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Real-time postural training effects on single and multi-person ergonomic risk scores

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Abstract: This article proposes and comments on the results achieved in recent laboratory testing activities to develop single and multi-person postural assessment and training in real-time. Research is carried out using the WEM-platform and is promising both in post-processing and in real-time analysis in manufacturing and logistics settings. Laboratory tests are conducted to quantify the impact of visual feedback intervention on workers' behavior based on individual experience and to determine the effect that different anthropometric characteristics can have on ergonomic risk score. Two inertial Motion Capture systems are jointly adopted and coupled with the WEM-platform to quantify the ergonomic risk of two operators employed in a multi-manned assembly station. The results are promising both in single and multi-manned configuration: the system is able to correct the postural behavior of workers when performing the tasks. Furthermore, the flexibility of the proposed platform permits a real-time ergonomic risk assessment for both the workers involved in the study and allow to investigate their mutual movements and collaborative tasks.

Keywords: Ergonomics, multi-manned, real-time, postural risk assessment, inertial motion capture, digital twin

1. INTRODUCTION

The role of humans in operations has undergone profound changes in the industrial context due to automation and Industry 4.0 solutions that have been introduced in production and logistics processes (Neumann et al., 2021). In this new working scenario, operators are scheduled to progress particularly high-value-added activities where human dexterity is fundamental to accomplish the role (Sgarbossa et al., 2020). Consequently, the same set of high repetitive tasks can be assigned to the same resource, leading to increased stress in local parts of the body and, consequently, to the development of work-related musculoskeletal disorders (WMSD). As a consequence, worker well-being can be negatively affected, as well as productivity reduction, due to absenteeism or higher turnover rates (Battini et al., 2011).

Therefore, it has become fundamental to manage the safety and well-being of the workforce through human-oriented production systems and physical workload analysis, which can prevent overexertion of workers' abilities during daily work activity (Berti et al., 2021). Industry 4.0 technologies brought many potential advantages to efficiently account for human factors and ergonomic risk evaluation by introducing cyber-physical systems and digital twin solutions that help workforce organization and management (Ivanov et al., 2021).

Real-time data capture is an innovative element since it adopts sensors that can continuously monitor the condition and performance of the industrial system. Real-time data help to cope with a work environment characterized by continuous changes and challenges.

For this reason, enabling technologies, such as depth cameras and inertial measurement units (IMUs), are increasingly gaining interest, with the aim of constantly providing information to efficiently manage the workforce (Kim & Nussbaum, 2013). In the literature, several works provide innovative and automatic solutions to progress ergonomic risk assessment in daily activities. However, to the best of the authors' knowledge, no work proposes a multi-person ergonomic risk evaluation, and limited studies address the impact of individual anthropometric characteristics on the overall ergonomic risk score of operators working together in the same workplace. Recently, Battini et al. (2022) developed an internal multi-purpose software, called WEM-Platform, which allows performing a real-time ergonomic risk evaluation and performance analysis. This software enables the progression of real-time data and the computation of ergonomic risk index scores, allowing operators, ergonomists, and safety managers to have real-time information to immediately intervene in injury prevention and workload balance. Furthermore, the software can support the initial design phase of the workstation by providing ergonomic evaluation concerning workplace and job design, such as the ergo-zone of the hands and the operator's movements. Moreover, the platform can also be of use during the re-design analysis of jobs and workstations to reduce the overall ergonomic risk level. Finally, the WEM-Platform also guarantees platform flexibility in terms of the tools collecting human posture in real-time and in the number of people monitored.

A first objective of this work is to demonstrate which are the effects that real-time postural training can have on workers' postural behaviors based on their levels of experience. Furthermore, we discuss the impact that individual physical characteristics of the worker can have on postural analysis scores. Finally, we present a multi-person ergonomic risk assessment for a multi-manned workstation to help managers

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collect data that can help them reduce and balance the ergonomic risk amongst operators in the same workstation. The remainder of this work is organized as follows. In Section 2, MOCAP technologies are briefly analyzed and the novelty of this work is explained. In Section 3, the methodology adopted for the laboratory test is described. Section 4 analyzes and discusses the results, while Section 5 provides conclusions and suggests opportunities for future research.

2. LITERATURE REVIEW

In production sites, especially for medium- and large-size product assembly lines, a group of workers can be employed at the same workstation to simultaneously perform different operations on the same product (Fattahi et al., 2011).

A multi-manned assembly line is a type of production line where tasks are simultaneously performed on the same individual product by groups of workers in multi-manned workstations. The literature already provides models and solutions to multi-manned assembly line balancing problems to reduce the number of operators involved in the workstations or minimize the cycle time (Roshani & Giglio, 2017).

The group of operators involved in these workplaces can have different levels of experience and different anthropometric characteristics. Dealing with such heterogeneity can be challenging for companies, which need advanced solutions to consider the individuality of the operator during the training phase and the assignment of the job. Postural training sessions are effective countermeasures against the onset of WMSD, however, the effectiveness of the training phase also depends on the level of experience of the trainee (Denadai et al., 2021).

The fourth industrial revolution has encouraged the development of novel approaches to perform risk analysis considering the characteristics of all subjects. The methods adopted to progress ergonomic risk assessments evolved in parallel with the increasing availability of technology in the manufacturing context. For this reason, self-based reports have been replaced first by observational methods and then by direct/instrument-based approaches (David, 2005).

Direct approaches led to the development of automatic and semi-automatic risk assessment systems exploiting real-time data collection to rapidly progress ergonomic risk scores computation. According to ISO standard 11228-3:2007(E) (ISO, 2007), the adoption of simplified ergonomic methods, such as the Rapid Upper Limb Assessment (RULA) (McAtamney & Corlett, 1993), the Rapid Entire Body Assessment (REBA) (Hignett & McAtamney, 2000), and the Ovako Working posture Assessment System (OWAS) (Karhu et al., 1977), can rapidly provide ergonomic risk evaluations.

The increasing availability of motion capturing devices at affordable prices, such as IMUs or depth cameras, allows MOCAP systems to be adopted in different industrial sectors. Motion capture technologies can be divided into three main categories: inertial, markerless and marker-based systems (Menolotto et al., 2020). Inertial systems adopt several IMUs (sensors composed of a three-axis accelerometer, gyroscope, and magnetometer) attached to the body to reconstruct the position and orientation of the limb they are attached.

Conversely, markerless systems adopt a fleet of cameras that allow tracking the position and orientation of limbs without any additional sensors. Finally, marker-based solutions adopt both cameras and active, or passive, markers placed on the subject's body, to track the position of the limbs where the markers were positioned. In production and logistics, manual activities are still relevant due to the difficulties of automation to replace the dexterity of the human workforce. In this regard, Reining et al. (2019) propose a collection of human activity recognition technologies adopted in production and logistics to automate human movement recognition.

Multi-person MOCAP systems could be adopted to simultaneously monitor workers' movements in multi-manned assembly activities and perform risk assessments between workstations and within each workstation. The literature already provides studies that adopt multiple cameras to perform real-time multi-person tracking (e.g., Malaguti et al., 2019). However, to the best of the authors, while open-source software are available to simultaneously detect multi-person motion, such as the renowned OpenPose (Cao et al., 2021) using RGB cameras, there are no previous works that performs a real-time multi-person ergonomic risk assessment.

As a recent example of multi-person estimation algorithm adoption, Agostinelli et al. (2021) developed a low-cost markerless MOCAP system based on frame images gathered from RGB cameras acquisition. The authors created a system to help ergonomists save time during postural risk evaluation. Despite the system adopting a multi-person pose estimation algorithm, it cannot automatically compute RULA scores or perform multi-person ergonomic risk assessments. For this reason, in this paper, we test and discuss the flexibility of a multi-purpose ergonomic risk assessment tool, called WEM-Platform, to evaluate real-time postural scores and ergonomic indexes for multiple people simultaneously, considering their experience levels and anthropometric characteristics.

3. LABORATORY TEST

This section describes the subjects who participated in the laboratory test, the experimental protocol and data processing to obtain the results presented in the next section.

3.1. Participants

Two volunteers have been recruited to carry out the activities described in Section 3.2.

- Operator #1: inexperienced worker with no previous experience in the product assembly process and not previously trained by the WEM-Platform (male, 30 y/o, 187 cm tall).
- Operator #2: experienced worker in the assembly process under study and previously trained by the WEM-Platform (male, 27 y/o, 174 cm tall).

Both participants have voluntarily participated in the study and signed a written consent to participate in laboratory tests.

3.2. Experimental Protocol

The laboratory tests presented in this work have two different objectives:

1. Investigate the influence of the individual's level of experience on the benefits obtained from the WEM-platform. Hence, we tested feedback intervention on two workers with different experiences on an assembly activity with and without the adoption of the WEM-Platform.

2. Prove that the WEM-Platform is capable of simultaneously assessing the ergonomic risk of two people in real-time. For this reason, in our laboratory, we analyzed two multi-person work scenarios from both the ergonomic and time performance perspectives.

The experimental analysis on the first objective focused on the postural improvement of the inexperienced worker. Indeed, the experienced operator is already trained to achieve good ergonomic risk scores and the WEM-Platform feedback does not have a significant impact.

To quantify the improvement of operators' performance, we scheduled the following three assembly activities:

- Scenario 1: Assembly task performed by Operator #1, without feedback from the ergonomic platform.
- Scenario 2: Assembly task performed by Operator #1, with feedback from the ergonomic platform.
- Scenario 3: Assembly task performed by Operator #2, with feedback from the ergonomic platform.

Both operators perform the same activity of a drawer assembly. Due to the small dimension of the assembled object, the operators can work standing in front of the workbench. The laboratory setup for the three initial scenarios is represented by a standard 1 meter high workbench.

During these scenarios, the WEM-Platform processes the data collected by an inertial MOCAP suit and computes in real-time the scores of RULA, REBA, and OWAS. Time performance is also considered an indicator of assembly activity efficiency. Only the RULA, REBA and OWAS indexes were adopted for this analysis because of their suitability for the particular assembly activities we evaluated. However, other ergonomic risk indexes can be integrated into the analysis depending on the industrial context analyzed.

As an example, for multi-person ergonomic risk assessment on multi-manned workstations of automotive assembly lines, the platform could be extended with the European Assembly Worksheet (EAWS) (Schaub et al., 2013) designed for the automotive industrial sector.

The first scenario involves only Operator #1. The operator performs the drawer assembly activity without any previous training experience or external feedback intervention. For this scenario, the WEM-Platform computes the RULA, REBA, and OWAS ergonomic risk indexes during the assembly task, but no visual feedback is provided to the operator during the progression of the assembly tasks.

In the second scenario, Operator #1 repeats the assembly task of the same drawer. In this case, however, the operator receives feedback from the WEM-Platform during the assembly. The WEM platform constantly monitors the operator's posture and assesses RULA, REBA, and OWAS ergonomic risk scores in real-time. Additionally, a virtual representation of the trainee's posture is shown on the workbench monitor to provide the operator with intuitive visual feedback while performing the assembly activity.

The last scenario (Scenario 3) of this first part of the analysis involves Operator #2, who executes the assembly task of the same object with the adoption of the WEM-Platform feedback notification.

The second part of the analysis focuses on multi-person ergonomic assessment in materials picking and in assembly activities performed in a multi-manned workstation.

In detail, the studied activities are:

- Scenario 4: Activity of picking up three large sheets and placing them in a shelving at three different heights.
- Scenario 5: Assembly activity of a medium-size cart performed in a multi-manned workstation.

Scenario 4 has been designed to analyze the effect that the anthropometric characteristics of different operators may have on ergonomic risk indexes. During the activity, the operator moves three large metal sheets from a 1 meter high workbench. He picks up the first one and walks about 2 meters to the rack to place the metal sheet at the ground level (i.e., 15 cm from the ground). He then goes back to take the second one and place it at the middle level (i.e., at the same height as the workbench). Finally, he picks up the last one and places it on the upper level of the rack (i.e., about 2 m. from the ground).

This analysis aims to determine how the difference in height between the two operators can affect their ergonomic risk scores while working in the same workplace. In this sense, our two volunteers have a height difference of almost 15 cm.

Finally, a multi-person ergonomic risk assessment is progressed for a cart assembly activity in a multi-manned workstation. The assembly process consists of assembling two shelves, initially placed on a pallet close to the workstation, at different heights on the cart. Each shelf is fixed with two bolts on both sides of the cart.

Due to the dimensions of the object, which can be considered a medium-sized product (150 x 93 x 70 cm), it was not possible to proceed with its assembly on the workbench. For this reason, assembly activity was carried out in front of the workbench, where two monitors displayed to both workers their postural risk assessment in real-time (Figure 1).

3.3. Data Collection and Processing

Raw data capturing and index scores assessment are performed in real-time by the WEM-Platform. In the laboratory tests, we used two IMU-based MOCAP suits (Xsens MVN Awinda). Each Xsens MVN Awinda suit includes 17 IMUs. They provide data up to 60 Hz wirelessly, with an indoor range of 20 meters.

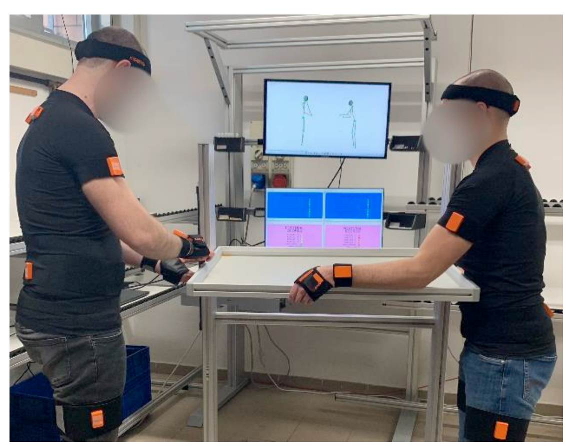

Figure 1: Real-time multi-person postural assessment

As shown in a recent study (Guidolin et al., 2021), such IMUs are extremely accurate, with an average error of 0.26° when tracking motion in the range characterizing most human movements. The choice of the input system is not mandatory, as the WEM-Platform does not depend on the adopted

MOCAP system as long as it can the joint angles describing the poses of the operators. For this reason, the analysis could also be performed with markerless systems, such as cameras, or other marker-based MOCAP. The setup phase on the Xsens MOCAP system requires collecting some anthropometric measures used during the motion capture section to enhance the accuracy of the performed analysis. Data collection includes the worker's standing height, upper leg height, knee height, upper arm length, and wrist breadth.

4. RESULTS

4.1. Feedback intervention in single-person workplace

The results (Table 1) obtained from the ergonomic risk assessment performed in the first part of the analysis highlight the postural improvement of Operator #1 in the drawer assembly activity. Table 1 provides RULA, REBA, and OWAS index scores for both sides of Operator #1. The improvement in postural behavior between the first and second scenarios is significant for all the ergonomic index scores. The REBA index for the right side has the highest score improvement, corresponding to 34,3% of the initial value.

Table 1: Impact of the feedback intervention on the inexperienced worker (Operator #1)

Index	**Side**	**Scenario 1**	**Scenario 2**	**Δ %**
		Operator #1		
RULA	Right	5.32	4.39	-17.5%
	Left	5.44	4.66	-14.3%
REBA	Right	6.1	4.01	-34.3%
	Left	6.09	4.17	-31.5%
OWAS	-	149.37	112.74	-24.5%
Time [sec]	-	260	261	0.4%

Table 1 shows that the greatest improvements are achieved on the right side of the body. The reduction of REBA score for both sides of the body is considerable, although the total assembly time did not increase. Table 2 reports the risk assessment of the assembly tasks performed while the WEM-Platform provided visual feedback first to the inexperienced worker (Operator #1) during his assembly activity (Scenario 2) and then to the experienced worker (Operator #2) during the same individual assembly activity (Scenario 3). This analysis aims to evaluate whether the adoption of the ergonomic platform reduces the differences between operators' postural risk during the same assembly activity.

Table 2: Ergonomic risk score comparison between inexperienced (Operator #1) and experienced (Operator #2) workers.

Index	**Side**	**Scenario 2**	**Scenario 3**	**Δ score**
		Operator #1	Operator #2	
RULA	Right	4.39	3.97	0.42
	Left	4.66	4.12	0.54
REBA	Right	4.01	3.98	0.03
	Left	4.17	4.17	0
OWAS	-	112.74	103.74	9
Time [sec]	-	261	230	31

Although the results obtained show that an experienced worker still behaves slightly better from an ergonomic perspective than an inexperienced worker, the differences are strongly reduced. In fact, it is possible to notice that WEM-Platform feedback intervention results in almost the same average value for the REBA index score for the two workers. From the duration of the time analysis, the assembly task duration of the experienced user is 31 seconds shorter than that of Operator #1.

4.2. Individual anthropometric features

The analysis performed in Scenario 4 aims to test whether anthropometric characteristics affect ergonomic index scores. The results reported in Table 3 confirm our expectations, especially for the REBA index time average values.

Table 3: Ergonomic risk assessment scores for multi-person pick and place activity

Index	**Side**	**Scenario 4**	
		Operator #1	Operator #2
RULA	Right	4.44	4.23
	Left	4.43	4.36
REBA	Right	3.42	4.82
	Left	3.49	4.93
OWAS	-	138.79	149.3
Time [sec]	-	36	

Despite the greater experience in the assembly activity of Operator #2, his risk score increased due to the hazardous postures maintained while moving the metal sheets.

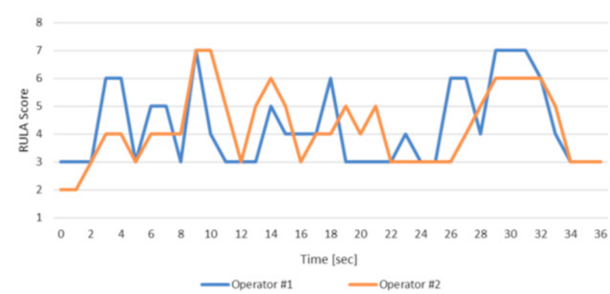

Figure 2: RULA index for pick and place activity (Scenario 4)

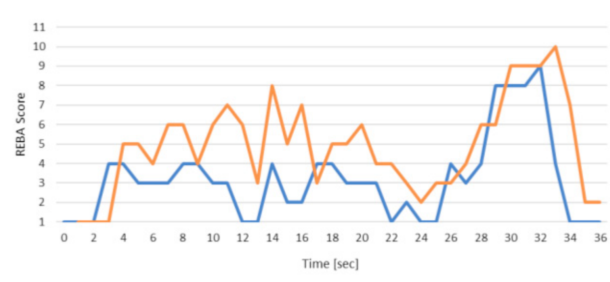

Figure 3: REBA index for pick and place activity (Scenario 4)

Regarding the RULA index (Figure 2), we can point out that there is a slight difference between operators' postural risks. Although the value represents a warning for operator safety (i.e., a RULA index score greater than 4 requires the implementation of some actions to reduce the value for this activity), the RULA index itself does not provide other helpful information on the anthropometric differences between the two operators. On the contrary, Figure 3 on the REBA index clearly indicates that there are only a few cases throughout the duration of the activity where the ergonomic risk of Operator #1 exceeds that of his shorter colleague.

4.3. Multi-Person Ergonomic Risk Assessment

In the last scenarios, we adopted the WEM-Platform to assess multi-person ergonomic risk for two operators. Table 4 reports the results of Scenario 5. This scenario involves two workers collaborating on a cart assembly task. Throughout the duration of the activity, the WEM-Platform provides real-time visual feedback through two monitors placed on a nearby workbench (Figure 1). The monitors show the digital representation of the operators, the NIOSH angles, together with the RULA, REBA and OWAS risk index scores.

Table 4: Ergonomic risk assessment of assembly activity in multi-manned workstation

Index	**Side**	**Scenario 5**	
		Operator #1	Operator #2
RULA	Right	4.54	4.24
	Left	4.92	4.12
REBA	Right	5.38	5.49
	Left	5.92	4.49
OWAS	-	205.21	145.43
Time [sec]	-	288	

The analysis aims to highlight the postural risk assessment of Operator #1 working together with an experienced operator. In a multi-manned assembly workstation, the activities performed by each operator may differ depending on product precedence constraints and task scheduling decision.

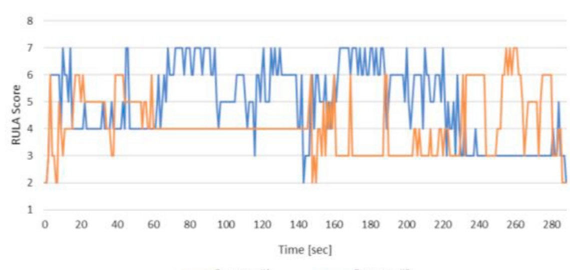

Figure 4: RULA index for multi-manned assembly station (Scenario 5)

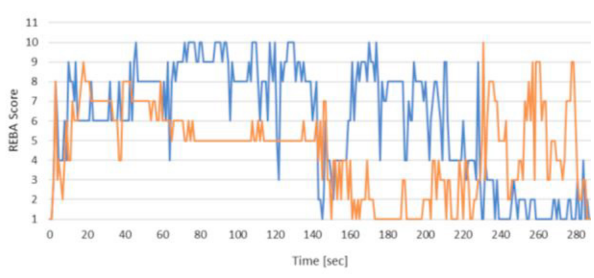

Figure 5: REBA index for multi-manned assembly station (Scenario 5)

For this reason, it is fundamental to monitor the behavior of both operators to highlight individual's postural risk scores. The computation of risk indexes in real-time allows the ergonomist to immediately detect uncomfortable postures during the progression of the activity (Figure 6). The scores reported in Table 4 show that Operator #2 completes the activity with a lower average ergonomic risk. Furthermore, Figures 4 and 5 show that Operator #1 usually exceeds Operator #2 scores for both RULA and REBA indicators. We can then conclude that Operator #2's expertise allowed him to achieve a lower average ergonomic risk compared to the inexperienced worker.

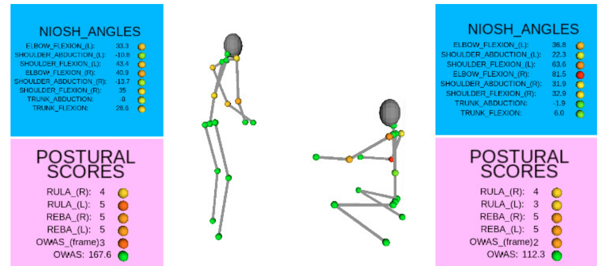

Figure 6: WEM-Platform multi-person real-time ergonomic assessment in multi-manned assembly workstation

5. DISCUSSION AND CONCLUSIONS

This work describes the first attempt toward real-time multi-person ergonomic risk assessment in logistic and manufacturing workplaces. The proposed research aims to demonstrate the effectiveness and flexibility of adopting an internally developed ergonomic platform during multiple ergonomic risk assessments and to provide insights from recent laboratory tests conducted in the logistic laboratory of the University of Padova. We demonstrated that the WEM-Platform can monitor multiple people simultaneously, providing a progression of the ergonomic indexes in real-time concurrently to operators performing collaborative tasks. This new feature extends the potential of the platform for simultaneous risk assessment compared to the single ergonomic risk assessment proposed in Battini et al. (2022).
To the best of the authors' knowledge, this is the first study on multi-person real-time ergonomic risk assessment. In this work, we also presented results that demonstrate that the WEM-Platform is able to correct and improving postures, especially for first and inexperienced workers. We showed that software feedback positively impacted ergonomic risk during the initial training phase. This solution can ease and speed up the safety introduction of new operators into the workplace.
The results also suggest that the management of the company workforce should consider the anthropometric features during task scheduling. We showed that workers' height can affect the ergonomic risk assessment. For this reason, managers must recognize that task scheduling activity must be performed with complete awareness of both the workplace and workers' characteristics (Berti et al., 2021). As a consequence, real-time postural training and worker oriented task assignment should be jointly executed in order to maximize the ergo quality of the work place. In its current form, the first limitation of this work is related to the number of people involved in the tests, which is not enough to provide statistically significant results and must be increased in future tests to strengthen the results.
We demonstrate the effectiveness of visual feedback for different levels of experience of workers only for the test case analyzed during individual assembly activity, but not for the multi-person assembly activities. This represents a limitation of the current work since visual feedback intervention is now provided only through the workbench monitor.
This type of feedback may lack effectiveness for medium- or large-sized products. For these products, it is common practice for the operators not to work on the workbench; thus, the video terminal could be ignored by the operator. Future research will investigate alternative modalities to provide inobtrusive feedback to operators during task execution using wearable tools (e.g., using augmented reality visors or smartwatches).

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