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REPETITION AS A RISK FACTOR FOR THE DEVELOPMENT OF MUSCULOSKELETAL DISORDERS

Summary: *Work-related musculoskeletal disorders (WRMSDs) are becoming a major problem in world economy. There is many and various risk factors that contribute to their development. Repetitive work is one of the most important risk factor. In this paper is described the body's response to repetitive strain, existing methods for evaluation/ quantification of repetition as risk factor for musculoskeletal disorders. The author proposes a new multidimensional scale for rating the level of risk of repetitive work, which may be useful in the risk assessment of the workplace.*

Key words: ergonomics, work related musculoskeletal disorders, risk assessment.

INTRODUCTION

The cause of the development of musculoskeletal disorders can be found in the fact that there are many, both professional as well as nonprofessional risk factors. The generally accepted view is that musculoskeletal disorders usually occur after exposure to a combination of risk factors, and the risk increases with increasing exposure. Although there is still no consensus about risk factors themselves, nor about their distribution, generally we can divide risk factors for musculoskeletal disorders to:

- Work risk factors,
- Organizational risk factors,
- Psychosocial risk factors and
- Individual risk factors.

Repetition / repetitive movements are one of the most important risk factors in the group of work risk factors.

Repetition can be defined as cyclical/repetitive work activity that involves repetitive movements of certain body parts. Repetition refers to tasks or series of movements that are executed over and over again with slight variations in the given time. Repetitive work became a hallmark of the industrial revolution, when the management have had the goal to increase production efficiency by eliminating or simplifying workers' movements. Today, this trend continues through the mass use of computers. Physiological problems that result from repetitive work or overuse of certain muscles, tendons and soft tissue are related to muscle fatigue, changes in the density of tissue and tissue exertion, which will be briefly discussed.

1. Repetition and exertion of the tissues

The exertion of the tissues due to repetitive movements can be explained in relation to the properties of the materials that constitute the tissue. All materials have certain essential characteristics that determine how each material will respond to the external load or force. Deformations and exertions are terms used to describe changes in the size or shape of the material as a response to the external load.

Material properties determine the extent of deformation. When an external force is applied, elastic materials suddenly warp or change shape, and then just as quickly eturned to its original state, when the force is removed. Viscoelastic material is slowly deform when force is applied, and also slowly returns to original shape after removal of the load. The majority of body tissues such as muscles, tendons and ligaments are made of viscoelastic materials (Leveau, 1992)

Relationship between the load (the applied force) and deformation (change in the shape of materials) is described by the Hooke's law, which states that the deformation increases in proportion to the applied load. In other words, the amount of deformation depends on the strength of the external load and the material's ability to resist to the load. For example, steel or bones are very hard materials and are therefore minimally deformed if the external force is acting on them. Wooden twig, on the other hand, is flexes (deforms) under the influence of low intensity force, because itself provides little resistance. Exertion-deformation curve describes the relationship between the total load (y axis) and deformation (x-axis). The curve represents the response of materials to progressively overload. Figure 1 shows that in the early stages of loading, the material returns to its original shape after the load is removed (elastic range). After a certain period of time, the material reaches a certain point where it no longer returns to its original shape (elastic limit) and becomes permanently deformed. After this point, further deformations are occurring even with very small increase in load (plastic range). Maximum durability is presented with the highest point M, and the point of failure is marked with the letter K. To deterioration or material failure may occur due to mechanical fatigue or plastic stretching of material.

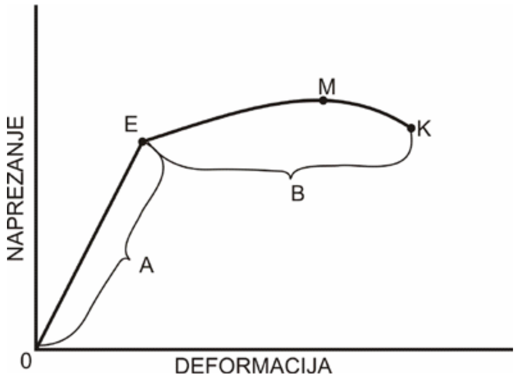

Figure 1. *Exertion-deformation curve*
A - elastic range; **E** - elastic limit; **B** - plastic range; **M** - maximum durability; **K** - point of failure

Mechanical fatigue refers to the cyclic load on material against his limit of durability. Plastic stretching of material refers to prolonged or permanent load of material over a maximum limit, which causes an increase of deformation over time.

Although human tissue differs from other material by the ability of self-healing, exertion-deformation model is relevant to the etiology of musculoskeletal disorders associated with repetitive work. External loads applied to the tendons during repetitive work lead to tendons stretching and creating micropitting of the tissue. At the beginning, viscoelastic tendons are recovering and returning to its original length (elastic range). This mechanism allows an employee to work without problems. However, if the external load is applied to the tissue too often or too fast, there is not enough time for full recovery of tissue and the damage to the tendon starts to develop. Over time, the tendon accumulate damage that can weaken, deform (plastic range) or create chronic inflammation. The worker begins to feel pain when performing common tasks. This model may help to explain why is for vulnerable worker harder to cope with repetitive effort, when they return to work after sick leave due to musculoskeletal disorders. For better understand of the relationship between repetitive work and the accumulation of damage in the tissue, Goldstein and his collaborators (1987) are studied the strain in the tendons during repetitive activites of capturing / holding with fingers (similar to pinching) at full load. The researchers exposed the finger flexor tendons to different loads and different work-rest cycles, and then measured the strain accumulated in the tendons. The results showed that work-rest cycles are significantly correlated with exertion in tendon. In the cycle of 2 seconds of work and 9 seconds of rest, there is no change in tendon exertion even after 500 cycles. In the cycle of 8 seconds of work and 2 seconds of rest, the accumulated exertion in the tendon after 500 cycles increased by 80%

Goldstein and colleagues are concluded that the rest time required for tissue repair is the most important indicator of tendon exertion during repetitive work.

2. Model of fatigue

It is clear that the duration of rest plays an important role in repetitive work. The concept of the work-rest cycles was presented by Rohmert (1973) and later developed by Rodgers (1987, 1988, 1994) in relation to musculoskeletal disorders in the industry. Rodgers (1987) found that the industry standards for repetitive tasks are based only on the amount of time needed to complete the move, irrespective of the amount of required effort or the time needed for tissue repair. When the worker required to perform physically difficult task as fast as physically easy task, it is clear that he will get tired faster. Rodgers suggested that work cycle in the industry (total time required to complete the task and rest periods from the task) incorporate muscular effort and duration of effort, allowing more recovery time for strenuous physical repetitive work. Rodgers also proposes a model of fatigue, which identifies the interaction between the duration of effort (or time of continuous effort), intensity of effort, the recurrence of certain activities and the overall cycle time.

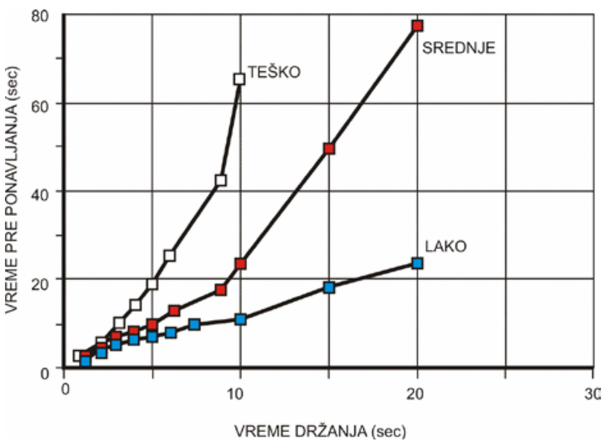

Figure 2. *Work-rest cycles for static repetitive work. Total cycle time (time before repeating, y axis) is a function of the duration of effort (x-axis) and intensity of exertion (shown curves)* (Rodgers S., 1987)

Figure 2. showing the duration of exertion (or continuous effort) on the x axis and intensity of exertion (curve) and the total cycle time necessary to perform the task (y-axis). The intensity of exertion corresponded to the percent of MVC (maximal voluntary contraction, the maximum capacity of muscle contraction) of the worker working in a particular position and can be measured as a function of the estimated exertion, and can be easy, moderate and severe exertion, because direct measurements are often not possible.

Table 1. *Correlation between the intensity of exertion (expressed as the maximum capacity of muscle contraction, MVC) and the duration of static muscle activity*

Maximum capacity of muscle contraction (%)	**Duration of static muscle or aerobic activity**	**Duration of aerobic work**
100	6 s	6 min
85	12 s	12 min
70	20 s	20 min
50	1,0 min	1 hour
40	2,5 min	2 hours
33	4,0 min	8 hours
15	7,5 min	16 hours

Table 1 shows the relationship between the intensity of exertion for static muscle contraction (% MVC) and the maximum time that muscle group (or person) can be carried out in a static contraction, before fatigue occurs. If the duration of work activities, without adequate rest, exceeds this period of time, cardiovascular and muscular energy decreases, and fatigue develops.

Recovery time can be calculated based on the diagram in Figure 2, subtracting the duration of the effort or time for holding/grasping the objects out of the total cycle time. For example, a task that requires low physical effort, but it is needed to hold/grasp for 10 seconds, will require the cycle time of 12 seconds, allowing 2 seconds for tissue recovery. For the completition of heavy physical task, while holding an object for 10 seconds, length of the cycle time of 65 seconds is required, allowing the muscle recovery period of 55 seconds.

Model of fatigue can be helpful in predicting the occurrence of muscle fatigue, in the evaluation of the physical demands of work, but also in solving problems related to the design of work. For example, using this model can be determined whether the recovery time for a specific effort is sufficient to prevent fatigue or effort should be reduced.

3. The link between repetitions and work related musculo-skeletal disorders

So far, scientists have mainly tried to isolate risk factors. However, this is almost impossible, because usually several risk factors are present in the work environment.

Numerous studies have investigated the relationship between repetition and work related musculo-skeletal disorders of the upper limbs, for example, Moore, 1992, Silverstein et al 1987, Osorio et al 1994, Chiang and colleagues in 1993. Among researchers there is generall agreement that it is best to consider repetition as one of exposure factor in association with other risk factors such as force, extreme body position, coldness and rarely with vibration.

Chiang and his colleagues are studied 207 employees in two factories for the production of frozen food. After observing, they divided the tasks into two categories, namely, low repetition of the wrist movements and high repetition of the wrist movements. Tasks are also divided with respect to whether employees are exposed to low temperatures during operation or not. Observed groups of workers were as follows: Group 1 - no coldness, low repetition, group 2 - exposure to coldness or to repetition; Group 3 - exposure to coldness and to high repetition. The existence of carpal tunnel syndrome was present in 3% of group 1, 15% in group 2 and 37% in group 3.

Silverstein and colleagues (1987) have primarily attempted to determine the repetition and force, and later to identify the risk of work related musculo-skeletal disorders from exposure to these risk factors in the workplaces. They examined 652 workers in 39 different jobs, where workers use force and repetition during performing the tasks by hands. All workers were observed, recorded with a video camera, and divided into four groups, based on the exposure to force and to repetition in the workplace. The division into four groups WAs as follows:

1. low intensity force - low repetition,
2. high intensity force - low repetition,
3. low intensity force - high repetition
4. high intensity force - high repetition.

The workers were selected from each of the 39 workplaces, the interviews and medical examinations were conducted, to determine the presence of symptoms associated with work related musculo-skeletal disorders. he results showed that the presence of the work related musculo-skeletal disorders was 5.6% in group 4 "high intensity force-high repetition", and 0.6% in group 1 "low intensity force-low repetition." Group 3 "low intensity force-high repetition" showed a slightly higher risk than group 2 "high intensity force-low repetition", which led to the conclusion that repetition is more important risk factor than force.

Numerous studies have shown that there is a correlation between high repetitive works and the occurrence of work related musculo-skeletal disorders, and also, the association between the occurrence of this disorders and repetition in combination with other risk factors (eg, with high exertions).

If the work tasks or movements repeated frequently (eg, every few seconds) muscles and tendons stress can accumulate, which can lead to permanent tissue damage. The tendons and muscles can often recover from the effects of repetitive stress, if there is enough time to rest between repetitions. Frequent repetition of certain work activities can also cause effects of unsuitable work postures and intense stress. Table 2 shows examples for the meaning of repetition for different body parts, and the degree of risk, whereby Kilby recommended to define repetition as the cycle time of at least 30 seconds, or when a basic cycle constitutes more than 50% of the whole cycles.

Table 2. *Examples of risks associated with repetitive work (Kilby, 1994)*

Body part	**The number of repetitions per minute**	**Risk level**	**Very high risk, if the following is present simultaneously**
Shoulders	More than 2,5	High	High external force, High speed, High static effort, Uncomfortable body position, Lack of training, High job demands, Long duration of work
Upper arm/elbow	More than 10	High	
Forearm/wrist	More than 10	High	
Fingers	More than 200	High	

Number of repetitive movements can be reduced or repetition can be eliminated by introducing changes and diversity in the work (by expanding work tasks), shortening the exposure, etc...

4. Assessment / quantification of repetition as a risk factor for work related musculo-skeletal disorders

There are several methods to achieve the desired level of quantification:

- Employee's assessment / ranking
- Expert's assessment / ranking
- Biomechanical analysis, and
- Measuring by instruments

It is generally recognized that **subjective evaluations** are the best way to measure the qualitative data, because they are based on individual impressions and include the evaluation of the subjects that perform specific work, taking into account individual characteristics of the respondents. Robertson and Hendrick (1985) find that the introduction of individual differences is of great importance for obtaining reliable estimate. Other advantages of the method of subjective assessment related to their sensitivity, ease of use,undisturbed performance of basic work tasks and speed data collection. An example of a linear scale for the subjective assessment is often used Borg's scale (RPE-ratings of perceived exertion) (Borg, 1978).

Repeated or continuous static exertion

Ponavljajuće ili trajno statičko naprezanje Repeated or continuous static exertion is related to the time pattern of the applied forces and body positions. Time patterns can affect the mechanical and physiological load of the musculoskeletal system. It is often described using a time of exertion, recovery time, cycle time and frequency of exertion. It is believed that only the data about the time cycles, can lead to erroneous conclusions. Job A (Figure 3) includes one effort of 3 s during the cycle of 10 s. Job B includes six efforts of 3 s for cycle time of 30 s. If consider only the time of cycle, the impression is that the job B is less stressful of job A, but the incidence of efforts, duration of efforts and recovery time are the same for both jobs. Job C also has a cycle time of 30 seconds, but requires only two efforts of 3 S, because the operator has to wait for the machine to complete its cycle. The operator who performs the job B will pause 40% of the time, while the operator at job C will pause 80% of the time. If everything else is exactly the same, a worker on the job B will be exposed to more stress than the worker on the job C. To be able to calculate the frequency of stress and needed recovery time, it is necessary to know the content of the work.

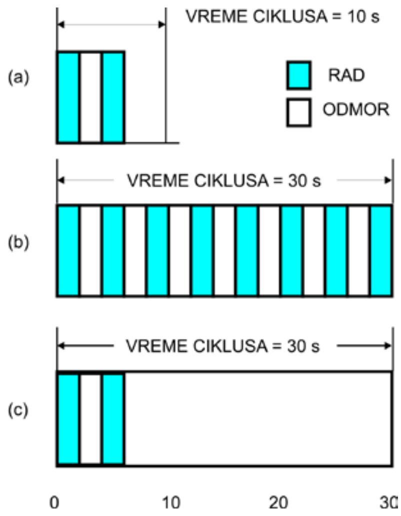

Figure 3. *Activity / repetition of hands for three different jobs*

Repetition can be determined also by observation of work, or by analyzing the video recording of representative work (Latko 1997). Figure 4 shows the scale for evaluation/ranking of repetition.

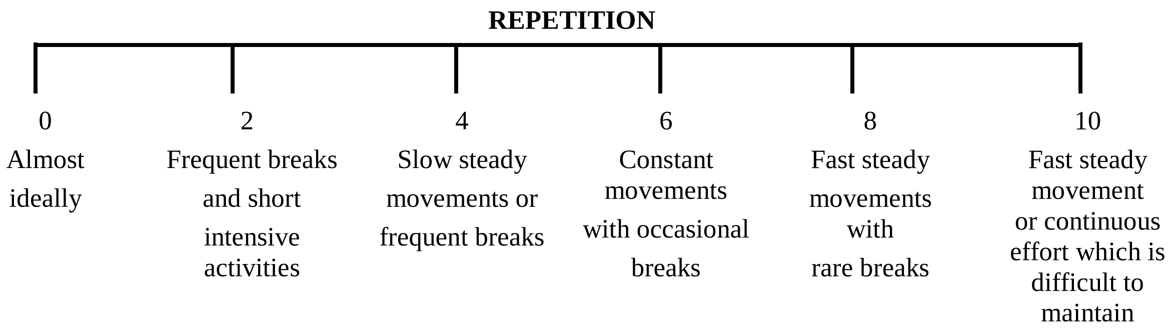

Figure 4. *The scale for the risk assessment of the development of work related musculo-skeletal disorders for risk factor REPETITION (Latko et al, 1997)*

It would be best if several operators or independent experts ranked a factor or factors, and then, through discussion, to reach consensus. It turned out these estimates are fairly accurate, so, since 2000. the ACGIH (American Conference of Industrial Hygienists) accepted these estimations together with normalized levels of forces, as the basis for the limit values for the monotype work of hands (ACGIH, 2000).

Repetition is measured in several ways. Doctors are mainly focused on the number of similar movements in a given period of time, and engineers are interested in the quantity of work, ie. time required for completion of the assignment. This would mean that, as the quantity of work is growing, the repetition is growing, too. However, repetition is increased only if all of the movements during performing the tasks involved the same or similar muscle groups. Silverstein and colleagues (1987) have developed a method by which jobs are categorized into two groups, namely low repetitive jobs and high repetitive jobs. This categorization was based on calculated cycle time of the assignment, and on the percentage of time performing the same basic cycle. Cycle time refers to the amount of time required to complete the assignment. Inside the cycle may be a series of steps or movements that are repeated, and these movements or steps are called the basic cycle. According to the method Silverstein and co-workers, jobs are classified as low repetitive, if the cycle time exceeds 30 seconds, and if less than 50% of the cycle time involves performing the same type of basic / primary cycle, ie. similar movements are repeated less than 50% of the time. Jobs are classified as highly repetitive, if the cycle time is less than 30 seconds, or if more than 50% of the cycle time involves performing the same type of basic cycle.

Different approaches to the measurement of repetition are based on measurement of repetitions, ie. average number of movements performed in a unit of time, such as the number of movements per shift (Putz-Anderson, 1988), where the number of movements greater than 10,000 and less than 20,000 per work shift falls within the category of high reps. Hammer (1934) measured the repetition as the number of movements per hour and found that more than 2,000 movements per hour, or 30-40 movements per minute can be considered repetitive work.

Although shown approaches are trying to quantify repetitive work, both consider only the speed at which the worker performs the movement, but not the quality of the movement. Armstrong and Ulin (1995) have recommended a qualitative scale that takes into account the ability of employees to continue with work, .so according to them, repetitive work can be divided into:

Very high: The body parts of worker are in fast, steady motion; worker has a problem to continue work in same pace.

High: The body parts of worker are in constant motion, any difficulty could led to the delay.

Moderate: The body parts of worker are in constant motion, but he is able to continue its work, taking time for a short breaks.

Low: There are frequent breaks during work, while waiting on the next job or the machine to complete its cycle.

Very low: The worker is idle most of the time, but occasionally uses his hands.

Instrumental methods for measuring repetition involve the use of electromyography to record muscle activity of the forearm, and the goniometer to measure the speed and acceleration of the wrist. These methods can examine the duration and frequency of force and motion. There are goniometers which can be fixed to the wrist to provide an electrical signal proportional to the position of the wrist. The signal is recorded in a computer and sums up as a frequency histogram. Position of a particular body part is repeated periodically for the repetitive work, which can be described using a series of sine waves. The velocity and acceleration of the repetitive movement can be presented as the first or second derivative of body part position.

Body part position $= \sum \theta_{pi} \sin(2t\pi / T_i + \Phi_i)$

Velocity $= \sum \theta_{pi} (2\pi / T) \cos(2t\pi / T_i + \Phi_i)$

Acceleration $= -\sum \theta_{pi} (2\pi / T)^2 \sin(2t\pi / T_i + \Phi_i)$

where:

θ_{pi} - peak amplitudes of movement,

t -time,

T_i – duration of movement,

Φ_i - phases between repeating movement

The velocity of the repetitive movement is a linear function of frequency and amplitude of motion, while the acceleration is a function of the square of frequency and amplitude. According to Marras and his associates (1993), the risk of work related musculo-skeletal disorders was significantly higher among workers who had average acceleration of the wrist (during flexion-extension movement) of 820 ° / s, than in those with a mean acceleration of only 490 ° / s.

Electromyography and electromechanical goniometers enable the quantitative measurement of efforts and patterns of movement, although it are rarely used as a routine tool for the analysis, except in situations where there is a very defined problem.

INSTEAD OF A CONCLUSION

Given the complex nature of risk factors, the lack of verified and generally accepted methods of measurement / quantification of some risk factors, as well as limited financial resources to research the causes of musculoskeletal disorders in the workplace in our country, the author advocates the access to a risk assessment based on the development of multidimensional scale for each of the risk factors. Unlike the one-dimensional, multi-dimensional scale can also provide information on the nature of the task, in addition to the usual information about the intensity or degree of difficulty (pain or discomfort).

The criteria for assessing repetition as a risk factor, with numeric and verbal determined levels, are the result of the extensive analysis of various researches and conclusion of the author (Pavlović-Veselinović S., 2008) and are presented in Table 3.

Table 3. *The proposed multidimensional scale for assessment of REPETITION as a risk factor, for different body parts*

RISK FACTOR	LEVEL OF RISK				
REPETITION	NO RISK 0,00-0,20	LOW RISK 0,21-0,40	MODERATE RISK 0,41-0,60	HIGH RISK 0,61-0,80	VERY HIGH RISK 0,81-1,00
Fingers	No movement or extremely rare movements	Up to 50 movements per minute	> 50-150 movement per minute; intensive typing up to a total of 2 hours daily	>150-200 movement per minute; intensive typing up to a total of 4 hours daily	More than 200 movements per minute; intensive typing more than 4h daily
Forearm / wrist	No movement or extremely rare movements	Up to 5 movements per minute	5-10 movements per minute	More than 10 movements per minute, up to 4h daily	More than 10 movements per minute, more than 4h daily
Upper arm / elbow	No movement or extremely rare movements	Up to 5 movements per minute	5-10 movements per minute	More than 10 movements per minute, up to 4h daily	More than 10 movements per minute, more than 4h daily
Shoulder	No movement or extremely rare movements	1 movement per minute	Up to 3 movements per minute	More than 3 movements per minute, up to 4h daily	More than 3 movements per minute, more than 4h daily
Knee / ankle	No movement or extremely rare movements	Rarely kneeling, squatting, climbing / descending a ladder or using the knee as a hammer	Occasionally kneeling, squatting, climbing / descending a ladder or using the knee as a hammer	Often kneeling, squatting, climbing / descending a ladder or using the knee as a hammer more than once per minute, up to 4 hours daily	Often kneeling, squatting, climbing / descending a ladder or using the knee as a hammer more than once per minute, more than 4 hours daily

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BIOGRAPHY

Sonja Pavlovic-Veselinovic, Ph.D., was born in Nis, where she graduated at the Faculty of Occupational Safety. She completed master's thesis and doctoral dissertation also at the Faculty of Occupational Safety in Nis, in the field of ergonomics. She is an associate professor at the Faculty of Occupational Safety on the undergraduate, master's and doctoral studies, for the subjects Basic of safety systems, Ergonomics, Ergonomic design, Product ergonomics and Ergonomics of automatised systems. Her main areas of interest in researches are human factors / ergonomics, ergonomic design of work and environment systems, safety and health at work, the work related musculoskeletal disorders, work places risk assessment, especially ergonomic risk assessment. Her work includes more than 40 papers published in international and national conference proceedings as well as in leading national and international scientific journals. Sonja Pavlovic-Veselinovic is the author of the monograph of national importance, called Ergonomic risk. She recived The Ronald and Eileen Weiser Center professional development award for 2012, at the University of Michigan.

PONAVLJANJE KAO FAKTOR RIZIKA ZA NASTANAK MIŠIĆNO-SKELETNIH POREMEĆAJA

Sonja Pavlović-Veselinović

Rezime: *Radom uzrokovani mišićno-sleletni poremećaji su postal veliki problem u privredama širom sveta. Postoje brojni i raznoliki faktori rizika koji doprinose njihovom nastanku. Ponavljanje / ponavljajući pokreti su jedan od najznačajnijih faktora rizika. U radu je prikazan odgovor tela na ponavljajuće naprezanje kao i postojeće metode za procenu / kvantifikaciju ponavljanja kao faktora rizika za nastanak mišićno-skeletnih poremećaja. Predložena je multidimezionalna skala za rangiranje nivoa rizika od ponavljajućeg rada, koja može biti od koristi pri proceni rizika radnog mesta.*

Ključne reči: ergonomija, mišićno-skeletni poremećaji uzrokovani radom, procena rizika.