. David et al. 2008), Rapid Upper Limb Assessment (RULA) (McAtamney
18
19 and Corlett 1993), Rapid Entire Body Assessment (REBA) (Hignett and McAtamney
20
21 2000), Ergonomic Assessment Worksheet (EAWS) (Schaub et al. 2013), the revised
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23 NIOSH equation (Waters et al. 1993), and Manual handling Assessment Charts (MAC)
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25 (Monnington et al. 2003). Table 2 shows the indicators evaluated by each of the
26
27 selected tools.
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33 The same researcher used eight simple MSD risk evaluation tools, one after the
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35 other for each workstation. The worst situation (i.e., the riskiest posture, the highest
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37 force exerted, and the more repetitions) was considered as risk factors when a simple
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39 tool was applied in a workstation. To compare the results and study their variations, we
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41 codified the interpretation scales for all of the tools across three levels: 1. Low-risk
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43 situation (acceptable), 2. Moderately risky situation (requires further investigation), and
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45 3. High-risk situation (changes required). Table 3 shows the interpretation scales
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47 formulated by the tool developers and the codifying carried out in this study. We used
48
49 only the whole-body score of the EAWS tool and excluded the score of upper limbs
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51 because the whole-body score was more representative of risk factors at the
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53 workstations.
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Indicators of situational operational leeway (SOL)

The assessor interviewed each worker about the three elements of SOL indicators: work strategy, effects on the health and performance (Figure 1; supplementary document 1) to determine whether there was adequate, potentially inadequate, or inadequate SOL. The SOL indicators collected two types of information: semi-quantitative information (a four-level system with ratings of 0-3; the lowest score being the most detrimental regarding SOL) and qualitative data to investigate the given status in more detail. This information was collected through 12 indicators for the work strategy process, four indicators for effects on health, and three indicators for impact on performance (see supplementary document 1; (Norval et al. 2019).

Semi-quantitative evaluation

The SOL indicator scores (semi-quantitative data) were transcribed to explore the adequacy of SOL for each of the ten reference situations (Table 4). The total scores were calculated separately for each of three components (the method for score calculation is explained in the supplementary document 2). We created an interpretation scale through three levels (low, moderate, and high) for each of the components based on the distribution of scores to ten reference situations. Given the effective distribution observed across three ranges of fairly distinct scores, we distributed “low,” “moderate,” and “high” scores in three groups of the same size (Table 4).

The results of the three components provided the general interpretation and classification of SOL for each reference situation:

- Inadequate SOL for a situation where at least one of the SOL components gives a “low” score

- Potentially inadequate SOL where at least two components give “moderate” scores
- Adequate SOL where at least two components give “high” scores

Qualitative evaluation

We created a model consisting of three components of SOL (work strategy process, direct effect on health, and performance) to reinforce the conclusions derived from the semi-quantitative data. The qualitative data obtained during the interview using the SOL indicators were transcribed to make the SOL model (figure 2), which provided a close look at the SOL classifications initially obtained from the semi-quantitative data. Company occupational health experts contributed to interpreting the components. The interpretation of each component was carried out based on the expertise of the ergonomists (the knowledge of ergonomist about SOL, population, workstations) and the indices gathered from the qualitative data.

Figure 2 shows an example of the reference situation Unscrewing connecting rods in the Connecting rod finishing workstation. Inadequate SOL is justified in this reference situation because of negative indices identified by three components of SOL. The negative indices observed for the work strategy process component were lack of variations in the work strategies, work pace with highly changeable rhythm (acceleration/deceleration), impossible to do the task in another way, few suggestions for improvements accepted, low levels of exchange between operators about the best practice, and low level of assistance between close colleagues. Regarding the direct effects on health component, intermittent pain and discomfort in the shoulders were identified, and significant fatigue was observed following the implementation of the reference situation. We recognized difficulties in keeping up with the rhythm of work

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3 pace (feeling of always lagging), baseline productivity sometimes not achieved, and a
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5 quantity of negative feedback on the quality of the products produced, which were the
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7 negative indices for the direct effects on performance. The same models were created
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9 for ten reference situations under study.
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12 A status of inadequate, potentially inadequate or adequate SOL was recorded for
13 each reference situation using three components observed separately:
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- 16 • Inadequate SOL where three components are negative
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- 18 • Potentially inadequate SOL where at least one component is negative
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- 20 • Adequate SOL where three components are positive
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26 ***Data analysis***

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28 The results of eight simple tools were descriptively analysed to study the difference
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30 between tools for risk evaluation in the same workstations. The SOL indicators were
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32 analysed with the semi-quantitative data, and a further level of analysis was provided
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34 using the qualitative data. The results were qualitatively compared to study the
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36 agreement/disagreement between the level of risk assessed by the simple tools and the
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38 level of SOL adequacy found by the SOL indicators.
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44 **Results**

45 ***Simple tools for evaluating MSD risk***

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47 The results of eight simple tools showed the variability between the results of different
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49 simple tools (inter-tool variance) for the same workstation (Table 5). The
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51 Manifold/turbo assembly preparation workstation was evaluated using ten different
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53 tools which gave identical results, while the evaluation of the Connecting rod finishing
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55 and Fixtures packaging workstations provided different results from one tool to another.
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3 Our results showed little variability in the results of the specific tools for manual
4 material handling for six workstations involving manual handling tasks (Table 5).
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8 The variability in the average score of the tools for ten workstations indicated a
9 difference between tools (inter-tool variability). Figure 3 shows the distribution of risk
10 status between low, moderate, and high risk for each simple tool. The OSHA checklist
11 and REBA rendered the highest number of extreme risk situations, with 8 and 6 out of
12 10 workstations, respectively. The Ergonomic Criticality tool and QEC identified 7 out
13 of 10 workstations as having low-risk status. The NIOSH equation and MAC (tools
14 specific to manual material handling tasks) classified ten workstations as low or
15 moderate risk (Figure 3).
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26 The OSHA checklist resulted in little variance between ten workstations
27 (SD=0.3), while RULA gave a standard deviation of 0.7. The results from the NIOSH
28 equation (SD=0.3) and MAC (SD=0.5) also showed the variability between
29 workstations (Table 5).
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36 ***Investigation of SOL indicators: semi-quantitative and qualitative data***

37 *SOL assessed by the semi-quantitative method*

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40 The results of three components of SOL indicators for each reference situation showed
41 that 50% of the reference situations had inadequate SOL (Unscrewing connecting rods,
42 Attaching engine to overhead conveyor, Injector assembly, and Equipping engine
43 flywheel pre-testing), 40% had potentially inadequate SOL (Connecting rod drilling,
44 Top end fitting and connecting, and Installation of turbo onto manifold), and 10% had
45 adequate SOL (Packaging of a small part). The score of each component of the SOL
46 indicators varies from low to high scores. For example, the reference situation
47 Unscrewing connecting rods for the workstation Connecting rod finishing had
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3 inadequate SOL. The low score was for the work strategy process and direct effect on
4 performance components, and a moderate score was given for the direct effect on health
5 component (Table 6).
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10 11 *SOL assessed by the qualitative method*

12 Table 7 presents a summary of the qualitative information used to classify the adequacy
13 of SOL in work situations. Our findings showed inadequate SOL for two reference
14 situations (Unscrewing the connecting rods and Injector subassembly), the possible
15 inadequacy of SOL for four reference situations (Roll top motor covering, Attaching
16 engine to overhead conveyor, Installation of turbo onto manifold, and Fixtures
17 bagging), and the adequacy of SOL for four reference situations (Connecting rod
18 drilling, Top end fitting and connecting, Equipping engine flywheel pre-testing, and
19 Packaging of a small part; Table 7).
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32 For ten reference situations studied, the direct effects on health component had
33 negative consequences for half of the reference situations (five negative statuses) and
34 most influenced on SOL inadequacy. Four negative statuses were found for the work
35 strategy process component and four for the direct effects on performance component.
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42 43 *Comparison between SOL assessed by the semi-quantitative method and the* 44 *qualitative method*

45 The qualitative data confirms the status given by the semi-quantitative data for five
46 reference situations in our sample. For the other five situations, the qualitative data
47 identified higher SOL adequacy than with semi-quantitative data. We retain the results
48 of the qualitative analysis in case of disagreement between semi-quantitative and
49 qualitative data. We considered that the qualitative results were more precise because
50 they were extracted based on the knowledge of the ergonomist (who observed and
51 analysed the workstations) and the discussion with the operators.
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Comparison between simple tools and the examination of SOL indicators

Contradictions between the results of the simple tools and SOL indicators were observed in the case of the OSHA checklist, the NIOSH equation, QEC, and REBA, with 90%, 84%, 80%, and 80% contradiction, respectively. The least contradictions were observed for the EC, RULA, and EAWS, at 60%. The average contradictions within the results of eight simple tools for evaluating MSD risk and the examination of SOL indicators was 72.6%. Among these differences, 42.6% of cases had a higher risk with the simple tools compared to the SOL indicators, and 30% had a lower risk with the simple tools compared to the SOL indicators (Table 8). For example, the OSHA checklist showed eight high-risk stations and two moderate-risk stations, while the SOL indicators showed two situations with an inadequacy, four situations with a possible inadequacy, and four situations with the adequacy of SOL. These results reflect the non-concordance (90%) of data and a higher risk estimate with OSHA compared to the SOL examination (80% of contradictions).

Discussion

Variability of results between simple tools

This study showed the variability of results between similar simple tools for MSD risk assessment in the same work situation. These results are compatible with the hypothesis that the simple tools might be improved for assessing MSD risks (Bao et al. 2009; Barriera-Viruet et al. 2006; Chiasson et al. 2012; Zare et al. 2017; Zare, Sagot, and Roquelaure 2018). Three factors can explain the variability of results: the nature of the simple tools (e.g., more sensitive to a given situation, the different focus of the theoretical model of each tool, the aetiology of MSDs, low repeatability/reliability of simple tools) (Aptel, Aublet-Cuvelier, and Cnockaert 2002; G. C. David 2005; Malchaire et al. 2011), the criteria related to using these tools (e.g., choice of tool,

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3 observation period, deployment method, distinguishing the scope of observation,
4 interpretation, and use of results), and the variability of work strategies between
5 operators (different ways of doing an activity by individuals) (Bao et al. 2009;
6 Bourgeois et al. 2006; Gaudez, Gilles, and Savin 2016; Zare, Sagot, and Roquelaure
7 2018). We observed low variability between the results of the tools specific to manual
8 material handling tasks. The risk factors evaluated by these tools were quite similar
9 between three tools (mostly biomechanical and physical factors), whereas simple
10 observation tools look for slightly varying parameters. Furthermore, the tools specific to
11 manual material handling evaluate one situation, while simple tools evaluate several
12 situations together. Other studies, such as those by Mohammadi et al. (2013), and
13 Kadikon & Rahman (2016) have reported similar results (Kadikon and Rahman 2016;
14 Mohammadi et al. 2013).

31 ***Examinations of SOL indicators***

32 Although SOL and its link with preventing MSDs have been recognized in the previous
33 literature, practitioners rarely invested in SOL in the workplace (Cuny-Guerrier 2016;
34 Cuny-Guerrier et al. 2015; Lux et al. 2017; Major and Vézina 2015; Vezina et al. 2016).
35 The reason might be that few kinds of literature developed the model or indicators of
36 SOL to encourage ergonomists and practitioners to use the concept of SOL in a real
37 setting. Vézina (2001) created a model of SOL, consisting of five components (Figure
38 1), for ergonomics intervention. We used three components of this model (work strategy
39 process, direct effect on health, and direct effect on performance) to study the state of
40 SOL adequacy, which allows identification of critical situations for MSDs. We
41 excluded the internal and external determinant components of Vézina's model (Figure
42 1) because they are unsuitable for recognizing critical situations and risk factors for
43 MSDs. Indeed, an ergonomic analysis of work that identifies the determinants of
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workers' empowerment (Roquelaure 2018) is not the aim of the risk assessment although a few simple tools explore some determinants (Norval et al. 2019).

Considering the activity's determinants implies that we can establish their number and nature from the start, which means taking into account determinants of determinants (which are sometimes remote in time and space); it also means understanding the complex interaction of determinants among themselves and the role and consequences of variability (production and individual) on these determinants. When seeking to identify critical situations, we do not aim to know the extent of SOL (characterized by the complicated relationship between the internal and external determinant and three components of SOL), but the state of SOL adequacy, which makes it possible to limit the consequences of the activity on health and performance (characterized by three SOL components). Determinants of the work situation (internal and external) can be studied during the ergonomic analysis prioritized for improvement in a critical situation.

In this study, we proposed to consider 19 indicators that are representative of three SOL components to complete the exposure evaluation derived from simple tools and understand how individuals encounter the constraints of the work situation. The SOL indicators used (Figure 1) were taken from the study by Norval et al. (2019) and are considered to be representative of work strategy processes and their effects on health and performance (Coutarel 2004; Cuny-Guerrier 2016; Durand et al. 2009; Gouédard and Rabardel 2012; Lux et al. 2017; Major and Vézina 2015; Tomás and Fernandez 2015). The indicators proposed are broad enough to avoid the restriction of the fields of study and to facilitate examination.

SOL exploration was conducted using a semi-quantitative and a qualitative method, which resulted in differing SOL adequacy in five reference situations. The

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3 contradictions observed can be explained by the accuracy of the examination methods.
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5 Although the study of semi-quantitative data reveals a trend relating to the state of SOL
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7 adequacy (differences always in the same direction), it seems crucial to take an in-depth
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9 look at the trends obtained through qualitative information, which are more accurate,
10
11 contextual, and interrelated (Hignett * and Wilson 2004; Messing et al. 2005). The most
12
13 suitable method for studying SOL indicators is analysing the work by combining the
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15 qualitative observations (such as auto-confrontation; (Clot et al. 2000)) and discussion
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17 with workers (qualitative analyses). This qualitative analysis specifies the detailed
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19 information in a multifactorial, systemic, and participatory approach that is consistent
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21 with existing literature and the development of etiological models (St-Vincent et al.
22
23 2011; Vézina 2001; Hignett and Wilson 2004).

Comparison of simple tools and the examination of SOL indicators

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26 We found differences in the estimation of MSD risk between the results of simple tools
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28 and the state of SOL adequacy. Simple tools tend to estimate the MSD risk to be higher
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30 compared to the assessment of SOL adequacy. This finding is consistent with the idea
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32 that SOL considers restrictions by integrating the resources of the work activity
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34 (Sznalwar and Hubault 2015; Daniellou * 2005). The use of simple tools is based on
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36 considering essential constraints (mostly biomechanical factors) in an observation
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38 window described as “here and now.” SOL, on the other hand, is based on work
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40 strategies (a strategy used when encountering the constraints) and the effects of a
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42 particular work situation by distinguishing between the workstation and critical
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44 situations among all the situations that constitute a workstation (Coutarel, Roquelaure,
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46 and Daniellou 2013; Cuny-Guerrier 2016; Vézina 2001). To target critical situations in
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48 this study, we distinguish between the workstation and the most critical situations
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50 (reference situations), which makes it possible to be more representative than an overall
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3 view of the exposure in the workstation.
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5 Our results show a lower risk during the SOL examination compared to the
6 results of simple tools. Simple tools mainly studied exposures to the physical risk
7 factors of the activity and direct the users' attention towards specific characteristics of
8 the activity (mainly biomechanical factors) that the tools' developers consider to be the
9 MSD risk factors (Norval et al. 2019). Nevertheless, the work activity mobilizes the
10 individual at all levels (physical, cognitive, subjective, and social, all of which are
11 inseparably linked) and is built within a framework of objectives, constraints, and
12 resources (Coutarel, Roquelaure, and Daniellou 2013; Sznelwar and Hubault 2015). The
13 work strategies studied during SOL examination are the result of the encounter between
14 constraints (environmental, organizational, and individual) and the resources used by
15 the individual to handle the activity and its variabilities (Cuny-Guerrier 2016;
16 Roquelaure 2018). Examples of resources are the possibility of assistance from close
17 colleagues, the possibility of changing the order of tasks, varying one's work strategies,
18 managing the work pace, using the available devices for manual tasks, and changing
19 workstations in the event of pain/discomfort. Furthermore, the development of an
20 efficient work strategy can be dependent on the internal and external determinants (such
21 as individual characteristics, organizational/environmental features). For example, the
22 operator's knowledge of the operation (gained through the experience at a workstation)
23 and the empowerment may arise from being at a company longer might help them to
24 develop strategies for a specific work condition.
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51 Hence why SOL presents results with lower risk compared to simple tools: SOL
52 considers the activity's resources that "compensate" for the constraints. Coutarel et al.
53 (2015) also showed the activity's resources to complement the activity's constraints to
54 prevent MSDs.
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3 The concept of SOL offers a paradigm shift; it is not “only” to reduce
4 constraints or exposure to specific risk factors, but it also proposes to prevent MSDs by
5 developing the individuals (e.g., expertise, knowledge, self-esteem) through developing
6 their professional activities (e.g., improving one’s work strategies, capacity to regulate a
7 task, and possibility of encountering the constraints of work) (Coutarel, Roquelaure, and
8 Daniellou 2013). In this developmental approach, introducing flexible production
9 systems takes priority over introducing systems adapted to a given nominal situation to
10 give resources to the workers’ future SOL (Badets, Merlo, and Pilniere 2017; Lux et al.
11 2017).

22 *Study limitations and perspectives*

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25 This exploratory study has several limitations. The investigation of SOL indicators
26 through other reference work situations (other than the one chosen) may produce
27 different results. Furthermore, SOL was examined through a unique work situation—
28 selected by the researcher together with the workers as being the reference situation
29 with the highest risk or with the most constraints among all the situations that
30 comprised the workstation—and only one worker per situation. Studying the more risky
31 situations with several operators might provide the other results and insight our eyes
32 into the different aspects of work activity. We believe that it is more representative to
33 assess the critical situations (most at risk) instead of calculating an average of risks of
34 all the scenarios.

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37 It should be noted that the checklist used to study the SOL adequacy must be
38 validated (repeatability, reliability) if it is to be re-used by occupational safety and
39 health experts in companies. Further study is needed to investigate the suspected role of
40 SOL adequacy in the appearance of MSDs. Another limitation might be related to the
41 focus of different simple tools used. Some simple tools differ in what is evaluated. For
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3 example, RULA evaluates the upper body, while EAWS and QEC evaluate several
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5 body parts, and it would be a source of difference between the results of the various
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7 simple tools
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11 **Conclusion**

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14 The results of simple MSD risk assessment tools were compared with the state of SOL
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16 adequacy. Considering the resources used by workers by work strategy process
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18 indicators, combined with information about the effects of activity on health and
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20 performance, increases the representativeness of the risk identification phase. The
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22 disagreement of results from the simple tools and the SOL examinations showed the
23
24 importance of suggesting a supplement to the simple tools currently used in companies.
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26 This study proposes to improve the quality of risk evaluation and the targeting of
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28 critical situations by considering the state of SOL adequacy, which supplements the risk
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30 evaluation by simple tools.
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37
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Table 1. Description of individual characteristics and case studies

Workstation	Description of tasks	Reference situation	Workstations	Primary constraints observed at the workstation following first meeting with the operator	Individual characteristics
		Description	Selection criteria		
Connecting rod finishing	Unscrewing, deburring, engine washing, check, sorting	Unscrewing for manual deburring and washing preparation	Most frequent reference and highest risk situation according to the operator	Heavy manual activity (carrying heavy loads), six different references	T ^a , 25 years old, M ^b , 175cm, R ^c , one year in the workstation, one year in the company
Connecting rod drafting	Rod drilling, diameter check, threading, notching, manual removal of trolley	Rod drilling	Most frequent reference and most demanding situation according to the operator	Manual handling, movement, work rate and management of time spent using machinery, six different references	T, 28 years old, M, 178cm, R, one year in the workstation, one year in the company
Pre-paintwork covering	Tape protection preparation, cover/roll-top motor, cover/roll lower motor, check, progression to painting	Mask top engine (upper part)	Reference with the most area to protect. Very high work rate according to the operator	Very high reference variability, risk of omission or error and increased impact	P ^a , 41 years old, M, 185cm, L, eight years in the workstation, eight years in the company
Final engine assembly line	Finishing of harness casing and checks, preparation of bracket spacing, push buttons, attach a hook on the motor, motor moved to the end of the line	Attachment and motor transfer to overhead conveyor	Most frequent and highest risk situation according to the operator	Trampling, advance bracket spacing (3, 4 and 6cyl), handling height and linked constraining postures	P, 30 years old, M, 165cm, R, six months in the workstation, 11 years in the company
Engine wiring unit assembly	Supply harness, positioning and screwing, harness connections and engine casing, visual inspection	Connecting harnesses and engine casing	Reference with the most connection tasks. Reference to anticipate due to being the longest and most demanding task to achieve according to the operator	High variability of references, high and variable work rate, a variable number of connections, knowledge of the manufacturing process and production diversity required	P, 39 years old, M, 165cm, R, one year in the workstation, ten years in the company
Engine injector kit preparation	Consult production checklist, preparation of parts, assembly of injectors, preparation of assembly kits, sent to the assembly line	Assembly of injector	Most frequent reference. Most constraining situation according to the operator	The high number of essential tasks, high variation of the work rate stipulated by the assembly line, very high reference variability	P, 52 years old, F ^b , 164cm, R, three years in the workstation, 11 years in the company
Manifold/turbo assembly preparation	Skid preparation, manifold placement, turbo-manifold assembly, screw and gasket installation, flexible positioning, assembly line preparation	Double turbo installation on the manifold (handling and installation)	Most constraining situation. Most demanding task according to the operator	Number of essential tasks, very high reference diversities, trampling, high and variable work rate stipulated by the production line	T, 20 years old, M, 177cm, R, seven months in the workstation, seven months in the company
Fixtures/equipment pre-testing	Fitting/unfitting of engine flywheel and belt, sealing and emptying after tests, visual inspection	Handling and positioning of the engine flywheel	Most constraining situation. Most demanding task according to the operator	Variable work rate, the variability of references, assisted load handling and equipment, static posture for drilling with vibration	P, 54 years old, M, 176cm, R, a genetic condition (Forestier's disease), nine years in the workstation, 12 years in the company
Preparation of small parts orders	Order taking, parts preparation, packing of parts per unit, put into boxes of six, preparation of kits and shipments	One piece package for kit preparation	Most frequently occurring and repetitive situation. Most representative reference according to the operator	Small and fragile parts, the variability of references, the repetitiveness of movements, autonomy in preparation	P, 52 years old, M, 174cm, R, two years in the workstation, 11 years in the company
Fixtures packaging	Prepare small parts order, e.g., screws for customer shipments, parts and machine preparation, semi-manual bagging and order shipping	Semi-manual bagging (part pick up, deposit in bag and press button closures)	Most frequent situation and highest risk reference according to the operator	Highly repetitive bagging task, a high number of references (screws and gaskets), high work rate and frequency of movements	P, 53 years old, M, 178cm, R, , 11 years in the workstation, 14 years in the company

^aStatus T/P: Temporary or permanent employment status.

^bSex M/F: Male or female sex.

^cR/L: Right or left hand of dominant use.

Table 2. Risk factors evaluated by the simple risk assessment tools used in this study

Evaluation tools / Variable	Force	Posture	Duration	Frequency	Load handling	Psychosocial	Operator feeling	Others ^a
OSHA checklist	x	x	x					x
Ergonomic criticality	x	x	x		x		x	x
QEC	x	x		x	x	x	x	x
RULA	x	x						
REBA	x	x						
EAWS	x	x	x	x	x			x
Revised NIOSH equation		x	x	x	x			x
MAC		x	x		x			x

^aOther factors: Gripping, distance carried, precision of activity, nature of the task, working environment, cycle time.

Table 3. Codification of interpretation scales (three levels system rating) for comparison of results between different tools

Simple tools	Interpretation scale provided by tool developer	Codification across three levels		
		Low risk (1)	Moderate risk (2)	High risk (3)
	< 3: no risk.			
OSHA checklist	< 5: no presumed risk.	< 5	≥ 5 and ≤ 9	> 9
	≥ 5: significant risk, occupational medicine must act promptly			
	> 9: very high risk and immediate action is required			
	Between 30 and 90 roles are considered low risk			
CE	Between 90 and 112 roles are considered moderately risky	< 90	≥ 90 and < 112	≥ 112
	> 112 roles are considered high risk			
	<40%: Acceptable level			
QEC	40-49%: Practicable action	<49%	≥49 and ≤69%	≥70%
	49-69%: timely action required			
	>70%: Immediate action required			
	1 and 2 = Acceptable			
RULA	3 and 4 = Investigate further	≥1 and ≤4	≥5 and ≤6	≥7
	5 and 6 = Investigate further and change soon			
	7 = Investigate and change immediately			
	1 = Negligible risk			
REBA	2 or 3 = Low risk, take action on confirmation			
	4 to 7 = Moderate risk, action required	≥1 and ≤3	≥4 and ≤7	≥8 and ≤15
	8 to 10 = High risk, short-term action required			
	11 to 15 = Very high risk, immediate action required			
EAWS ^a	0-25 points: Low risk, no action required			
	25-50 points: Potential risk, further investigation needed to evaluate risk.	0-25 points	25-50 points	>50 points
	>50 points: High risk, risk reduction action required			
Revised NIOSH equation	< 1 = acceptable handling			
	>1 = Chronic risk	≤1	>1 and ≤3	>3
	>3 = Acute risk			
MAC	<7: Low risk: Examine any of the constituent parts of the activity to reduce risk			
	Between 7 and 11: Moderate risk: examine the risk situations and minimize the degree	<7	≥7 and <11	>11
	>11: High risk: analyze all high-risk situations and lessen the degree			

^aUpper limb score of EAWS tool was excluded from the analysis.

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3 Table 4: The cutoff point for assigning the SOL score for each component. The cutoff
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5 point was determined based on the distribution of scores in three groups of the same
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Components	Maximum score	Low score	Moderate scores	High scores
Work strategy (12 indicators)	36	≤ 20	= 21	≥ 22
Effects on performance (3 indicators)	9	≤ 5	= 6	≥ 7
Effects on health (4 indicators)	12	≤ 5	≥ 6 and < 11	≥ 11

Table 5. The results of eight simple MSDs risk assessment tools for each workstation

Workstation	Reference situation	Simple observational tools ^a						Manual material handling tools			
		OSHA	CE	QEC	RULA	REBA	EAWS	Final score of workstation mean(±SD)	NIOSH	MAC	Final score of workstation mean(±SD)
Connecting rod finishing	Unscrewing connecting rods	3	1	2	3	3	3	2.5 (0.7)	2	2	2 (0)
Connecting rod drafting	Connecting rod drilling	3	1	2	3	3	2	2.3 (0.7)	2	2	2 (0)
Pre-paintwork covering ^b	Roll top motor covering	3	1	2	2	3	2	2.2 (0.6)	1	1	1 (0)
Final engine assembly line	Attaching engine to overhead conveyor	3	2	2	2	3	2	2.3 (0.4)	1	2	1.5 (0.5)
Engine wiring unit assembly	Top end fitting and connecting	3	2	3	3	3	3	2.8 (0.3)	1	2	1.5 (0.5)
Engine injector kit preparation	Injector assembly	2	1	2	1	2	2	1.7 (0.4)	1	1	1 (0)
Manifold / turbo assembly preparation	Installation of turbo onto manifold	3	3	3	3	3	3	3 (0)	1	2	1.5 (0.5)
Fixtures / equipment pre-testing ^b	Equipping engine flywheel pre-testing	3	1	2	2	2	2	2 (0.3)	1	1	1 (0)
Preparation of small parts orders ^b	Packaging of a small part	2	1	2	1	2	1	1.5 (0.5)	1	1	1 (0)
Fixtures packaging ^b	Fixtures bagging	3	1	3	1	2	1	1.8 (0.8)	1	1	1 (0)
Final cores for ten workstations mean(±SD)		2.8 (0.3)	1.4 (0.6)	2.3 (0.4)	2.1 (0.7)	2.6 (0.5)	2.1 (0.5)	-	1.2 (0.3)	1.5 (0.5)	-

^aInterpretation scale: 1-low risk; 2-moderate risk; 3-high risk.

^bNo manual material handling tasks (designated low risk)

Table 6. Semi-quantitative assessment by SOL indicators for the reference situation of ten workstations

Workstation	Reference situation	Score work strategy process ^a	Score direct effect on performance ^b	Score of direct effect on health ^c	SOL adequacy of situation ^d
Connecting rod finishing	Unscrewing connecting rods	17 (Low)	3 (Low)	8 (Moderate)	Inadequate
Connecting rod drafting	Connecting rod drilling	26 (High)	6 (Moderate)	11(High)	Adequate
Pre-paintwork covering	Roll top motor covering	22 (High)	5 (Low)	11 (High)	Inadequate
Final engine assembly line	Attaching engine to overhead conveyor	20 (Low)	6 (Moderate)	6 (Moderate)	Potentially inadequate
Engine wiring unit assembly	Top end fitting and connecting	21(Moderate)	9 (High)	5 (Low)	Inadequate
Engine injector kit preparation	Injector assembly	16 (Low)	6 (Moderate)	4 (Low)	Inadequate
Manifold/turbo assembly preparation	Installation of turbo onto manifold	21(Moderate)	5 (Low)	11(High)	Inadequate
Fixtures/equipment pre-testing	Equipping engine flywheel pre-testing	22 (High)	6 (Moderate)	2 (Low)	Inadequate
Preparation of small parts orders	Packaging small parts	24 (High)	7 (High)	10 (Moderate)	Adequate
Fixtures packaging	Fixtures bagging	21 (Moderate)	5 (Low)	12 (Low)	Inadequate

^a1. Low scores ≤ 20 ; 2. Moderate scores between = 21 ; 3. High scores ≥ 22 (maximum score: 36 points).

^b1. Low scores ≤ 5 ; 2. Moderate scores between = 6 ; 3. High scores ≥ 7 (maximum score: 9 points).

^c1. Low scores ≤ 5 ; 2. Moderate scores between ≥ 6 and < 11 ; 3. High scores ≥ 11 (maximum score: 12 points).

^dSOL is inadequate if at least one column shows a low score; SOL is potentially inadequate if at least the scores of two columns are moderate; SOL is adequate if at least two columns show a high score.

Table 7. The qualitative examination of SOL indicators identified by the reconstruction of the human-centered activity model (Vézina 2001)

Work Stations	Reference situation	Work strategy process	Direct effects on performance	Direct effects on health	SOL adequacy ^a
Connecting rod finishing	Unscrewing connecting rods	<p>=> Negative:</p> <ul style="list-style-type: none"> - Lack of variation in the work strategy - Lack of assistance - Wide variation in work rhythm 	<p>=> Negative:</p> <ul style="list-style-type: none"> - Recurring delays in production - Negative representation of performance - Difficulty in adhering to the cycle time 	<p>=> Negative:</p> <ul style="list-style-type: none"> - Recurring shoulder/arm pain - Feeling of fatigue 	Inadequate
Connecting rod drafting	Connecting rod drilling	<p>=> Positive:</p> <ul style="list-style-type: none"> - Several strategies observed - Steady work rate - Assistance - Several resources for accomplishing the activity 	<p>=> Positive:</p> <ul style="list-style-type: none"> - No difficulty achieving the required performance - No delays - Adherence to productivity and quality 	<p>=> Positive:</p> <ul style="list-style-type: none"> - No health difficulties - No pain 	Adequate
Pre-paintwork covering	Roll top motor covering	<p>=> Positive:</p> <ul style="list-style-type: none"> - Several work strategies - Anticipations of actions - Steady work rate - Assistance, - The possibility of changing in the event of pain 	<p>=> Negative:</p> <ul style="list-style-type: none"> - Delay observed at the workstation during several cycle times with the same productions. Risk of forgetting the marouflage - Poor quality raised by the operator (marouflage tape) 	<p>=> Negative:</p> <ul style="list-style-type: none"> - Some recurring neck/shoulder pain - Fear of forgetting the marouflage, which causes stress 	Potentially inadequate
Final engine assembly line	Attaching engine to overhead conveyor	<p>=> Negative:</p> <ul style="list-style-type: none"> - Lack of variability in work strategy - Impossible to change (technique) - No possibility of changing in the event of pain - Wide variation in work pace 	<p>=> Positive:</p> <ul style="list-style-type: none"> - The risk of delay is frequent but compensated by the assistance - No quality problems 	<p>=> Negative:</p> <ul style="list-style-type: none"> - Shoulder/back pain - Severe fatigue - Recurring stress according to the operator (many production diversity increase risk of line blockage) 	Potentially inadequate
Engine wiring unit assembly	Top end fitting and connecting	<p>=> Positive:</p> <ul style="list-style-type: none"> - Several work strategies - Frequent help and change in the event of pain - Steady work pace (no speeding up/slowing down and individual time management) - Possibility of changing the order of tasks 	<p>=> Positive:</p> <ul style="list-style-type: none"> - Little return despite the risk of important errors - Recurring delays but very quickly caught up with significant assistance 	<p>=> Positive:</p> <ul style="list-style-type: none"> - No pain - No discomfort or stress about the situation 	Adequate
Engine injector kit preparation	Injector assembly	<p>=> Negative:</p> <ul style="list-style-type: none"> - Lack of variation in the work strategy - Little or no assistance - Impossibility of changing the order of tasks 	<p>=> Negative:</p> <ul style="list-style-type: none"> - Perception of work delays - Difficulty in following work pace - Recurring quality problems 	<p>=> Negative:</p> <ul style="list-style-type: none"> - Pain in several body regions (neck, shoulder, wrist, upper and lower back) related to this work situation - Stress linked to work pace 	Inadequate
Manifold/turbo assembly preparation	Installation of turbo onto manifold	<p>=> Positive:</p> <ul style="list-style-type: none"> - Several work strategies - Much assistance - Steady work pace (individual time management) - Possibility of changing the order of tasks 	<p>=> Negative:</p> <ul style="list-style-type: none"> - Some quality problems (missing clamping or missing piece) - Recurring delay according to production diversity 	<p>=> Positive:</p> <ul style="list-style-type: none"> - No pain - No stress - Perfect representation of health 	Potentially inadequate
Fixtures / equipment pre-testing	Equipping engine flywheel pre-testing	<p>=> Positive:</p> <ul style="list-style-type: none"> - Several work strategies - Steady work pace - Assistance - Possibility of changing in the event of pain - Possibility of changing the order of tasks 	<p>=> Positive:</p> <ul style="list-style-type: none"> - Slight delay compensated by the assistance - Productivity and quality by demand 	<p>=> Positive:</p> <ul style="list-style-type: none"> - Severe and recurring pain but not related to the actual occupation (pain without relation to the situation) - No stress - Special attention from management 	Adequate
Preparation of small parts orders	Packaging of a small part	<p>=> Positive:</p> <ul style="list-style-type: none"> - Several work strategies - Steady work pace (individual time management) - Significant assistance (possibility of working in pairs) - Possibility of changing the order of tasks - Possibility of changing in the event of pain 	<p>=> Positive:</p> <ul style="list-style-type: none"> - No order delay - Productivity by demand - A few quality problems (missing part) 	<p>=> Positive:</p> <ul style="list-style-type: none"> - Significant recurring pain (without relation to the work situation) - No stress and a positive representation of work condition 	Adequate
Fixtures packaging	Fixtures bagging	<p>=> Negative:</p> <ul style="list-style-type: none"> - Distinct lack of variability of work strategy - No assistance - Impossibility of anticipating or changing the order of tasks 	<p>=> Positive:</p> <ul style="list-style-type: none"> - Highly productive (more than prescribed targets) - No quality problems - A feeling of efficiency by operators 	<p>=> Negative:</p> <ul style="list-style-type: none"> - Severe pain and fatigue after the observed work situation - Pathogenic history associated with pain 	Potentially inadequate

^aIf three components are positive then SOL adequacy; if at least one component is negative then possible SOL inadequacy; if three components are negative then SOL inadequacy.

Table 8. Agreement/disagreement in the results of simple tools for evaluating MSDs risk and the exploration of SOL (situational operational leeway) indicators from qualitative data

Tools	Workstation finishing	Connecting rod drafting	Connecting rod drafting	Pre-paintwork covering	Final engine assembly line	Engine wiring unit assembly	Engine injector kit preparation	Manifold/turbo assembly preparation	Fixtures / equipment pre-testing	Preparation of small parts orders	Fixtures packaging	Agreement/disagreement between simple tools and SOL indicators		
												Tool = SOL	Tool < SOL	Tool > SOL
SOL ^a	3	1	2	2	1	3	2	1	1	2	-			
OSHA checklist ^b	3	3	3	3	3	3	2	3	3	2	3	10%	10%	80%
EC ^b	1	1	1	2	2	1	3	1	1	1	1	40%	60%	-
QEC ^b	2	2	2	2	2	3	2	3	2	2	3	20%	20%	60%
RULA ^b	3	3	2	2	3	1	3	2	1	1	1	40%	20%	40%
REBA ^b	3	3	3	3	3	3	2	3	2	2	2	20%	10%	70%
EAWS ^b	3	2	2	2	3	2	3	2	1	1	1	40%	20%	40%
NIOSH equation ^b	2	2	No handling	1	1	1	1	No handling	No handling	No handling	No handling	16%	67%	17%
MAC ^b	2	2	No handling	2	2	1	2	No handling	No handling	No handling	No handling	33.4%	33.3%	33.3%
Total average												27.4%	30%	42.6%

^aInterpretation scale for SOL: 1= Adequate; 2 = Potentially inadequate 3= Inadequate SOL.

^bInterpretation scale for simple tools: 1= Low risk; 2 = Moderate risk; 3= High risk.

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3 Figure 1. Human-centered model of work situations focused on the individuals and their
4 work activity (N. Vézina, 2001). This study focused on 19 indicators of situational
5 operational leeway.
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9 Figure 2. Reconstitution of the three components of SOL indicators for the reference
10 situation of “Connecting rod finishing” (model adapted from N.Vézina, 2001).
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14 Figure 3. Distribution of the number of workstations identified as low, moderate and
15 high-risk status by each simple risk assessment tools
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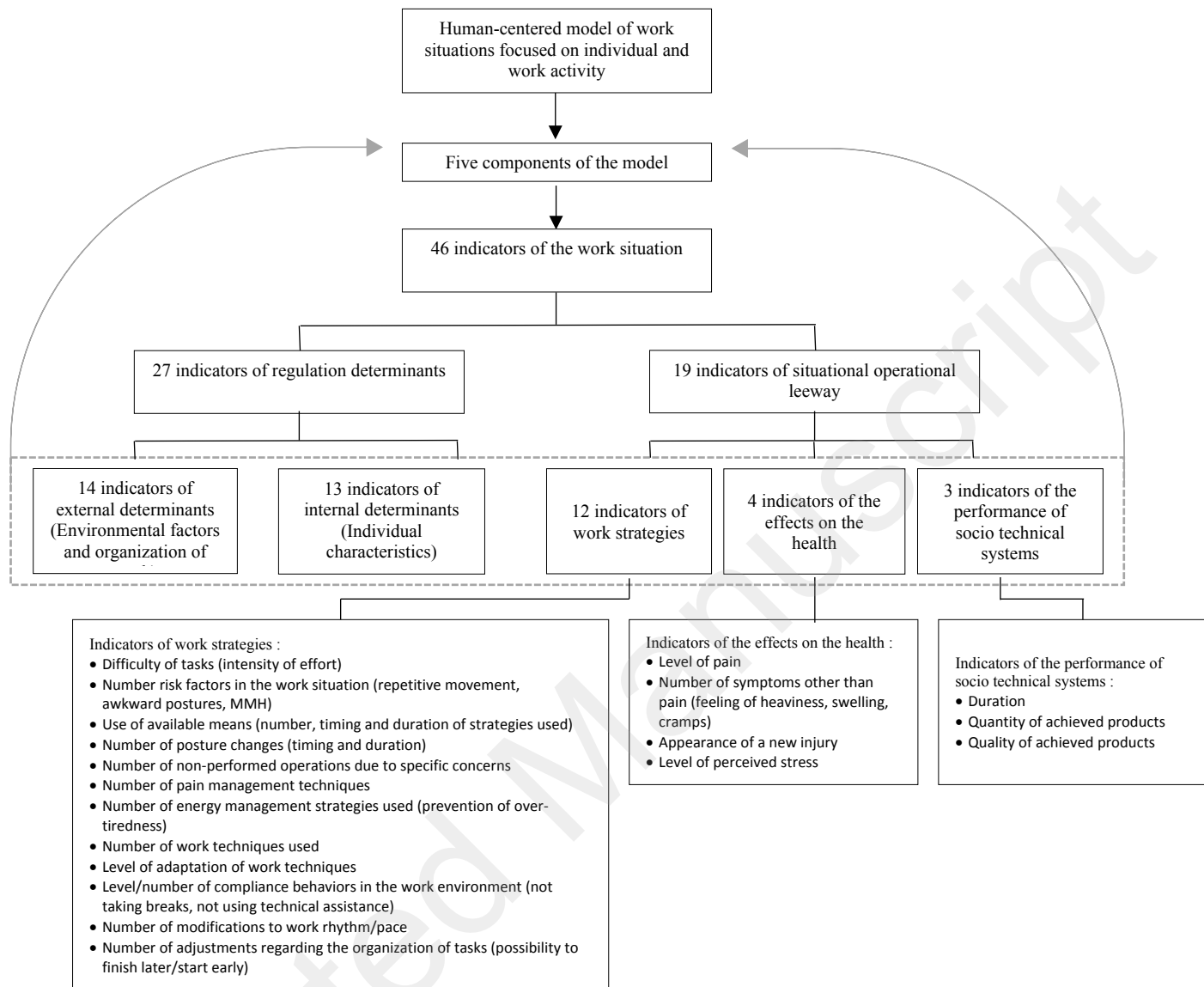
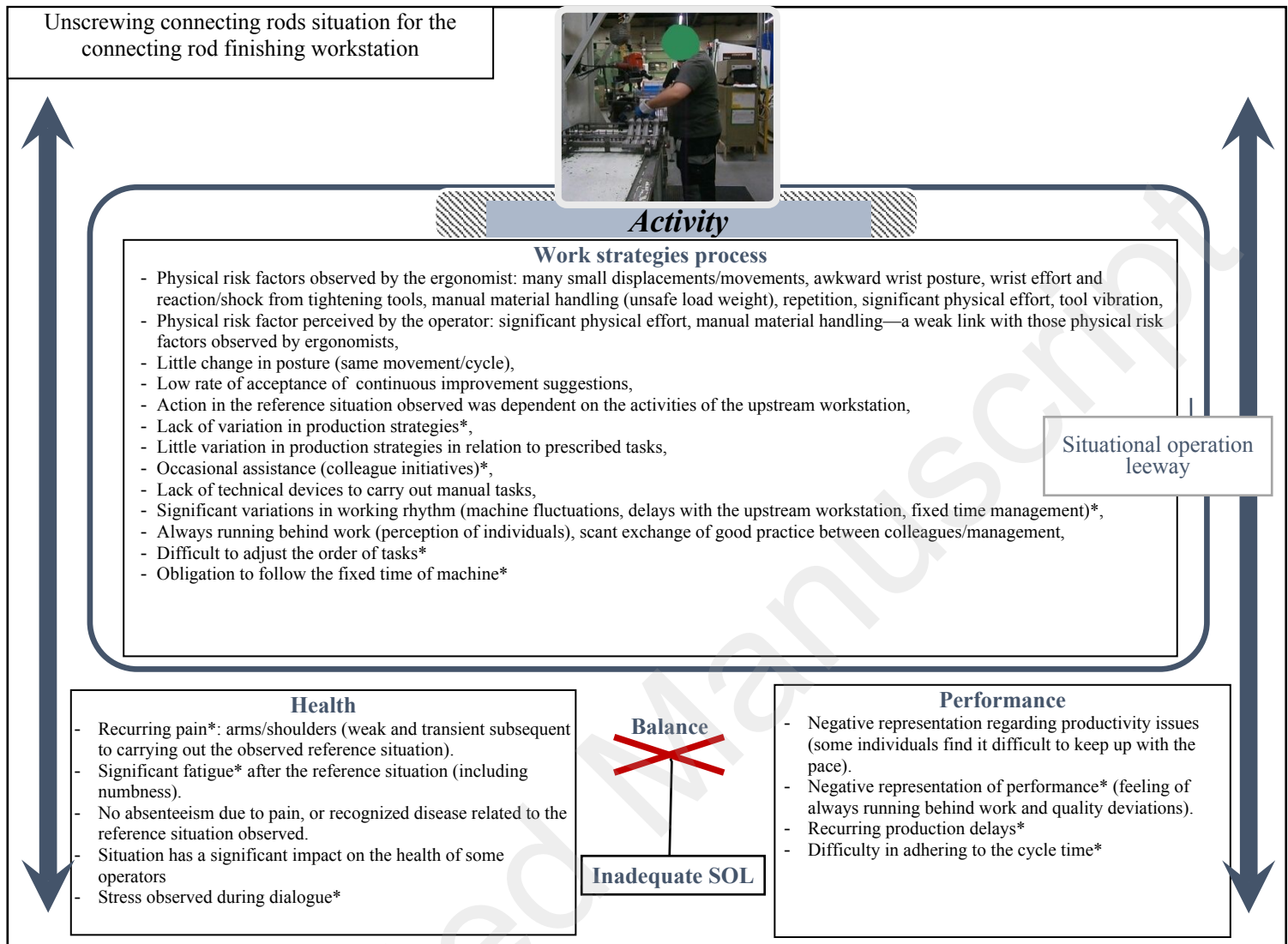


Figure 1. Human-centered model of work situations focused on the individuals and their work activity (N. Vézina, 2001). This study focused on 19 indicators of situational operational leeway.



*The indices used to define the adequacy of SOL for the 3 SOL components.

Figure 2. Reconstitution of the three components of SOL indicators for the reference situation of “Connecting rod finishing” (model adapted from N.Vézina, 2001).

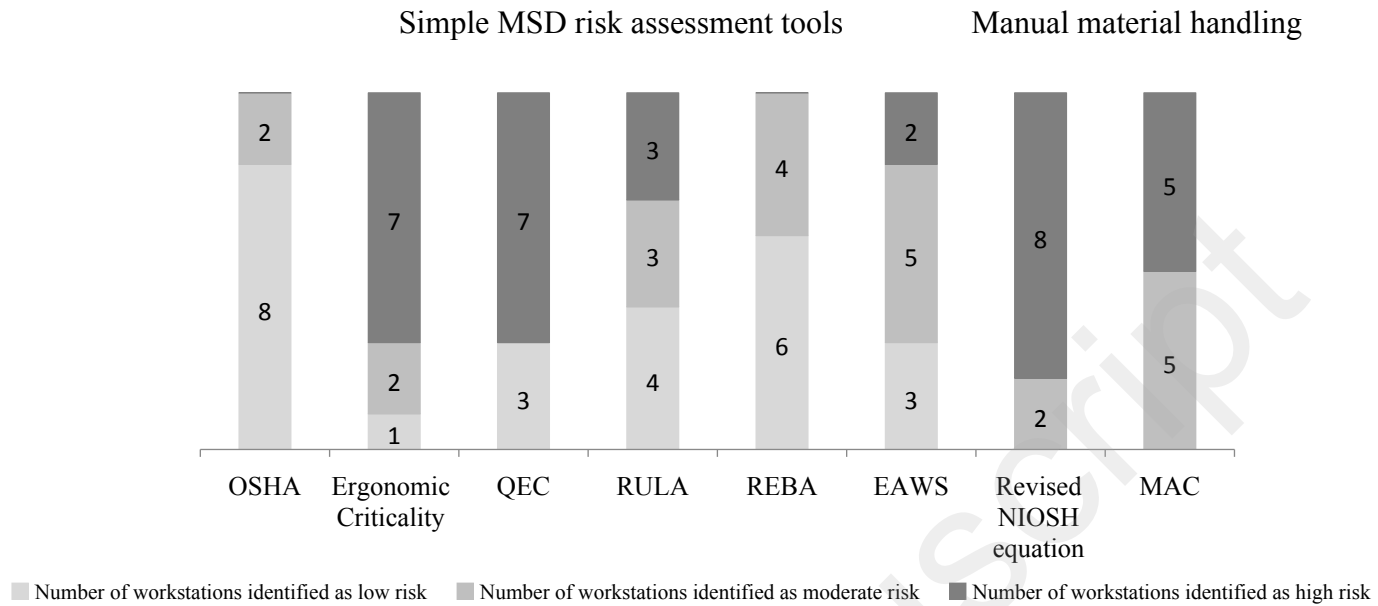
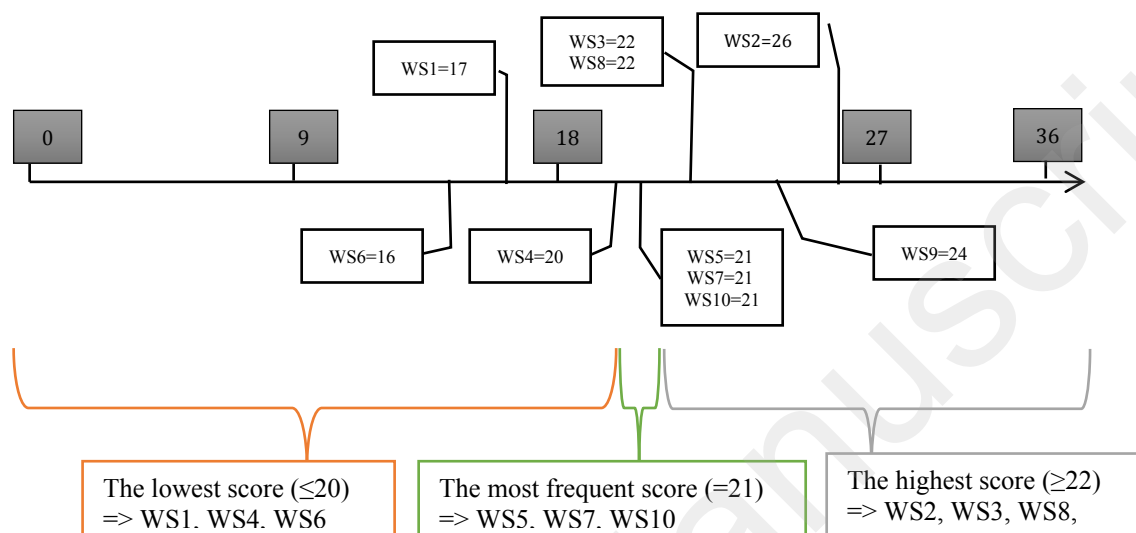


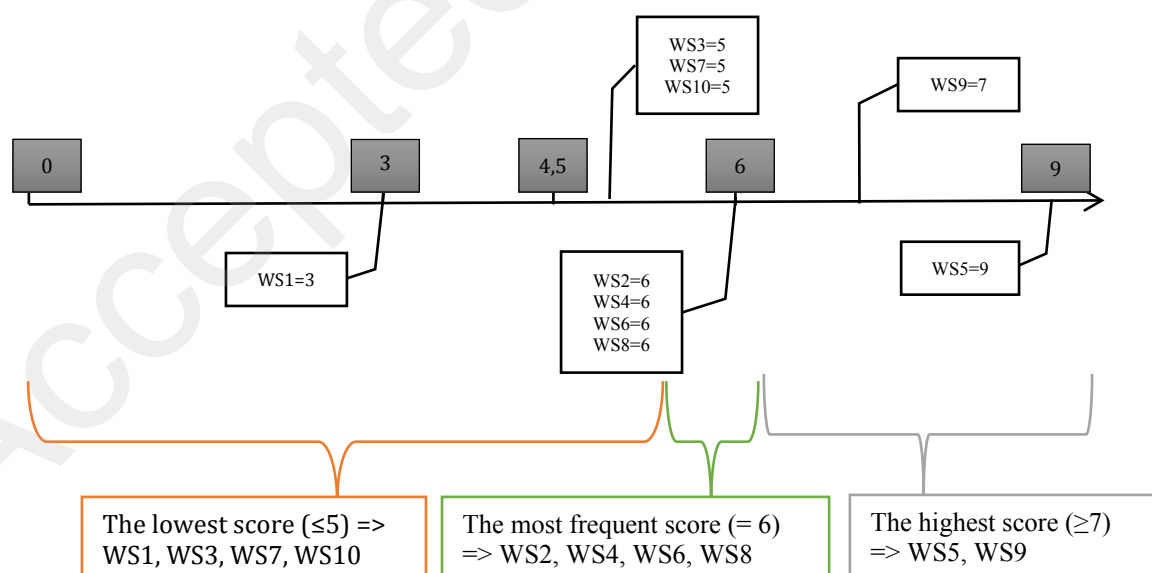
Figure 3. Distribution of the number of workstations identified as low, moderate and high-risk status by each simple risk assessment tools

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3 supplementary document:
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6 The distribution of scores for the work strategy component (12 indicators; WS: workstation)
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34 The distribution of scores for effect on performance component (3 indicators; WS: workstation)
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The distribution of scores for effect on health component (4 indicators; WS: workstation)

