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Review article

The Multitask General Exposure Index (MultiGEI): An original model for analysing biomechanical risk factors in multitask jobs featuring weekly, monthly and annual macro-cycles

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ABSTRACT

The assessment of exposure to biomechanical risk factors requires multiple different working risk factors to be considered and integrated in some way to determine overall exposure levels and risk. A particular challenge is posed when workers rotate between different tasks not only on a daily basis but over longer macro-cycles (which may be weekly, monthly, or even annual). There may be large numbers of rotated manual tasks, each with a different level of exposure and distribution pattern. This makes the multitask analysis more complex insofar as it must factor in multiple work activities over extended periods of time. This article presents a new general model specifically adapted to evaluating multiple tasks rotating over longer macro-cycles: the MultiGEI (**M**ultitask **G**eneral **E**xposure **I**ndex). The MultiGEI model uses similar criteria to current models to study daily rotations in tasks involving repetitive movements and exertions of the upper limbs (OCRA method) and manual lifting (the Revised NIOSH Lifting Equation or RNLE and Sequential Lifting Index). It can be applied to a variety of production and service sectors (agriculture, building construction, cleaning, retail, packaging, canteens, healthcare, etc.). It can also be applied to data obtained by other methods (other than OCRA and RNLE, here not presented) that specifically consider the relevant aspects of which tasks, their duration and their intrinsic risk score. The proposed approach is presented along with examples of applications, and advantages and limitations are discussed. A video showing examples of calculations carried out using free software, is also available.

1. Introduction

According to the European Agency for Safety and Health at Work (EU-OSHA European Agency for Safety and Health at Work, 2007), Work Related Musculo Skeletal Disorders (WMSDs) are mainly caused by working activities involving manual handling, heavy physical work, awkward postures, repetitive movements or exertions of the upper limbs, and vibrations. Moreover, the risk for WMSDs may increase in faster paced tasks, and in situations of low job satisfaction, highly demanding work and stress.

On the other hand, it is a well-known fact that for each of the above conditions (i.e. manual load handling, awkward postures, repetitive movements), which in general can be labelled as conditions of potential "biomechanical overload", multiple working risk factors must be considered from an integrated perspective, and organizational factors (i.e. pace, duration of exposure, breaks, task rotation, etc.) play a fundamental role in determining overall exposure levels.

A recent report published by the same European Agency (EU-OSHA, 2019), indicates that WMSDs are still the most common work-related health problem in the European Union. Roughly three out of every five workers in the EU report WMSD complaints and the most common are backache (overall prevalence = 46%) and muscular pains in the upper limbs (overall prevalence = 43%).

The same report indicates that 32% of all European workers (about

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2/3rds men and 1/3rds women) spend at least 25% of their working time performing manual load handling activities. About 43% of the labor force is exposed (without significant gender differences) to awkward postures during at least 25% of their working time, and about 61% of European workers perform repetitive movements of the upper limbs for almost 25% of their working time whilst about 30% are in the same conditions for most of their working time.

Considering that "Risk (or Exposure) Assessment" is the pillar of any preventive strategy, the dimension of the reported values suggests the urgency of adopting models for evaluating exposure to different conditions of biomechanical overload especially when these conditions vary over time.

Manual workers may in fact be required, for a certain period of time, to perform a variety of different tasks on a rotating basis. In such cases, an analysis of the worker's exposure to biomechanical overload conditions (manual handling of loads, repetitive movements of the upper limbs, awkward working postures) must take into account the contribution of the various rotating tasks also in relation to the duration of each task within a specific period. This is what we call a "Multitask analysis".

In most sectors of industry, workers generally rotate between manual tasks the same way every day and therefore the Multitask analysis may be applied to just one representative working shift.

Conversely, in certain manufacturing environments (e.g. maintenance work or situations where one day per week might be very different from the rest of the week) and in other production sectors (such as building construction, agriculture, commercial cleaning, retail, seasonal food packaging, canteens, healthcare, and so on), manual tasks may be rotated not only on a daily basis but over longer macro-cycles (the most common being weekly, monthly, or annual), and there may be dozens or even hundreds of rotated manual tasks, each with a different level of exposure and distribution pattern. This naturally makes the multitask analysis all the more complex insofar as it must factor in multiple work activities over extended periods of time.

Recommendations for analysing multiple manual tasks with daily rotations can be found in the literature and in ISO standards; in particular for lifting tasks, as an extension of the Revised NIOSH Lifting Equation (RNLE) (Waters et al., 1994; Waters et al., 2007; Colombini et al., 2013; ISO, 2014; Waters et al., 2016; Garg and Kapellusch, 2016). For tasks characterized by repetitive movements of the upper limbs, the assessment methods that offer recommendations for analysing multiple tasks would include the OCRA method and, in particular, the OCRA Checklist (Occhipinti et al., 2009; ISO, 2014; Colombini and Occhipinti, 2017), the Revised Strain Index method (Garg et al. 2017a, 2017b), the Upper Limb Localized Fatigue Threshold TLV (ACGIH, 2016) and the HAL TLV (ACGIH, 2018). A somewhat different approach is provided by the application of Fatigue Failure (Gallagher and Schall, 2016; Gallagher et al., 2017).

Some of the methods currently employ average, time-weighted average or peak exposures (e.g., TLV for HAL and the Upper Limb Localized Fatigue TLV) to assess exposure variables and risk. Others (RNLE, OCRA method, Revised Strain Index) utilize a so-called *incremental approach* where the individual task (or subtask) generating the highest overload (peak task), according its actual duration or frequency, is taken as the minimum, to which is added the contribution of all the other tasks in relation to their intensity and duration or frequency.

Time Weighted Average approaches may result in exposure misclassification particularly for long, irregular or variable cycles (Dempsey, 1999; Garg and Kapellusch, 2016; Garg et al., 2017b).

However, there is still a small number of authors (Colombini and Occhipinti, 2017) who propose solutions for multitask analysis when rotations take place over longer macro-cycles (e.g. weeks, months or years).

Considering this background, the aim of this paper is to start from the existing proposals for Multitask analyses on a daily basis (mainly using the *incremental approach*) and to define procedures and criteria for conducting a Multitask analysis of manual tasks featuring complex macro-cycles presenting potential biomechanical overload conditions: this paper proposes and discusses the MultiGEI - **M**ultitask **G**eneral **E**xposure **I**ndex, a new and original model, specifically adapted to the aforesaid purpose.

In order to facilitate the reader's comprehension, Table 1 provides a short list of terminology used in this paper.

2. Analysis of daily rotations when performing repetitive and manual lifting tasks and the derived new approach for rotations over periods longer than a day: *the "Multitask General Exposure Index" (MultiGEI)*

2.1. Summary of the daily rotation approach

For studying upper limb repetitive movements, reference is made here to the OCRA method (Colombini et al., 1998, 2001, 2002, 2017, Occhipinti, 1998), and in particular the OCRA Checklist (Colombini and Occhipinti, 2017).

The OCRA method for assessing risk associated with repetitive movements of the upper limbs consists of two tools, the OCRA Checklist (OCRAck) and the OCRA Index. The tools feature different analytical details and purposes, although both are inspired by the same conceptual model. OCRAck is the simpler method used for the initial screening of workstations (ISO, 2014); the OCRA Index is more complex and was chosen as the reference risk assessment method by international standards relating to high-frequency repetitive manual work (ISO, 2007b).

Table 1
Brief list of terminology used in the paper.

BIOMECHANICAL OVERLOAD: a condition where a load that can be considered "excessive" is applied to parts of the human motor system (muscles, tendons, cartilage, intervertebral discs, etc.). In working contexts, the condition could be determined by the manual handling of loads; repetitive movements and exertions of the upper limbs; whole body awkward postures; vibrations; etc.

HOMOGENEOUS GROUP: a group of workers performing the same tasks, in the same workplace and with similar durations (or time patterns) during a specific period (macro-cycle). The group is homogeneous for exposure to similar working conditions and not for other factors such as weight, age, culture, gender, etc.

INTRINSIC EXPOSURE VALUE: the exposure value for an individual task, considering that task (only theoretically) as the only one performed by the worker all the time (i.e. for the whole shift). When computing the intrinsic OCRA Checklist Score, reference is made to a shift scenario featuring 430/480 net minutes of repetitive work and 3 breaks (one 30-min meal break and two additional 10-min breaks). When computing the intrinsic LI (or CLI; VLI) for lifting tasks, reference is made to a "long duration" scenario (more than 2 and up to 8 h of consecutive manual lifting in the shift).

NET DURATION OF REPETITIVE TASK: in a work shift, the net duration of the repetitive and/or manual lifting task/s is obtained by subtracting the actual duration of the breaks and the time dedicated to other short (less than 60-min) secondary activities from the total duration of the shift (cleaning, occasional supplies, changing clothes, etc.). The exposure risk is calculated based on the net time. It is emphasized that in multitask risk assessments the net repetitive work time is also extended to tasks involving manual handling, which are also to be considered as repetitive tasks of the upper limbs (lifting with them!), in addition to manual lifting, which instead causes overload of the spine.

MACRO-CYCLE: the period of time during which all the rotating tasks assigned to a worker are completed and a new (similar) macro-cycle starts again. A macro-cycle typically lasts more than one day and usually macro-cycles of a week, a month or a year are considered.

ARTIFICIAL WORKING DAY REPRESENTATIVE OF A MACRO-CYCLE: the transformation of a macro-cycle (whatever its duration) into an artificial day, which, through the use of constants, becomes representative of the macro-cycle itself. It is an artificial daily shift (not a literal shift) where all the manual tasks performed by the homogeneous group are considered with their respective durations (in minutes) estimated on the basis of the proportion of time over which the tasks are distributed in the macro-cycle. Its purpose is to not represent the literal duration of the shift but the nature of the risk of the macro-cycle.

TIME CONSTANT: a reference duration scenario (i.e.: 8 h/day or 5 days/week) used to adjust to a standard condition the proportional duration of tasks in the macro-cycle so as to consequently estimate the duration of tasks in the *artificial representative working day.*

Both tools show a significant association between exposure levels and the overall prevalence of UL-WMSDs in exposed working populations (Occhipinti and Colombini, 2004, 2007; Colombini and Occhipinti, 2017). Moreover, the OCRAck interrater reliability scores are among the highest reported in the literature for semi-quantitative physical exposure assessment tools of the upper extremity (Paulsen et al., 2015).

The OCRA Checklist (OCRAck) consists of five parts that focus on the four main risk factors (frequency, force, awkward posture/stereotyped movement, lack of recovery periods) and a number of additional risk factors (vibrations, low temperatures, precision work, repeated impacts, etc.). It also factors the net duration of repetitive jobs into the final estimate of risk. The classic analysis proposed by OCRAck entails using pre-assigned scores (the higher the score, the higher the risk factor) to define the level of exposure associated with each of the aforementioned factors. The sum and product of the partial values generate a final score that estimates one of four exposure levels (green, yellow, red, purple). The calculation procedure for reaching the final result (one for each upper limb), proposed in Fig. 1, shows how all the risk factors and the relative scores are included: the *lack of recovery period* factor is a multiplier (*Recovery Multiplier*), along with the *duration* factor (and its *Duration Multiplier*), to be applied to the sum of the scores for the other risk factors.

One OCRAck is used to describe a workstation and estimate the exposure level embedded in the task, as if this task was the only one performed by a single worker for the entire duration of the shift.

When two or more repetitive tasks are rotated, OCRAck should be used to estimate the overall level of exposure associated with the combination of rotating tasks; the length of time during which the individual rotated tasks are performed must be known.

For the study of daily multitask exposures using OCRAck, two mathematical models (Colombini and Occhipinti, 2017) have been proposed: *the Time-Weighted Average model (CkTWA*) and the *Multitask Complex model (CkMC)*.

The *Time-Weighted Average model* (Ck *TWA*) typically involves weighting the final individual checklist scores for the different tasks under examination, based on the total duration of repetitive tasks in the shift and their corresponding specific duration (expressed in time fractions). This approach and calculation model could be used when the task rotation rate is fairly high, for instance once every 90 min or less (Occhipinti et al., 2009; ISO, 2014). This approach is recommended when different products (or different versions of the same product) are processed at the same workstation during the shift (as happens for instance in the production of cars, domestic appliances, remote controls, etc.). In such cases, it can be assumed that higher exposure is somewhat offset by lower exposure, with the worker alternating between the two within a relatively short time frame.

The *Multitask Complex model* (*CkMC*) is an incremental model based on the concept of taking the task generating the highest overload (peak task), according to its effective continuous duration, as the minimum, to which is added the contribution of the other tasks in relation to their intensity and duration. With this approach, the final result will be, at the very least, no less than the highest OCRAck score calculated using its actual duration and no higher than the score for the same task calculated considering the overall duration of all the rotating repetitive tasks present in the shift. This model should be used when the repetitive task is rotated more than once every 90 min (Occhipinti et al., 2009; ISO, 2014; Colombini and Occhipinti, 2017).

To better understand the meaning of the two proposed approaches (*CkMC* and *CkTWA*) here is a simple example: in an 8-h exposure, two repetitive tasks, one "light" and the other "more tiring" and each lasting 4 h are present: the worker benefits by rotating between the two tasks every hour (in the case use of the *CkTWA* calculation model). However, if four continuous hours are spent in the morning on light work and 4 h are spent in the afternoon on heavy work, the condition will certainly be more tiring: in this case it is preferable to use the Multitask Complex model (*CkMC*). In this last case the final exposure level will be higher than if the worker rotates every hour.

If all the rotating tasks have similar scores, the final results of the *CkTWA* and *CkMC* models will be comparable.

For the study of manual lifting tasks, reference is made here to the Revised NIOSH Lifting Equation - RNLE (Waters et al., 1993) and its extensions, as published and embedded in international standards (Waters et al., 1994; Waters et al., 2007; Colombini et al., 2013; ISO, 2014; Waters et al., 2016).

In the study of manual lifting activities, four types of lifting tasks and relevant turnover can be operationally identified (Colombini et al., 2013; ISO, 2014): Table 2 lists the respective definitions and features.

For the study of daily multitask exposure, reference should be made to the *Sequential Lifting Index (**SLI**)* approach, which was specifically developed for analysing manual lifting tasks when a daily shift includes several different lifting tasks (Mono and/or Composite and/or Variable), each performed continuously for at least 30 min (Waters et al., 2007; Colombini et al., 2013; ISO, 2014).

The *Sequential Lifting Index (**SLI**)* approach is a typical incremental approach similar to the *Checklist Multitask Complex model (CkMC)*; it offers the advantage, with respect to other extensions of the RNLE, of

Table - 2
Different types of lifting tasks and approaches of the RNLE and its extensions.

MONO (SINGLE) TASK: this task involves lifting objects generally of the same type and weight, with no changes in the parameters of the equation. In this case, the *classic Monotask Lifting Index (MLI)* (Waters et al., 1993, 1994) calculation method can be used.

COMPOSITE TASK: this task involves lifting objects generally of the same type and weight but with different "geometries". In this case, the "Composite Lifting Index (CLI)" (Waters et al., 1994) can be computed following the specific procedure.

VARIABLE TASK: this refers to lifting/lowering objects of different weights and/or "geometries" (vertical heights, horizontal distances) within the same time period of the shift. In this case the "Variable Lifting Index (VLI)" is the calculation methodology to be used (Colombini et al., 2013; Waters et al., 2016).

SEQUENTIAL TASK: this is when a daily shift includes several different lifting tasks (Mono, Composite or Variable), each performed continuously for at least 30 min. In this case, where there is a real rotation between different lifting tasks, the "Sequential Lifting Index (SLI)" (Waters et al., 2007; Colombini et al., 2013*)* is the approach to be used.

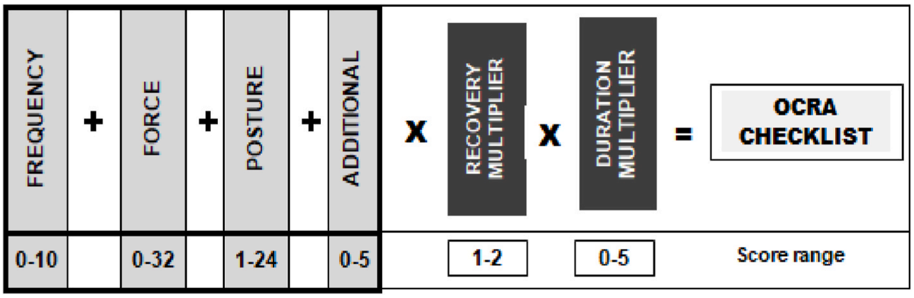


Fig. 1. OCRA Checklist: final score calculation.

considering the duration of each rotating task, and lends itself – suitably adapted – to forming the basis for analysing multi-day rotating lifting tasks.

2.2. The derived new approach: the "Multitask General Exposure Index (MultiGEI) for rotations over periods longer than a day

The two incremental approaches briefly presented above (the *OCRA Checklist Multitask Complex* and *Sequential Lifting Index)* are here summarized in a more general model and formula, called the *"Multitask General Exposure Index"* (***MultiGEI***). In a multitask analysis of macro-cycles, it offers the possibility to calculate any exposure index (EI) using data and tools for analysing the various aspects of biomechanical overload, as suggested in the literature or in international standards (awkward postures, manual load handling including pushing and pulling, repetitive movements of the upper limbs), provided that they specifically consider duration and time, which are essential for applying the MultiGEI model.

Multitask General Exposure Index (MultiGEI) formula:

$$\text{MultiGEI} = \text{EIeff1} + (\Delta\text{EI1} \ \text{x} \ \text{KEI}) \quad [1]$$

where:

MultiGEI: is the final value of the **M**ultitask **G**eneral **E**xposure **I**ndex for studying multiple rotating manual tasks;

EI $_{\text{eff1}}$: is the score for task$_1$ (the highest score task) calculated considering Dm$_1$ *(Duration Multiplier* according to its *actual duration* in the artificial working day representative of the macro-cycle);

EI $_{\text{max1}}$: is the score for task$_1$ (the highest score task) calculated considering Dm$_{\text{tot}}$ (*Duration Multiplier* for the *total duration* of all relevant tasks in the artificial working day representative of the macro-cycle);

$$\mathbf{\Delta EI}_{\mathbf{1}} = \text{EI}_{\text{max1}} - \text{EI}_{\text{eff1}}$$

$$\mathbf{KEI} = [(\text{EImax} \ 2 \ \text{x} \ \text{TF2}) + \ldots.(\text{EImax} \ j \ \text{x} \ \text{TFj})\ldots\ldots + (\text{EImax} \ n \ \text{x} \ \text{TFn})] / \ \text{EI} \ \text{max} \ 1 \quad [1a]$$

where:

1,2,3 … j …, n: is a connotation of the tasks listed, according to their individual actual score (EI$_{\text{eff}}$), with task$_1$ being the task with the highest EI$_{\text{eff}}$ score and task$_n$ the task with the lowest EI$_{\text{eff}}$ score;

EI$_{\text{max j}}$: is the score of task j calculated considering Dm$_{\text{tot}}$ (*Duration Multiplier* for the *total duration* of all relevant tasks in the representative artificial working day;

TF$_{\text{j}}$: is the time fraction (between 0 and 1) of task j with respect to the total working time minus the working time devoted to task$_1$ in the artificial working day representative of the macro-cycle.

In the **MultiGEI** formula the main assumption is that, as in the *OCRA Checklist Multitask Complex* and *Sequential Lifting Index*, the final exposure value will be between the value for the most overloading task (peak task), estimated for its effective duration (**EI $_{\text{eff1}}$**), and the maximum value of the same task (**EI $_{\text{max1}}$**), estimated as if it, alone, lasted the whole period.

K$_{\text{EI}}$ is a "weighting" factor of the difference between **EI $_{\text{max1}}$** and **EI $_{\text{eff1}}$**: it is the ratio between the time-weighted average of the **EI$_{\text{max}}$** scores of all the "other" tasks (except the first one) and **EI $_{\text{max1}}$**, and is used to estimate how much of that difference (**ΔEI $_{\mathbf{1}}$)** should be considered, in the incremental model, to increase the initial value of **EI $_{\text{eff1}}$**. If the "other" tasks have, basically, low scores, the increase will be low; if, on the contrary, the "other" tasks have high scores, the increase will be more significant.

It should be noted that in the **MultiGEI** formula, once the peak task has been identified (task$_1$), it is not strictly necessary to sort the "other" tasks by their respective values: this kind of sorting is suggested only for clarity when processing the results and is not compulsory, as in other referenced incremental models (Waters et al., 1994, 2016; Garg et al., 2016). The way **K$_{\text{EI}}$** is computed facilitates assessing the contribution of several rotating tasks in the general model of multitask analysis of macro-cycles.

It should also be noted that in the general model for computing **MultiGEI**, the formula for calculating **K$_{\text{EI}}$** [1a] has been slightly modified with respect to previous proposals in the literature (Waters et al., 2007; Colombini et al., 2013; Colombini and Occhipinti, 2017). The updated procedure is now aimed at avoiding the undue contribution of task$_1$ (the one with the highest score) in determining the value of **K$_{\text{EI}}$.**

In the present paper, the MultiGEI approach to multitask macro-cycle analysis will be utilized, but, only for tasks with repetitive movements, the TWA approach will also be used only for comparing the different results obtained by the two different methodological approaches proposed for daily rotations.

2.3. The duration multipliers

In all multitask analysis models the use of appropriate *Duration Multipliers* is extremely important.

Table 3 shows the OCRAck *Duration Multipliers* (Colombini and Occhipinti, 2017) to be used as a function of both the overall duration (in minutes) of all the repetitive tasks (sum duration of each repetitive task present in the shift and included in the rotation) and of the actual duration of each individual task. The Multipliers shown in Table 3 are sufficiently reliable and well established for durations between 30 and 480 min (the most common in daily rotations). Multipliers for durations of less than 30 min or over 480 min have been determined by the following equation:

$$\text{Dm} = (\text{Min x } 0.008) + (-\ 2.547 \times 10–5 \text{ x Min2}) + (2.875 \times 10–8 \text{ x Min3})[3]$$

Where:

Dm = Duration Multiplier;
Min = Minutes

A very similar approach for considering the daily duration of repetitive tasks (and corresponding Duration Multipliers) has been proposed by the authors of the Revised Strain Index - RSI (Garg et al., 2017a).

In Fig. 2 the relationship between the *Duration Multiplier* in the OCRA Checklist and the RSI methods and the duration of the task in the shift is reported in graphic form.

The two approaches are referred to here because they are significant for considering duration (and duration multipliers) in the subsequent proposals for the study of task rotations in longer macro-cycles. Despite there being a major discrepancy between the OCRA and RSI Duration Multipliers beyond 480 min, it should be noted that, for the most common repetitive task daily durations (between 100 and 450 min) they are very similar and could be used interchangeably in the general approach for studying rotating manual tasks in longer macro-cycles. In this paper, for practical reasons, reference will be made to the *Duration Multipliers* of the OCRA Checklist method reported in Table 3.

3. Rotations over periods longer than a day: the macro cycle (e.g. weekly, monthly, yearly)

3.1. General procedure

After dealing with daily task rotations, in order to apply the MultiGEI approach, the next step is to define a set of procedures and criteria for estimating exposure in more complex situations, where workers rotate several manual tasks that have different levels of exposure and are

Table 3
OCRA Checklist *Duration Multipliers* (OCRA Dm) as a function of the duration of repetitive tasks in the shift (Colombini and Occhipinti, 2017).

Net Duration of repetitive task (minutes)	*< 1.9*	*1.9–3.6*	*3.7–7.4*	*7.5–14*	*15–29*	*30–59*	*60–120*	*121–180*	*181–240*	*241–300*	*301–360*	*361–420*	*421–480*	*481–540*	*541–600*	*601–660*	*661–720*
Central value (minutes)	1.5	2.8	5.5	10.7	22.5	40	90	150	210	270	330	390	450	510	570	630	690
Duration Multiplier	**0.007**	**0.018**	**0.05**	**0.1**	**0.2**	**0.35**	**0.5**	**0.65**	**0.75**	**0.85**	**0.925**	**0.95**	**1**	**1.2**	**1.5**	**2**	**2.8**

variously distributed, in qualitative and quantitative terms, over periods longer than a day (macro-cycles of different durations). In this case an organizational analysis becomes even more relevant.

The key elements and fundamental steps of this procedure are listed in the diagram in Fig. 3. Methodological details about each of these steps are provided further below; a step by step example will illustrate how to apply the procedure.

3.2. Identification of the rotation period (macro-cycle)

The first step is to define the period, i.e. the *macro-cycle* during which all the significant tasks in the analysis are rotated.

The types of macro-cycle durations may well be nearly infinite, but, for practical purposes, the suggestion is to use the pre-defined *macro-cycle periods of a week, a month, or a year* as a modal representation of the different real macro-cycle durations.

The modal macro-cycle periods appear to be, at least in the sectors of agriculture, building construction and services, accurately representative of job cycles. In agriculture, task rotations are typically annual, but one can use annual cycles even when multiple cycles of fewer months in each year are repeated identically (e.g. multiple harvests per year of the same product). In the construction sector there is generally a yearly cycle for large construction sites, but a monthly cycle (modal) is more frequent in smaller-scale constructions and civil renovation projects. In other sectors (such as logistics for retail chains, cleaning services, food preparation facilities), the most common rotation scenario is monthly, while in yet other situations (supermarkets, for instance) tasks may be rotated on a weekly or occasionally monthly basis.

In summary, some practical suggestions are provided here for using the pre-defined macro-cycle (*weekly, monthly, yearly)*, thus certainly simplifying subsequent evaluations:

- if several identical sub-macro-cycles are repeated over the year, use the annual macro-cycle;
- if several identical sub-macro-cycles (week, fortnight, etc.) are repeated within the month and if the following months are similarly repeated, use the monthly macro-cycle.

Whichever macro-cycle duration is chosen, the criteria and procedures for dealing with the biomechanical overload analysis are the same.

3.3. Identification of the homogeneous group of workers and the manual tasks they perform

Since the focus of the analysis is on the exposure of workers to a set of conditions determined by the tasks they are assigned to perform, it is necessary to identify which workers, who constitute a homogeneous group in terms of exposure, need to be examined. The homogeneous group of workers is the group that performs the same tasks, in the same workplace and for similar durations (or time patterns) during the selected period (macro-cycle). It should be noted that there are certain groups of workers who are homogeneous in terms of exposure to similar working conditions but not homogeneous for other factors such as weight, age, culture, gender, etc.

Note that a homogeneous group may sometimes be made up of just one person, if no other workers perform the same qualitative and quantitative tasks. Moreover, if two groups of workers perform the same tasks in the same workplace, but for different durations or time patterns (e.g. one group works full-time and the other works part-time), the two groups must be analysed separately.

It should also be noted that it is better to have a complete list of all the manual tasks performed in the same company, before attributing these tasks to one or more homogeneous groups of workers.

Fig. 4 shows an example of different homogeneous groups identified in the same company.

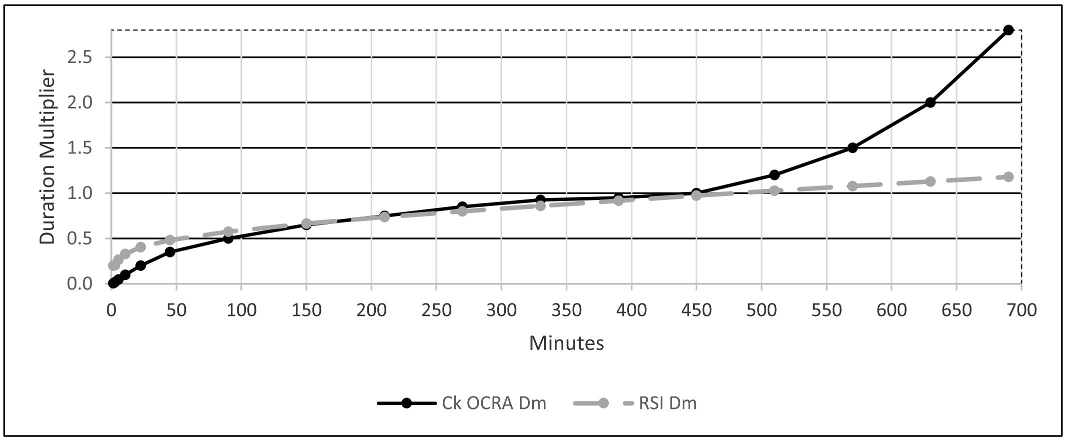


Fig. 2. *Duration Multipliers* as a function of the duration of repetitive tasks in the shift using the OCRA Checklist method (Colombini and Occhipinti, 2017) versus the Revised Strain Index method (Garg et al., 2017a).

3.4. Analysis of the duration and sequence of all manual tasks performed by each homogeneous group over the macro-cycle

This step involves assigning the tasks performed by the homogeneous group (or individual exposed workers) qualitatively and quantitatively. This part of the analysis is the most difficult since it is necessary to know how much time is spent during the macro-cycle (be it a week, month, year) in performing the different tasks. Extreme accuracy is not required when defining the proportional assignment of tasks (the employer, or even the members of the homogeneous group, should be able to provide this information). However, it should be considered that the level of accuracy greatly influences the final output of the procedure.

With the collected data the total number of hours worked by the homogeneous group on each task in the macro-cycle can be computed.

Starting from Fig. 5 and, step by step, in the following figures, an example of Multitask calculation over an annual macro-cycle is presented, relating only to homogeneous group nr.1, which will be completed up to the estimate of the final exposure level.

For this homogeneous group of workers, the first step is to know, month by month, how many hours are worked per month/per person, which, in the example, appears to be different (they do not work in February).

Considering the different tasks (Fig. 5, part a), it can also be noted that the same tasks are not performed qualitatively and quantitatively in the same way during all the months of the year, therefore the proportional duration differs (this kind of organization is typical, for example, in agriculture or building construction).

Fig. 5, part b reports the number of hours worked per task and per month: these data are obtained by applying the proportional task duration in the month to the total hours worked that month (see Fig. 5, part a).

In Fig. 5, part c the task duration in hours is adjusted using the percentage reduction (%Reduc) between the full shift duration and the net task duration for each month. The net worked hours in the year, for all tasks as a whole and for each individual task, are thus obtained. These data represent the basis of the exposure calculation in the annual macro-cycle, because they allow for the extrapolation of the corresponding *Duration Multipliers.*

Fig. 6 shows how this difference, here equal to 90%, is calculated (i.e. the net working time is 90% of the duration of the gross (whole) shift). Indeed, to complete the organizational data for the group, it is necessary to know how the shift is organized each month (i.e. the "modal" shift) in terms of the number of breaks, their duration, and the duration of non-repetitive (or secondary) work. This is needed in order to obtain: the net duration of the shift; the % reduction in the shift between net and gross duration (%Reduc); the number of hours without adequate recovery; and the consequent *Recovery Multiplier* per month and over the whole year (Fig. 6).

3.5. Analysis of typical biomechanical overload for each individual task: the intrinsic exposure value

All the manual tasks performed by the workers should be studied using the appropriate method for analysing the different biomechanical overload conditions (in the present paper, OCRAck for upper limb repetitive movements and RNLE for manual lifting) and to calculate the corresponding *intrinsic exposure value* for each task.

Calculating the *intrinsic exposure value* for a certain task means evaluating the task as if it is (theoretically) the only one performed by the worker all the time (i.e. for the whole shift and the whole macro-cycle).

When computing the intrinsic OCRA Checklist Score (Cki), reference is made to a shift scenario featuring:

- 430/480 net min of repetitive work (modal value = 440, *Duration Multiplier* = 1)
- one 30-min meal break and two additional 10-min breaks (*Recovery Multiplier* = 1.33).

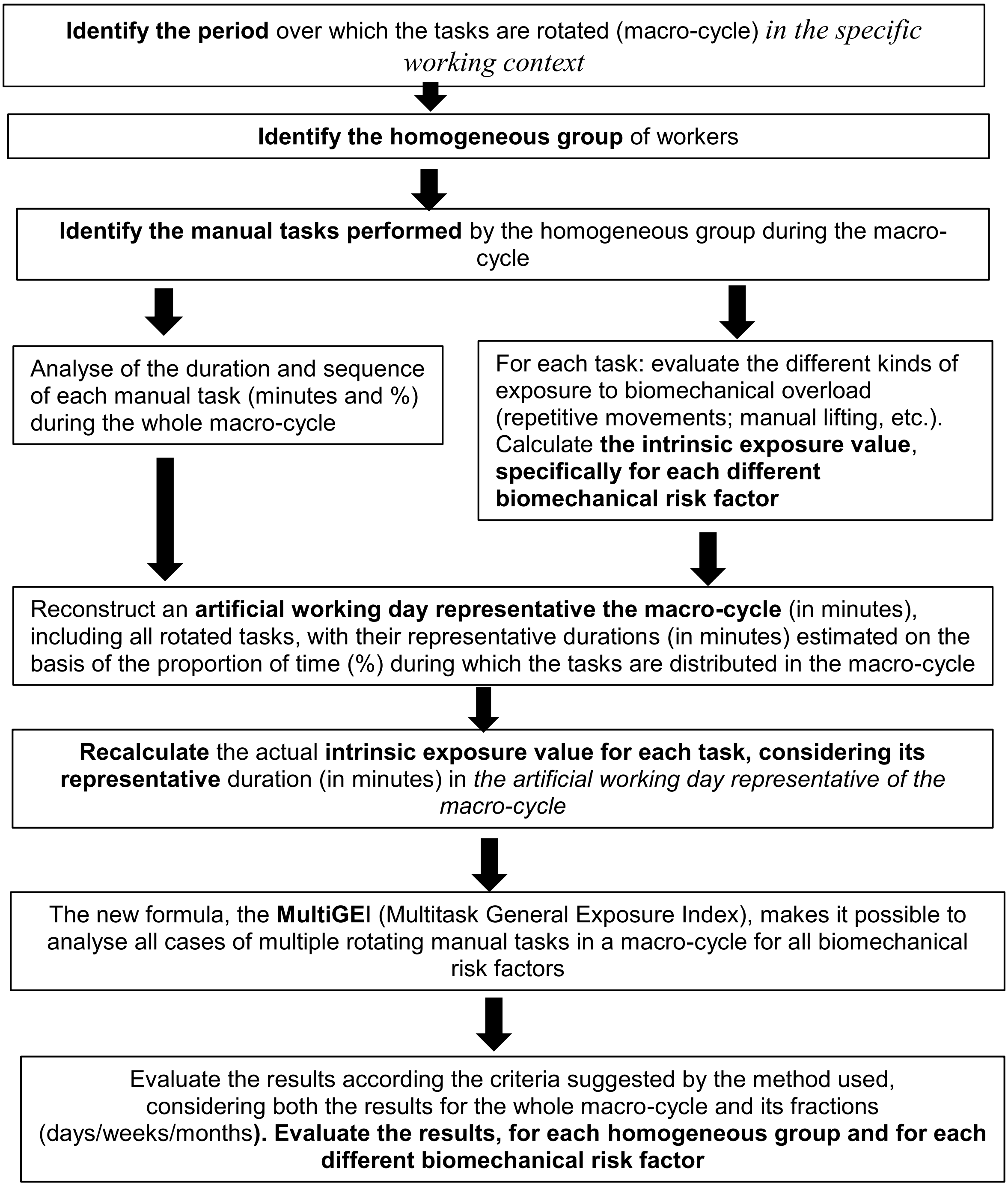
Fig. 7 shows the intrinsic exposure values calculated with OCRAck for the six tasks performed by homogeneous group nr.1.

For lifting tasks, when computing the intrinsic Lifting Index (Waters et al., 1993, 1994, 2016), reference is made to a *long duration scenario* (more than 2 h of consecutive manual lifting in the shift) with the corresponding *Frequency Multiplier* (FM).

Fig. 8 emphasizes that different conditions (potentially causing biomechanical overload) can be present at the same time in the most varied combinations: repetitive movements, manual lifting, pushing/pulling, awkward postures (especially for the lower limbs and spine). In homogeneous group nr.1, in fact, it is noted that, while repetitive movements and awkward postures are present in all six tasks, manual lifting is present only in tasks 3, 4 and 5, as well as pushing/pulling only in task 6.

3.6. Reconstruction of the "artificial working day, representative of the macro-cycle" (in term of total duration and duration of each task)

Based on the analysis carried out in step 3.4, it is possible to calculate or estimate the proportion of time that the homogeneous group spends on each manual task (Fig. 5, part c). This proportion may be calculated with reference to the total working time of the group in the period (macro-cycle).



Identify the period over which the tasks are rotated (macro-cycle) *in the specific working context*

Identify the homogeneous group of workers

Identify the manual tasks performed by the homogeneous group during the macro-cycle

Analyse of the duration and sequence of each manual task (minutes and %) during the whole macro-cycle

For each task: evaluate the different kinds of exposure to biomechanical overload (repetitive movements; manual lifting, etc.). Calculate **the intrinsic exposure value, specifically for each different biomechanical risk factor**

Reconstruct an **artificial working day representative the macro-cycle** (in minutes), including all rotated tasks, with their representative durations (in minutes) estimated on the basis of the proportion of time (%) during which the tasks are distributed in the macro-cycle

Recalculate the actual **intrinsic exposure value for each task, considering its representative** duration (in minutes) in *the artificial working day representative of the macro-cycle*

The new formula, the **MultiGE**I (Multitask General Exposure Index), makes it possible to analyse all cases of multiple rotating manual tasks in a macro-cycle for all biomechanical risk factors

Evaluate the results according the criteria suggested by the method used, considering both the results for the whole macro-cycle and its fractions (days/weeks/months**). Evaluate the results, for each homogeneous group and for each different biomechanical risk factor**

Fig. 3. Summary of the steps involved in evaluating exposure to biomechanical overload in a non-daily cycle (macro-cycle).

HOMOGENEOUS GROUPS OF WORKERS	TASKS						DAILY DURATION	YEARLY DURATION
Group nr.1	task 1	task 2	task 3	task 4	task 5	task 6	420 minutes/day	11 months/year
Group nr.2		task 2			task 5	task 6	420 minutes/day	6 months/year
Group nr.3	task 1		task 3				240 minutes/day	4 months /year

Fig. 4. Example of identification of different homogeneous groups of workers in the same company.

However, since the total working time of the group may vary from group to group (for example, one group may work full-time and another part-time) or within the same group over the period (seasonal farm workers, for example), it becomes necessary to transform the macro-cycle, whatever its duration, into a constant and standardized period, i.e. a working day called an "*artificial working day representative of the macro-cycle*".

To this end, the proportional task duration in the macro-cycle is

Part a: task distribution and proportional duration over a year

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Hrs/worked/month	**32**	**0**	**81**	**161**	**161**	**161**	**200**	**230**	**161**	**161**	**81**	**34**
task 1	50%		40%	30%	40%	30%	20%			40%	50%	80%
task 2	50%		20%	20%	20%	30%	10%			40%	40%	20%
task 3			20%	30%	20%	20%	30%	40%	40%	20%	10%	
task 4			15%	15%	10%	20%	20%	40%	40%			
task 5			5%	5%	10%		10%	10%	10%			
task 6							10%	10%	10%			
	100%	**0%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Part b: task duration in hours over a year

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	PROPORTION	Hours/year
task 1	16		32	48	64	48	40	0		64	41	27	25%	**382**
task 2	16		16	32	32	48	20	0		64	32	7	17%	**269**
task 3			16	48	32	32	60	92	64	32	8		27%	**386**
task 4			12	24	16	32	40	92	64				20%	**281**
task 5			4	8	16		20	23	16				6%	**87**
task 6							20	23	16				5%	**59**
Hrs/worked/month	**32**	**0**	**81**	**161**	**161**	**161**	**200**	**230**	**161**	**161**	**81**	**34**	100%	**1,463**

Part c: task duration in hours adjusted using the % reduction (%Reduction) between full shift duration and net duration of repetitive tasks for each month

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	PROPORTION	Net hours/year
task1 net	14		29	44	58	44	37			58	37	25	**346**	26%
task2 net	14		15	29	29	44	18			58	29	6	**243**	18%
task3 net			15	44	29	29	55	84	58	29	7		**351**	26%
task4 net			11	22	15	29	37	84	58				**256**	19%
task5 net			4	7	15		18	21	15				**79**	6%
task6 net							18	21	15				**54**	4%
Hrs/worked /month	**29**	**0**	**73**	**146**	**146**	**146**	**183**	**211**	**146**	**146**	**73**	**31**	**1,329**	**100%**

Fig. 5. Homogeneous group nr.1: analysis of the sequence of all the various manual tasks performed over the macro-cycle (year) and their duration in % (part a) and in hours (part b). In part c the task durations in hours are adjusted using the % reduction (%Reduc) between full shift duration and net duration of repetitive tasks for each month (see Fig. 6).

estimated with respect to standard work duration scenarios such as those typical of industry. These scenarios are called "*exposure time constants*" and are detailed in Table 4.

The proportion of time that the homogeneous group spends on each manual task with respect to exposure time constants is the basis for re-estimating the time (now in *artificial minutes*) spent on each task in the *artificial working day representative of the macro-cycle.* Having thus estimated the time (in artificial minutes) spent on each manual task within the artificial day, it is then possible to fully reconstruct an "*artificial working day representative of the macro-cycle*", based on which the final evaluations will be made using the Multi GEI formula [1].

In the example relating to exposure to repetitive movements and awkward postures of homogeneous group nr.1 (Fig. 9), the procedure for calculating the duration of the *artificial day representative of the year* is illustrated. Starting from 1329 h (net duration of the repetitive work present in all tasks in the year), divided by 220 (constant number of working days per year) and multiplied by 60 (transforming hours into minutes), 362 min are obtained, which constitute the duration of the repetitive tasks in the *artificial day representative of the year.*

The same calculation procedure is used for the duration in minutes of all the tasks present in the year: therefore also the task durations, originally in hours, can be transformed into *artificial minutes* to create the *artificial day representative of the year* (Fig. 9). Now, using Table 3, it is possible to obtain all the Duration Multipliers both for the total duration of all the tasks and for each individual task (Fig. 9).

For manual lifting, it is necessary to again reconstruct the specific *artificial day representative of the macro-cycle* (a year, in this example) in terms of the total duration of all tasks involving manual lifting in the year and the duration of each individual task. In fact, exposure times rarely coincide for the different potential biomechanical overload conditions.

In homogeneous group nr.1, all six tasks are considered repetitive, while only three of them also involve manual lifting (tasks 3,4 and 5): the overall duration of the manual lifting tasks during the *artificial day representative of the year* is estimated at 187 min. Fig. 10 reports the entire computational procedure for manual lifting tasks.

The use of *exposure time constants* is essential to better estimate task durations in the *artificial day representative of a macro-cycle.* In this regard, Fig. 11 shows some examples of calculations of *artificial day* durations using *exposure time constants* when considering annual, monthly

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
SHIFT NET DURATION (MINUTES)	**420**		**420**	**420**	**420**	**420**	**480**	**480**	**420**	**420**	**420**	**420**
Nr. of breaks with actual duration over 7 minutes (excluding meal break)	2		2	2	2	2	2	2	2	2	2	2
Actual duration of breaks (minutes) (excluding meal break)	30		30	30	30	30	30	30	30	30	30	30
Meal break duration within the shift (paid)												
If the shift is not consecutive (e.g. with unpaid meal breaks) mark the number of interruptions if the duration is >= 30 min..	1		1	1	1	1	1	1	1	1	1	1
Total duration of breaks in the shift	30	0	30	30	30	30	30	30	30	30	30	30
Total minutes of non-repetitive or secondary tasks in the shift	10	0	10	10	10	10	10	10	10	10	10	10
NET REPETITIVE WORKING TIME (minutes)	**380**	**0**	**380**	**380**	**380**	**380**	**440**	**440**	**380**	**380**	**380**	**380**
% reduction (net duration) considering the total duration of the shift and the duration of the repetitive tasks	**90%**	**0%**	**90%**	**90%**	**90%**	**90%**	**92%**	**92%**	**90%**	**90%**	**90%**	**90%**
Nr. of hours in the shift without adequate recovery periods	3	0	3	3	3	3	4	4	3	3	3	3
RECOVERY MULTIPLIERs per month	1.20		1.20	1.20	1.20	1.20	1.33	1.33	1.20	1.20	1.20	1.20
RECOVERY MULTIPLIERs per year	1.22 (average score)											

Fig. 6. Homogeneous group nr.1: typical work shift (modal shift) representative of each month, for calculating %Reduction and Recovery Multipliers for each month and for the whole year.

TASKS	**recovery multiplier**	**hours without recovery**	**frequency**	**force**	side	shoulder	elbow	wrist	hand	stereotipy	**posture total**	Additional	**OCRAck INTRINSIC value**
task 1	**1.33**	**4**	3	0	RIGHT	0	0	0	2	0	2		**6.65**
task 2	**1.33**	**4**	4	0	RIGHT	0	0	0	3	0	3		**9.31**
task 3	**1.33**	**4**	3	0	RIGHT	2	0	1	4	3	7		**13.30**
task 4	**1.33**	**4**	4	2	RIGHT	1	2	3	8	3	11		**22.61**
task 5	**1.33**	**4**	6	0	RIGHT	8	0	0	8	0	8	1	**19.95**
task 6	**1.33**	**4**	4	0	RIGHT	0	0	0	3	0	3		**9.31**

Fig. 7. Homogeneous group nr.1: OCRAck "Intrinsic values" (right limb) for all repetitive tasks. Values of individual risk factors in OCRAck are also reported.

		task 1	task 2	task 3	task 4	task 5	task 6	**Constant organizational factors for evaluating intrinsic exposure values**
Exposure to Repetitive Movements (OCRAck) right side		6.65	9.31	13.30	22.61	19.95	9.31	430/460 net minutes of repetitive work (modal value=440, Duration Multiplier=1 with one 30-minute meal break and two additional 10-minute breaks (Recovery Multiplier = 1.33).
Exposure to Manual Lifting (RNLE: MLI/CLI/VLI)				0.9	1.5	3		Reference is made to a "long duration" scenario with the corresponding Frequency/Duration Multiplier (FM).
Exposure to PUSHING/PULLING	peak						1.8	430/460 net minutes of repetitive work (modal value=440, Duration Multiplier=1)
	sustained						1.3	
Exposure to awkward postures (TACOs)		8.4	8.4	13.5	15.2	16.5	13	

Fig. 8. Homogeneous group nr.1: intrinsic exposure values for different conditions that may determine typical biomechanical overload for each individual task.

Table 4
Exposure time constants.

HOURS/DAY CONSTANT	8	HOURS/MONTH CONSTANT	160
MINUTES/DAY CONSTANT	**440**	DAYS/MONTH CONSTANT	**20**
DAYS/WEEK CONSTANT	**5**	MONTHS/YEAR CONSTANT	**11**
MINUTES/WEEK (440 min * 5 days) CONSTANT	**2200**	DAYS/YEAR CONSTANT	**220**
WEEKS/MONTH CONSTANT	**4**	HOURS/YEAR CONSTANT	**1760**

and non-predefined macro-cycle durations.

3.7. Recalculation of intrinsic exposure indicators according to real task duration

All the intrinsic exposure values previously obtained for each task (Fig. 8) must now be adjusted in relation to the effective estimated duration of tasks in the *artificial day representative of the macro-cycle*. The correction is made through the use of *Recovery Multipliers* obtained from the organizational analysis of the “typical working shift” (see the example in Fig. 6) and the use of *Duration Multipliers* (Table 3) applied to the *artificial working day representative of the macro-cycle*.

Note that from this point onwards, the connotations in the MultiGEI (Multitask General Exposure Index) formula [1] will be used.

With reference to homogeneous group nr.1, Fig. 12 shows an example of intrinsic exposure values recalculated using OCRAck, and adjusted with respect to their actual duration in the macro-period (a year, in this case).

For each task, two exposure indices are calculated:

- *Exposure Index as if each task lasts (on its own) for the whole macro-cycle* ($EI_{max\ 1,2,3,\ \ldots\ j\ \ldots\ n}$).

The calculation procedure begins by excluding from the intrinsic OCRAck value (column a), the Intrinsic Recovery Multiplier (divide by 1.33, corresponding to the constant of two short breaks and one meal break in an 8-h shift), then inserting the actual Recovery Multiplier (in the example: multiply by 1.22 - column d corresponding to the actual durations and distribution of breaks) obtained from Fig. 6.

The calculation is completed by multiplying the exposure value by the actual Duration Multiplier (here, 0.95 - column c - data from Fig. 9) given that the overall duration of repetitive tasks in the *artificial working day representative of the macro-cycle* is estimated at 362 min (column b). The calculation procedure is presented, in full, in column e.

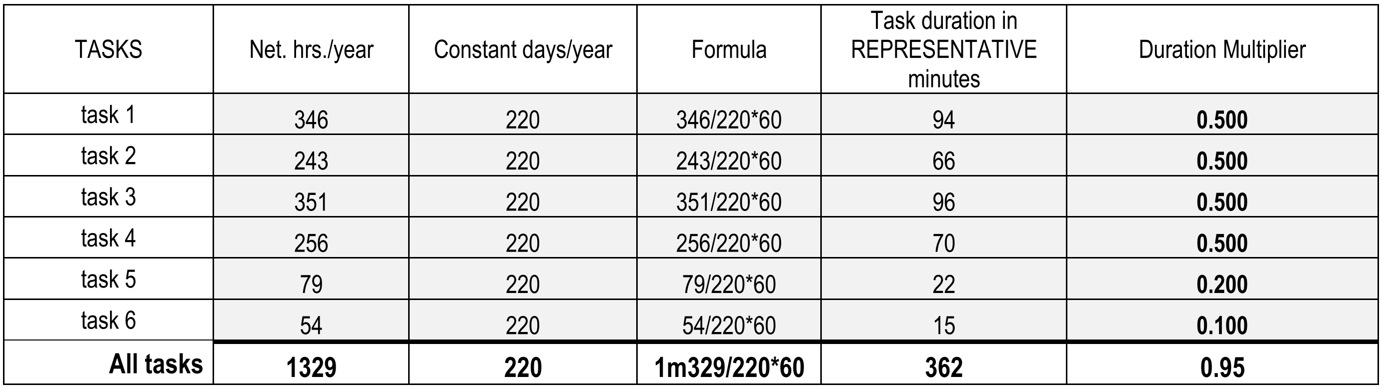
Column f indicates the *actual intrinsic exposure indices* recalculated for each task: i.e. EI_{max} and, among them (column g), the highest one is identified ($EI_{max\ 1}$)

- *Exposure Index of each task according to the actual duration* of an individual *task* ($EI_{eff\ 1,\ 2,3,\ \ldots\ j\ \ldots\ n}$).

Column h shows the duration of the individual tasks, expressed in artificial minutes within the *artificial day representative of the year* (data from Fig. 9): the corresponding Duration Multipliers were obtained for each task (column i). The actual Recovery Multiplier is the same as the one used previously (1.22 - column i - data from Fig. 6). In the calculation procedure proposed in column m, the intrinsic OCRAck value of column a is divided by 1.33, multiplied by 1.22 (introducing the actual Recovery Multiplier) and multiplied by the actual Duration Multiplier, now specific for each task (column i).

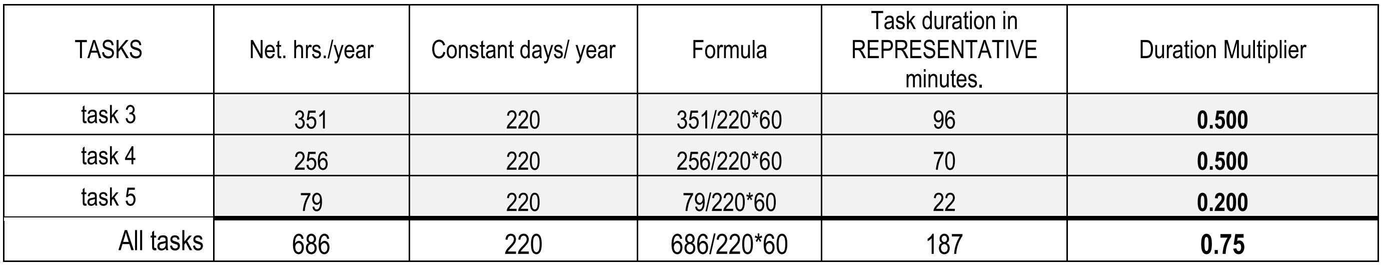
Column n lists the new OCRAck scores, this time calculated according to the real individual task duration (EI_{eff}): among these, column o highlights the highest value ($EI_{eff\ 1}$) that is the leading value for calculating the final exposure index (together with the corresponding $EI_{max\ 1}$).

The last column p, shows the “TF values” used to estimate the factor K_{EI} in the final formula.



TASKS	Net. hrs./year	Constant days/year	Formula	Task duration in REPRESENTATIVE minutes	Duration Multiplier
task 1	346	220	346/220*60	94	**0.500**
task 2	243	220	243/220*60	66	**0.500**
task 3	351	220	351/220*60	96	**0.500**
task 4	256	220	256/220*60	70	**0.500**
task 5	79	220	79/220*60	22	**0.200**
task 6	54	220	54/220*60	15	**0.100**
All tasks	**1329**	**220**	**1m329/220*60**	**362**	**0.95**

Fig. 9. Homogeneous group nr.1 (repetitive movements and awkward postures): reconstruction of the *artificial working day representative of the year* in terms of total duration of all tasks and of each individual task.



TASKS	Net. hrs./year	Constant days/ year	Formula	Task duration in REPRESENTATIVE minutes.	Duration Multiplier
task 3	351	220	351/220*60	96	**0.500**
task 4	256	220	256/220*60	70	**0.500**
task 5	79	220	79/220*60	22	**0.200**
All tasks	686	220	686/220*60	187	**0.75**

Fig. 10. Homogeneous group nr. 1 (manual lifting): reconstruction of the *artificial working day representative of the year* in terms of the duration of all manual lifting tasks and of each individual task.

	REPRESENTATIVE DAY IN ANNUAL MACRO-CYCLES
1	- if the overall hours worked in the year are 1,760 (in this case the hours worked/year match the constant), they correspond to a representative day of 480 minutes: **1,760 hours actually worked per year * 60 / 220 days worked per year constant = 480 minutes**.
2	- if the overall hours worked in the year are 880 (part-time job, 4 hours per day), they correspond to a representative day of 240 minutes: **880 hours actually worked per year * 60 / 220 days worked per year constant = 240 minutes.**
	REPRESENTATIVE DAY IN MONTHLY MACRO-CYCLES
1	- if the overall hours worked in the month are 160 (in this case the worked hours/month match the constant), they correspond to a representative day of 480 minutes (160 hours actually worked per year/20 hours worked per day per month constant *60): **160 hours really worked per month * 60 / 20 days worked per month constant = 480 min.**
2	- if the overall hours worked in the month are 80 (part-time job, 4 hours per day), they correspond to a representative day of 240 minutes: **80 hours actually worked per month * 60 / 20 days worked per year constant =240 min**
	REPRESENTATIVE DAY IN A NOT PRE-DEFINED MACRO-CYCLE DURATION
1	- if the macro-cycle duration is 66 days, the constant days for that period amount to 44 days obtained through the following formula: **X:66=20:30 or 66 * 20/30 or 66 * 0.667** (from Table 5).
2	- Now, if the overall hours worked in this macro-cycle are 352 (44 days*8 hours worked /day, representing the hours worked in 66 days of macro-cycle) this corresponds to the obtained constant and the representative day corresponds to 480 minutes: **352 hours actually worked * 60 / 44 days worked constant = 480 min**

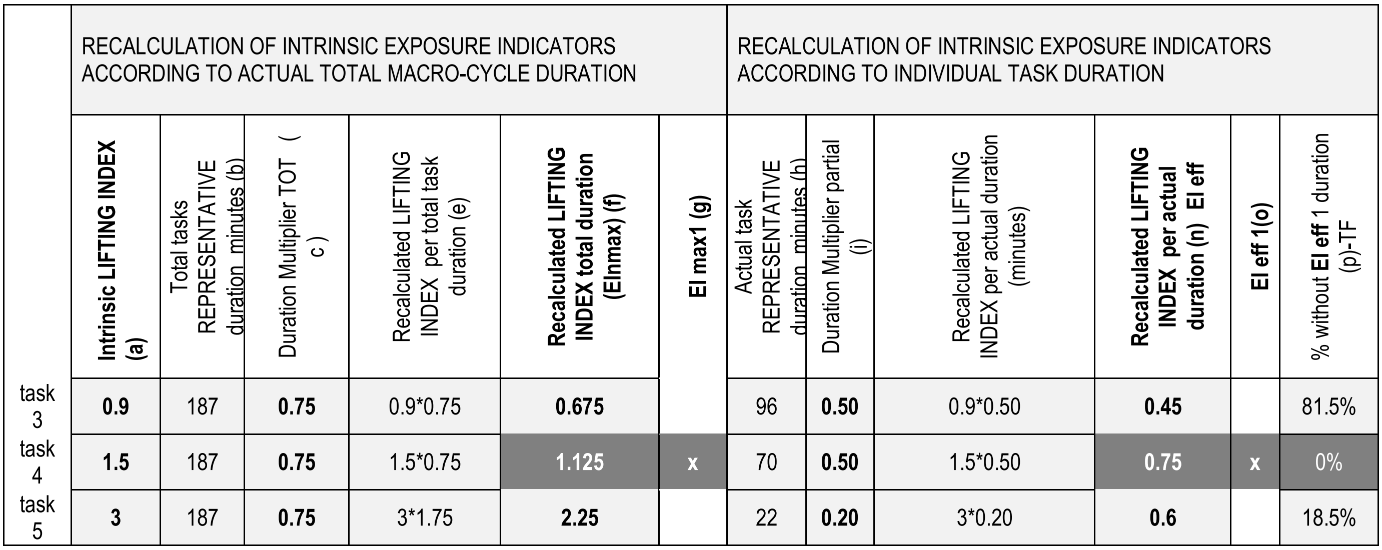
Fig. 11. Examples of representative day calculations, in annual, monthly and non-predefined macro-cycles.

	RECALCULATION OF INTRINSIC EXPOSURE INDICATORS ACCORDING TO THE ACTUAL TOTAL DURATION OF TASKS IN THE MACRO-CYCLE AND ARTIFICIAL DAY							RECALCULATION OF INTRINSIC EXPOSURE INDICATORS ACCORDING TO THE ACTUAL INDIVIDUAL TASK' DURATION IN THE MACRO-CYCLE AND ARTIFICIAL DAY						
	Intrinsic OCRA Ck - Right side (a)	Total tasks REPRESENTATIVE duration minutes (b)	Duration Multiplier TOT (c)	Recovery Multiplier (d)	Recalculated OCRA Ck formula - total task duration (e)	**Recalculated OCRA CK risk total duration (EImax) (f)**	**EImax 1(g)**	Actual task REPRESENTATIVE duration minutes (hr)	Duration Multiplier partial (i)	Recovery Multipler (l)	Recalculated OCRA CK formula actual duration (m)	**Recalculated OCRA CK formula actual duration (n) EI eff**	**EIeff 1(o)**	**TF** without **EI 1eff** duration (p)
task 1	**6.65**	362	**0.95**	1.22	6.65/1/1.33*0.95*1.22	**5.81**		94	**0.50**	1.22	6.65/1.33/1*1.22*0.50	**3.1**		32.2%
task 2	**9.31**	362	**0.95**	1.22	9.31/1/1.33*0.95*1.22	**8.14**		66	**0.50**	1.22	9.31/1.33/1*1.22*0.50	**4.3**		22.7%
task 3	**13.3**	362	**0.95**	1.22	13.3/1/1.33*0.95*1.22	**11.62**		96	**0.50**	1.22	13.3/1.33/1*1.22*0.50	**6.1**		32.7%
task 4	**22.61**	362	**0.95**	1.22	22.61/1/1.33*0.95*1.22	19.76	x	**70**	**0.50**	**1.22**	22.61/1.33/1*1.22*0.50	10.4	x	0%
task 5	**19.95**	362	**0.95**	1.22	19.95/1/1.33*0.95*1.22	**17.44**		22	**0.20**	1.22	19.95/1.33/1*1.22*0.50	**3.7**		7.4%
task 6	**9.31**	362	**0.95**	1.22	9.31/1/1.33*0.95*1.22	**8.14**		15	**0.10**	1.22	9.31/1.33/1*1.22*0.50	**0.9**		5.0%

Fig. 12. Homogeneous group nr.1: examples of recalculation of intrinsic exposure indicators according to actual task duration for repetitive movements.

These represent the proportional duration, in the *artificial working day representative of the macro-cycle*, of the various tasks starting from task 2, in relation to the overall duration of all the tasks minus the duration of task 1 (the peak task).

A similar procedure is also applied to the study of manual lifting tasks (Fig. 13). The *Recovery Multiplier*, specific for repetitive movements, is not applied here and the *intrinsic values* for the manual lifting tasks present in a macro-cycle are all computed exclusively considering



	RECALCULATION OF INTRINSIC EXPOSURE INDICATORS ACCORDING TO ACTUAL TOTAL MACRO-CYCLE DURATION						RECALCULATION OF INTRINSIC EXPOSURE INDICATORS ACCORDING TO INDIVIDUAL TASK DURATION					
	Intrinsic LIFTING INDEX (a)	Total tasks REPRESENTATIVE duration minutes (b)	Duration Multiplier TOT (c)	Recalculated LIFTING INDEX per total task duration (e)	**Recalculated LIFTING INDEX total duration (EImax) (f)**	**EI max1 (g)**	Actual task REPRESENTATIVE duration minutes (h)	Duration Multiplier partial (i)	Recalculated LIFTING INDEX per actual duration (minutes)	**Recalculated LIFTING INDEX per actual duration (n) EI eff**	**EI eff 1(o)**	% without **EI eff** 1 duration (p)-TF
task 3	**0.9**	187	**0.75**	0.9*0.75	**0.675**		96	**0.50**	0.9*0.50	**0.45**		81.5%
task 4	**1.5**	187	**0.75**	1.5*0.75	**1.125**	x	70	**0.50**	1.5*0.50	**0.75**	x	0%
task 5	**3**	187	**0.75**	3*1.75	**2.25**		22	**0.20**	3*0.20	**0.6**		18.5%

Fig. 13. Homogeneous group nr.1: examples of recalculation of intrinsic exposure indicators according to actual task duration for manual lifting.

a *long duration* scenario.

3.8. Application of the Multitask General Exposure Index (MultiGEI) formula to calculate the final exposure indexes

3.8.1. General aspects and presentation of practical examples

Starting from the assumption that almost all the manual tasks that characterize a productive process are "repetitive for the upper extremities" (other occasional tasks are in fact considered as non-repetitive - or secondary - and are thus excluded from consideration), it should be recognized that the same repetitive tasks may also involve manual lifting of loads (where the operators lift objects weighing 3 kg or more using the upper limbs), pushing/pulling, or awkward postures of the whole body.

This implies that, in these latter cases, it is necessary to apply both the analysis for the upper limbs and the analysis for different aspects of manual handling and, potentially, for whole body awkward postures. The analysis follows the same general approach but also features slight differences when considering upper limb repetitive movements or manual load handling, especially in the reconstruction of the corresponding *artificial working day representative of the macro-cycle* that represents one of the fundamental elements for estimating the level of exposure.

When analysing upper limb repetitive movements using OCRAck, in order to calculate the final exposure index MultiGEI, it is necessary to convert both the total duration (in hours) of manual tasks in the macro-cycle and also the duration of each individual task into *representative minutes*.

With this procedure it is possible to recalculate *the intrinsic Checklist scores* reflecting the actual organizational conditions of the homogeneous group, through both the actual effective *Duration and Recovery Multipliers* (Fig. 12).

The final exposure is obtained using the general Multitask General Exposure Index formula (MultiGEI) [1].Final exposures are assessed with reference to the OCRAck classification system (Table 5) as reported in the recent literature and ISO standards (ISO, 2014; Colombini and Occhipinti, 2017).

For the analysis of manual lifting tasks, basically the same procedure is used (except for the *Recovery Multiplier*) as shown in Fig. 13. The final exposures could be assessed with reference to the Lifting Index classification system (Table 6), whichever extension of RNLE is used, as reported in the recent literature (Fox et al., 2019).

As already stated, the two existing approaches used for daily multitask rotation (*OCRA Checklist Multitask Complex* and *Sequential Lifting Index)* have been merged into a more general model and formula called the *"Multitask General Exposure Index" (MultiGEI),* which can be used starting from any exposure index (EI) suggested in the literature or from international standards for analysing various aspects of biomechanical overload (awkward postures, manual load handling including pushing and pulling, repetitive movements and exertions of the upper limbs) in a multitask setting featuring macro-cycles.

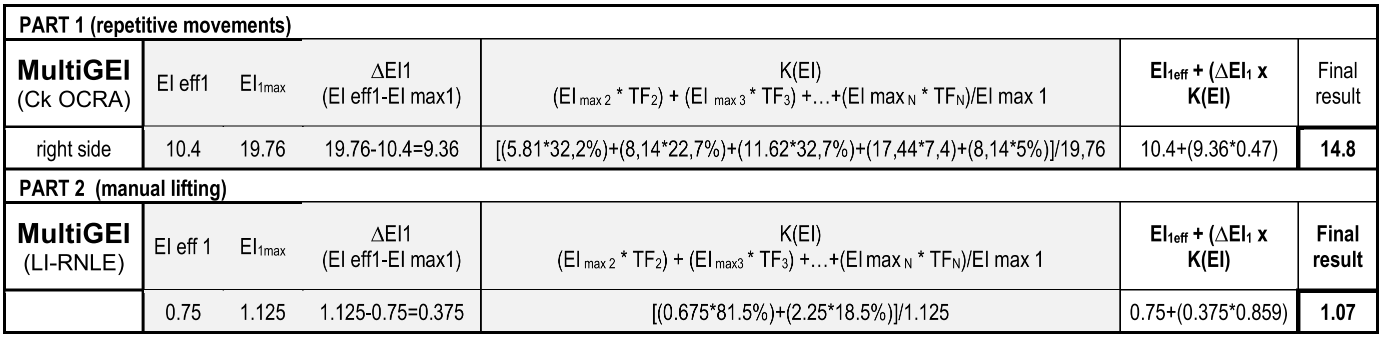
In addition to the aforementioned RNLE and OCRA methods, specific reference could be made to the Revised Strain Index (Garg et al., 2017a, 2017b), the TACOs method (Colombini and Occhipinti, 2018), methods for assessing pushing and pulling actions as summarized in ISO 11228–2

Table 5
Classification of OCRA Checklist final score.

OCRA CHECKLIST SCORE	EXPOSURE LEVEL	COLOR		SUGGESTED ACTIONS
≤7.5	Acceptable	Green		None
7.6–11.0	Borderline or very low	Yellow		Recheck; if possible, improve working conditions
11.1–14.0	Light	Red	light	Improve working conditions according to priorities
14.1–22.5	Medium		medium	
≥22.6	High		high	

Table 6
Interpretation of Lifting Index and derivatives (MLI, CLI, VLI, SLI) and consequent recommendations.

LIFTING INDEX VALUE (EXPOSURE LEVEL)	RISK IMPLICATION	RECOMMENDED ACTIONS
LI ≤ 1.0	Very low	None in general for the healthy working population
1.0 < LI ≤ 1.5	Low	Pay attention to low frequency/high load conditions and to extreme or static postures. Include all factors in redesigning tasks or workstations and consider efforts to lower the LI to values ≤ 1,0
1.5 < LI ≤ 2.0	Moderate	Redesign tasks and workplaces according to priorities to reduce the LI
2.0 < LI ≤ 3.0	High	Changes to the task to reduce the LI should be a high priority.
LI > 3.0	Very high	Changes to the task to reduce the LI should be made immediately.



PART 1 (repetitive movements)						
MultiGEI (Ck OCRA)	EI eff1	EI$_{1max}$	ΔEI1 (EI eff1-EI max1)	K(EI) (EI $_{max\ 2}$ * TF$_2$) + (EI $_{max\ 3}$ * TF$_3$) +…+(EI max $_N$ * TF$_N$)/EI max 1	**EI$_{1eff}$ + (ΔEI$_1$ x K(EI)**	Final result
right side	10.4	19.76	19.76-10.4=9.36	[(5.81*32,2%)+(8,14*22,7%)+(11.62*32,7%)+(17,44*7,4)+(8,14*5%)]/19,76	10.4+(9.36*0.47)	**14.8**
PART 2 (manual lifting)						
MultiGEI (LI-RNLE)	EI eff 1	EI$_{1max}$	ΔEI1 (EI eff1-EI max1)	K(EI) (EI $_{max\ 2}$ * TF$_2$) + (EI $_{max3}$ * TF$_3$) +…+(EI max $_N$ * TF$_N$)/EI max 1	**EI$_{1eff}$ + (ΔEI$_1$ x K(EI)**	**Final result**
	0.75	1.125	1.125-0.75=0.375	[(0.675*81.5%)+(2.25*18.5%)]/1.125	0.75+(0.375*0.859)	**1.07**

Fig. 14. Homogeneous group nr. 1: examples of applying the final MultiGEI formula to calculate the final exposure index for repetitive movements (part 1) and manual lifting (part 2).

(ISO, 2007a), but also to other acknowledged methods and tools, provided that they specifically consider the relevant qualitative and quantitative task features that are essential for applying the MultiGEI model. Practitioners should choose the methods and tools that best suit their industries and circumstances; obviously, a separate analysis is required for each potential biomechanical overload condition (i.e. upper limb repetitive movements, manual load lifting, pulling and pushing, awkward postures, etc.).

Fig. 14 proposes the final MultiGEI calculation for homogeneous group nr.1, both for repetitive movements (part 1) and for manual lifting (part 2). All the elements in formulas [1] and [1a] are presented, as derived from previous analyses (see Figs. 12 and 13).

Fig. 15 graphically depicts the results of the biomechanical overload assessment for homogeneous group nr.1 presented in the paper: the graphs show the different levels of exposure to occupational biomechanical overload, obtained respectively for upper limb repetitive movements (using OCRAck), for manual lifting using the RNLE-LI approach, adopting the reference masses (or recommended weight limits) suggested in ISO TR 12295 for gender and age (ISO, 2014), and for pushing/pulling, where the indexes are representative of the ratio between exerted forces and the recommended forces as suggested in ISO 11228–2 (ISO, 2007a). The exposure levels for each of these aspects are also calculated for each month of the year.

From this perspective, the resulting monthly trends in exposure levels are more important than the global annual exposure index. "At a glance" it becomes immediately clear when an ergonomic intervention is necessary and urgent.

3.8.2. *Application of MultiGEI: specific procedures when more than 10 rotating tasks are present*

It is worth noting that in many cases, especially when manual task rotations take place in monthly and annual scenarios, analyses are generated for dozens of tasks that the homogeneous group performs in the period, each of which has a *representative duration* of only a few minutes. In such cases, and whenever there are more than 10 rotated tasks included in the *artificial working day*, the suggestion is to group together tasks with a similar score; in each group the sum of the relative durations will thus become more significant also in relation to the application of the *Duration Multipliers* in Table 3.

Although tasks can be grouped in various ways, here we recommend grouping the results of the various tasks included in the *artificial working day representative of the macro-cycle* into six categories. These six categories could be determined according to the distribution of the individual exposure scores preferably using sextiles as key points for grouping: this solution is the most precise and reliable. As a simpler alternative, one may obtain six key points by dividing the range of EI scores (i.e., maximum EI – minimum EI) by 6. In any case, the original durations (in the *artificial working day representative of the macro-cycle*) of individual tasks are consequently grouped and included in the six categories.

Within each resulting category a representative score is chosen: this value corresponds to the resulting time-weighted average of all the tasks considered in that category. This produces the representative score and cumulative duration of each category, which will likely be longer in terms of minutes. With these two elements it is possible to apply the general MultiGEI [1] formula to six exposure index categories, taking into account the duration multipliers indicated in Table 3.

4. Discussion and conclusions

Starting from well-established methods for measuring biomechanical overload in repetitive and/or lifting tasks on a daily rotation schedule, the next step was to define and suggest criteria and procedures for analysing exposure to biomechanical overload conditions when workers perform multiple tasks with rotations in macro-cycles of more than a day (e.g. weekly, monthly, yearly).

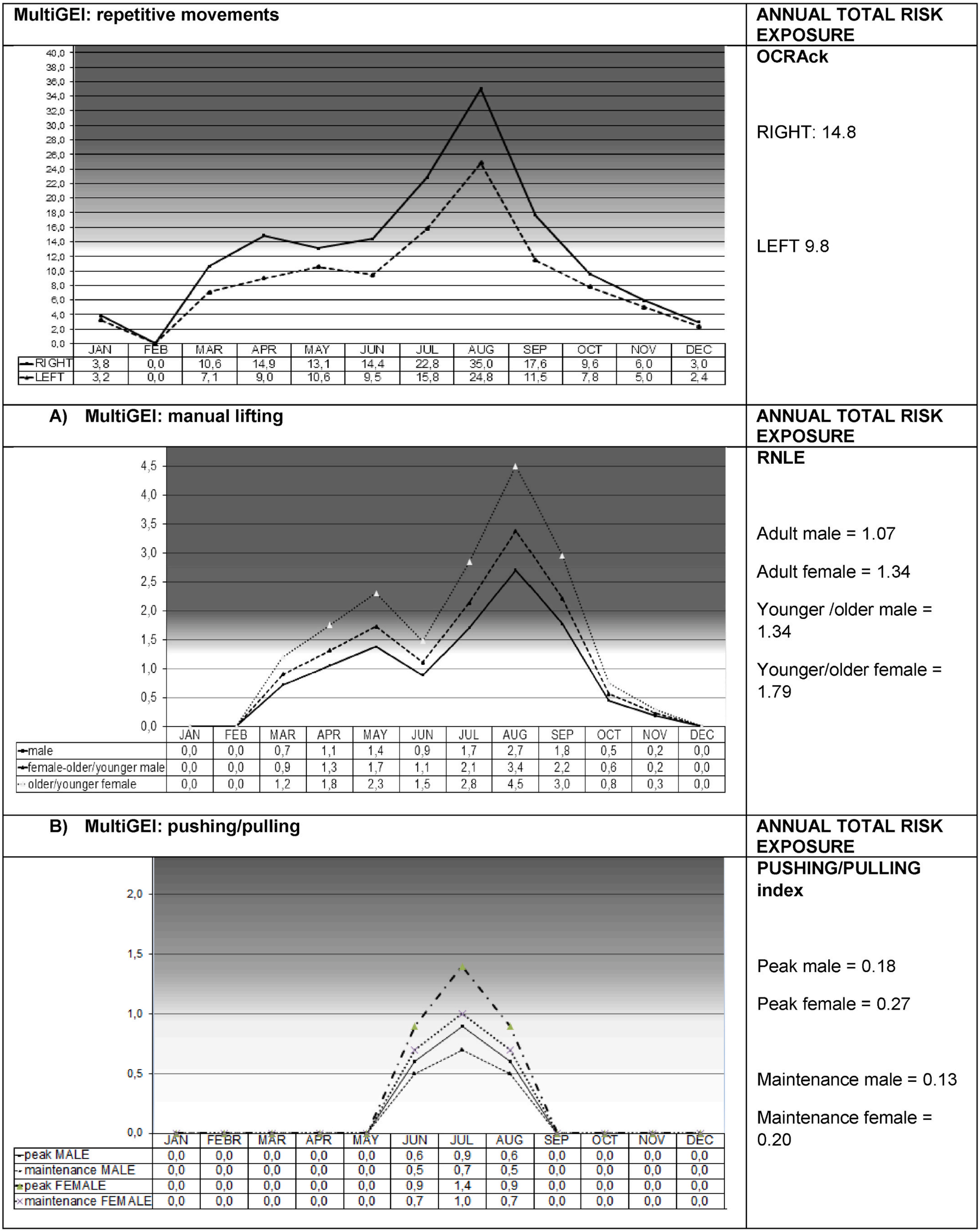
In the present proposal the MultiGEI (Multitask General Exposure Index) is the preferred approach for calculating the overall exposure level. It is based on the value of the most overloading task in the macro-cycle in terms of its duration, plus the partial contribution of all the other tasks considered by their respective durations. This is a particularly useful model when there is variable exposure to different tasks and the tasks are not distributed evenly within the relevant macro-cycle.

Moreover, it is worth noting that the analysis should not be focused only on the computation of the final score and its classification, but also detail the trends and characteristics of the exposure throughout the entire period in question. The trends, the exposure characteristics and the resulting scores should be expressed month by month for annual macro-cycles, week by week for monthly macro-cycles and day by day for weekly macro-cycles.

A crucial aspect of the proposed procedure is the determination of the *Duration Multipliers*. The *Duration Multipliers* that have been suggested (Table 3) are those used for the analysis of multiple daily rotating repetitive tasks involving the upper limbs using the OCRA Checklist (Colombini and Occhipinti, 2017). The *Duration Multipliers* proposed for the same tasks using the Revised Strain Index (Garg and Kapellusch, 2017a) are very similar for the more common daily task durations (60–480 min), whilst for very short durations (only a few minutes) and especially for durations over 480 min, they present some differences.

The two *Duration Multipliers* could be used interchangeably for the final *MultiGEI* computation. However, it should be noted that the differences for very short durations can be overcome, when analysing several tasks in a macro-cycle, by grouping tasks and durations and using multipliers for more common grouped durations in computing the final results.

That said, the same *Duration Multipliers* shown in Table 3 have also been proposed for the analysis of rotating lifting tasks in macro-cycles of more than one day using an adaptation of the Sequential Lifting Index (SLI) approach (Waters et al., 2007; Colombini et al., 2013): this choice is absolutely consequential to the rationale of the SLI approach that



MultiGEI: repetitive movements

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RIGHT	3,8	0,0	10,6	14,9	13,1	14,4	22,8	35,0	17,6	9,6	6,0	3,0
LEFT	3,2	0,0	7,1	9,0	10,6	9,5	15,8	24,8	11,5	7,8	5,0	2,4

ANNUAL TOTAL RISK EXPOSURE

OCRAck

RIGHT: 14.8

LEFT 9.8

A) MultiGEI: manual lifting

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
male	0,0	0,0	0,7	1,1	1,4	0,9	1,7	2,7	1,8	0,5	0,2	0,0
female-older/younger male	0,0	0,0	0,9	1,3	1,7	1,1	2,1	3,4	2,2	0,6	0,2	0,0
older/younger female	0,0	0,0	1,2	1,8	2,3	1,5	2,8	4,5	3,0	0,8	0,3	0,0

ANNUAL TOTAL RISK EXPOSURE

RNLE

Adult male = 1.07

Adult female = 1.34

Younger /older male = 1.34

Younger/older female = 1.79

B) MultiGEI: pushing/pulling

	JAN	FEBR	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
peak MALE	0,0	0,0	0,0	0,0	0,0	0,6	0,9	0,6	0,0	0,0	0,0	0,0
maintenance MALE	0,0	0,0	0,0	0,0	0,0	0,5	0,7	0,5	0,0	0,0	0,0	0,0
peak FEMALE	0,0	0,0	0,0	0,0	0,0	0,9	1,4	0,9	0,0	0,0	0,0	0,0
maintenance FEMALE	0,0	0,0	0,0	0,0	0,0	0,7	1,0	0,7	0,0	0,0	0,0	0,0

ANNUAL TOTAL RISK EXPOSURE

PUSHING/PULLING index

Peak male = 0.18

Peak female = 0.27

Maintenance male = 0.13

Maintenance female = 0.20

Fig. 15. Graph reporting the final results of the biomechanical overload assessment for homogeneous group nr.1: the data show, also month by month, the different levels of exposure to occupational biomechanical overload, obtained for upper limb repetitive movements, manual lifting and pushing/pulling, respectively.

assigns great relevance to the portions of time spent on different rotating lifting tasks as well as periods spent on "light" tasks.

Generally speaking, it should be emphasized that the use of the proposed *Duration Multipliers* better differentiates the results when the overall working time varies substantially between groups of workers performing the same tasks from the qualitative standpoint.

A great deal of experience has already been acquired applying the OCRA Checklist to assess exposure of the upper limbs to repetitive tasks with regards not only to agriculture, but also to the services sector, such as supermarkets, industrial cleaning, food preparation, industrial laundries and health care (Colombini and Occhipinti, 2017). There is less experience in assessing multiple day exposure to manual handling tasks and jobs.

In the present paper the concept of "exposure" (exposure assessment, exposure index) has been systematically used instead of "risk". Risk refers in fact to the probability of an adverse health effect.

The methods referred to in the paper, such as the OCRA method and the RNLE Lifting Index (including CLI and VLI), when used for typical daily scenarios, have been proved to be, on the basis of epidemiological studies and within definite limits, useful methods for risk assessment respectively of UE WMSDs and lower back pain (Occhipinti and Colombini, 2004, 2007), (Colombini and Occhipinti, 2017), (Fox et al., 2019).

However, when considering macro-cycles of more than a day (e.g. weekly, monthly, yearly), these assumptions may not necessarily be true and the Authors have preferred to use the concept of "exposure", as it better fits the methods referred to in the paper as well as with other methods used to analyse biomechanical overload conditions when applied to the multitask analysis of macro-cycles of more than a day.

In this sense, *MultiGEI* represents the first step towards quantifying "exposure" in future epidemiological studies in the specific working sectors aimed at verifying the validity of the model to be associated with different WMSDs.

Admittedly, it is still difficult to gather significant amounts of clinical data for epidemiological purposes in the relevant sectors in order to validate the proposed models for analysing multi-day exposure. Based on preliminary findings involving about 300 workers in the agri-food sector, the *MultiGEI* method (used with OCRAck) is sufficiently predictive of UE-WMSDs for annual exposure schedules covering at least most months.

In light of these considerations, it is important to note that the proposed model should be regarded as useful for estimating levels of exposure to various biomechanical overload conditions when task rotations are scheduled over multi-day macro-cycles. For the time being it cannot be considered as a precise model for estimating the risk of adverse health effects (WMSDs), insofar as further epidemiological studies are needed to verify the strength of association between estimated exposure levels and consequent health effects.

Lastly, it appears obvious that the analyses proposed here are somewhat complex, especially as regards collecting organizational data. However, exposure cannot be assessed without having some idea of where, for how long and in what sequence a worker performs certain tasks. Consequently, if these aspects are complex the analysis may necessarily also be more complex, but certainly not impossible.

Since the procedures and calculations for calculating the final exposure indexes presented here are so complex, especially when the work entails numerous tasks, it is virtually impossible to manage them manually.

Therefore, a number of free Excel® spreadsheets (*ERGOepmVINCIocraNIOSHpushTAengYEAR*; *ERGOepmVINCIocraNIOSHpushTAengWEEKmonth*) have been made available and can be downloaded free from www.epmresearch.org. They will help the user to collect the necessary organizational data and, after measuring all the "intrinsic" exposure levels for each condition of potential biomechanical overload (basic knowledge of methods such as OCRA checklist, RNLE, push/pull, etc. Is therefore required), all other intermediate computations and the final exposure values in graphics are generated automatically.

In addition, the authors provide a video with practical examples of how to use these free spreadsheets (see https://youtu.be/F4wn67x9ppo).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ergon.2021.103212.

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