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PROCESS SIMULATE VERSUS INERTIAL MOCAP SYSTEM IN HUMAN MOVEMENT EVALUATION

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Abstract
There are various tools for evaluating physical ergonomics. Two main computer-assisted approaches can be recognized in the literature: analytical evaluation using simulation software like Siemens Jack or Process Simulate, and empirical evaluation by tracking human body movement. Both methods have their own advantages and disadvantages. This article compares an analytical method using Process Simulate software and an empirical evaluation using an inertial motion tracking system and highlights the strengths and limitations of both approaches. The information from the tracking system is processed by the Process Simulate software and an ad-hoc ergonomic analysis module developed in Unity. Given the limited license of Process Simulate, the ergonomic comparison is performed using two indices, RULA and OWAS. Other comparison metrics discussed in the article are the time required for the analysis, the additional functionality each solution offers and the possibility of augmenting the assessment with virtual or augmented reality solutions. The results show some limitations of using Process Simulate with the tracking data and the great versatility of the solution developed in Unity.
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Key Words: Ergonomics, Simulation, Analytical Evaluation, Empirical Evaluation

1. INTRODUCTION

According to the International Ergonomics Association (IEA), physical ergonomics is the scientific discipline that deals with the anatomical, anthropometric, physiological and biomechanical characteristics of humans during physical activity [1]. Creating ergonomic environment offers companies numerous advantages. First and foremost, an ergonomic workplace promotes the psychophysical well-being of employees and improves job satisfaction [2]. In addition, the correct execution of work tasks reduces absenteeism and injuries, thereby increasing productivity and company profits [3, 4]. In general, a healthy work environment attracts and retains talent, maintaining a good brand reputation [5].

Currently, there are various methods for assessing physical ergonomics in the industrial sector [6]. The observation method is the most popular approach nowadays. It is based on direct observation and video analysis of the activities performed by employees [7]. These analyses make it possible to evaluate postures and movements under real working conditions. However, recent studies show that the reliability of these assessments is sometimes low, especially when analysing hand and wrist postures [8]. Another method relies on self-assessments through questionnaires and interviews with operators. While self-assessment methods provide practical insights from the operator's perspective, they often lack the objectivity required for accurate ergonomic analysis. The integration of empirical data through motion capture systems provides a more detailed understanding of body mechanics [9], which can reduce subjective bias and improve the accuracy of ergonomic assessments.

Several studies have investigated the validity and reliability of self-report questionnaires to assess physical ergonomic stress at work, such as Barrero et al. [10] in their study. These studies show that self-report questionnaires, when properly designed and validated, provide a practical and cost-effective way of assessing ergonomic strain compared to direct observation or instruments, with acceptable consistency, validity and ability to distinguish between high and low-strain groups. These techniques provide direct feedback on users' perceptions and experiences but can be affected by subjective biases and the ability of operators to express themselves.

To overcome these limitations, ergonomic analysis has benefited greatly in recent decades from advances in information technology that enable the use of simulation software to evaluate and optimize workstations more efficiently and accurately [11, 12]. Simulation software for ergonomic analysis represents a significant advance over traditional methods based on direct observations and manual measurements. These tools enable the modelling and evaluation of complex scenarios with greater precision and in less time, even with collaborative robots [13]. Simulation software such as Process Simulate, Siemens Jack, DELMIA by Dassault Systèmes and AnyBody Modelling System help ergonomists to simulate a specific task in a virtual work environment and optimize it based on an ergonomic analysis [14-16]. These software programs are widely used in industry to analyse human-machine interactions, predict ergonomic risks and optimize production processes [17]. They provide the ability to create detailed three-dimensional models of workstations and evaluate the impact of design changes on operator health and safety. One of the main advantages is the ability to integrate real-world data and provide interactive visualization, which facilitates the identification of ergonomic issues and communication of results to stakeholders. However, the use of commercial simulation software also comes with some challenges. The high cost of licenses and the need for specialized training can be a significant barrier, especially for small and medium-sized companies. Furthermore, the complexity of these tools can require a steep learning curve for less experienced users [18].

In this context, the use of open-source game engines to develop customized ergonomic analysis solutions offers a viable alternative. Game engines such as Unity and Unreal Engine are primarily known for game development, but also offer powerful rendering and simulation capabilities [19] that can be used to create highly customized and interactive ergonomic simulation environments. Solutions based on these tools can be developed at a lower cost and with greater flexibility compared to commercial software. The ability to customize every aspect of the simulation allows researchers to tailor the tool to the specific needs of a project, improving the accuracy and relevance of ergonomic analyses. On the other hand, automating the entire assessment process for each physical ergonomics index is difficult to accomplish.

Various applications of simulation software and game engines for ergonomic analyses have been investigated in the scientific literature. Kumar Sharma et al. [20] analysed the use of computer-based applications for industrial ergonomics such as Anybody Modelling System and DELMIA considering cost, capacity, and versatility for the best option to determine the need for interventions. Baskaran et al. [21] investigated the use of Process Simulate (PS) to evaluate human-machine interaction in the automotive industry and introduced ROS (Robot Operating System) – Industrial for real-time robot control. Finally, Paravizo and Braatz [22] evaluated the suitability of a game engine simulation to support the analysis of human factors and ergonomics, considering not only the physical aspects but also cognitive and organizational ergonomics.

Nevertheless, there is no specific comparison between simulation software and game engines in this area. In this context, the thesis aims to compare the evaluation of physical ergonomics using two specific tools: Siemens Process Simulate and a customized solution developed with the open-source game engine Unity. This comparison aims to demonstrate the potential and limitations of each approach and provide insights to improve ergonomic assessment practices.

2. METHODS

In this study, the ergonomics evaluation is performed using two different tools: the commercial software called Process Simulate, which is part of Siemens' Tecnomatix portfolio, and a custom module developed with the Unity 3D game engine, specifically designed for the work previously analysed by the authors in [23, 24]. PS is a 3D manufacturing simulation and validation software tool used to optimize production processes. With this software, manufacturers can simulate, analyse and improve complex manufacturing processes, including robotic operations, human tasks and entire assembly lines, in a virtual environment. Key features of PS include 3D visualization, robot simulation, human task simulation, process validation and virtual commissioning. PS is used in numerous industries, including automotive, aerospace, electronics and consumer goods, to ensure efficient, safe and cost-effective production processes. By enabling companies to digitally validate processes, it helps to minimize production risks, reduce costs and improve overall production quality. On the other hand, Unity 3D is a versatile game development platform that allows you to create interactive 2D and 3D experiences, including video games, simulations and virtual reality (VR) applications. Unity 3D's key features include cross-platform development, real-time 3D rendering, an extensive asset store, scripting and customization. Unity 3D is widely used not only in game development, but also in industries such as film, architecture, automotive and education, thanks to its flexibility and powerful features for creating immersive and interactive experiences.

For the ergonomic analysis, both analytical evaluations (from simulations in the Process Simulate software) and empirical evaluations from recordings from an inertial motion capture (Mocap) system called Xsens are used. Since the recorded data is then used by both software programs for the ergonomic evaluation, the final results are presented within three different approaches (see Fig. 1): PS with simulated assessment, PS with recorded data, and assessment with Unity modules based on the information from the body sensing system. Each tool was evaluated not only in terms of its ergonomic assessment capabilities, but also in terms of its ease of use, flexibility and adaptability in different industrial contexts. The study aimed to provide a comprehensive analysis by taking into account these additional factors that are crucial for practical implementation in different environments.

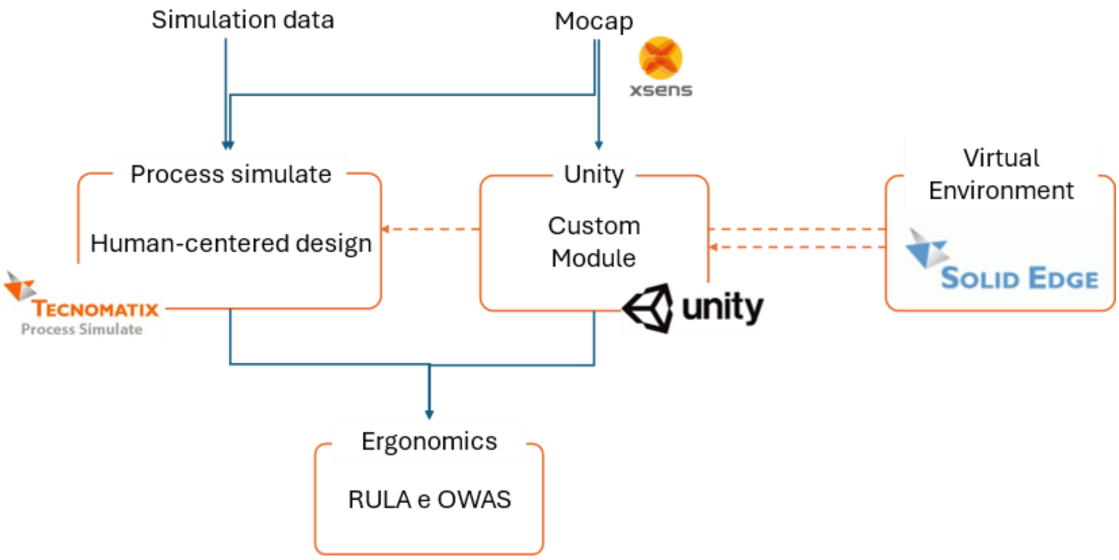

Figure 1: Physical ergonomics analysis framework.

The comparison methods chosen are as follows:

- **Ergonomic evaluation:** among the various ergonomic indices in the literature, the Process Simulate license allows evaluation only for RULA (Rapid Upper Limb Assessment) and OWAS (Ovako Working Posture Analysis System). Process Simulate provides an immediate assessment with the possibility to generate a final report allowing an analytical assessment for static positions. The software does not provide an average value of the index over time, so it must be manually assessed later. The estimated result is considered reliable for the RULA index as it is a single value that is stable over time. For the OWAS index, on the other hand, it is unreliable as it contains five values that fluctuate significantly over time. Therefore, the dynamic ergonomic values for the OWAS index determined by Process Simulate are not included in the results.

- **Time required** for environment creation, simulation and ergonomic assessment.
- **Customizations** and **additional functionalities**.
- Potential for **VR/AR solutions**.

The creation of the environment is quite similar in both systems. Both software allows the import of external objects or the creation of simple geometric volumes such as parallelepipeds for the creation of a 3D environment. For the recreated scene, a 3D chair was modelled using the Solid Edge modelling software, while the rest of the environment was created using the volumes provided by the software. The environment recreated in Unity was created solely for comparison with PS, even though its creation was not necessary for the ergonomic evaluation.

3. TEST

The framework proposed in Fig. 1 can be used for industrial applications. Nevertheless, in order to better compare the two evaluation systems, a sequence of simple actions is proposed. The designed test includes three dynamic actions, and four static postures contained in a circuit, the so-called ‘polygon circuit’. Fourteen volunteers took part in the first tests, including 9 people with physical disabilities and the remaining healthy people. This selection makes it possible to check whether the simulation software can reproduce different realistic situations during the ergonomics assessment. The participants are of different ages and backgrounds. Table I lists all the information about the test subjects. Before the test, each subject takes a seat and their blood pressure and heart rate are measured to ensure that they are healthy. After measuring height and shoe length, the two data points the MVN software needs to start recording, the subject is carefully fitted with the Xsens Awinda suit with its 17 sensors. At this point, the subject is informed of the path they will take after the system has been calibrated. The sequence of actions involved in the path is shown in Fig. 2.

Table I: Participants information.

Participants	Gender	Age	Blood pressure	Heart rate
test person 1	M	69	109/66	75
test person 2	F	60	135/82	46
test person 3	F	42	150/84	64
test person 4	M	23	138/70	89
test person 5	M	29	117/66	54
test person 6	M	59	148/88	71
test person 7	M	58	153/89	73
test person 8	M	56	147/83	74
test person 9	F	43	122/72	52
test person 10	F	59	161/104	67
test person 11	F	43	163/105	105
test person 12	F	62	163/108	92
test person 13	F	63	152/92	81
test person 14	M	44	120/70	78

A sequence of actions:

a. Walking: Walking along a straight path of approximately 6 meters
b. Obstacle: Walking over 3 meters with 3 obstacles
c. Walking backwards: walking 3 + 2 meters backwards
d. Squat: squatting position
e. Arm raised: position with arms raised as if reaching for something high
f. Sitting: Sitting position
g. T-posture: arms in T-position and one leg raised (volunteer's choice) for 30 seconds

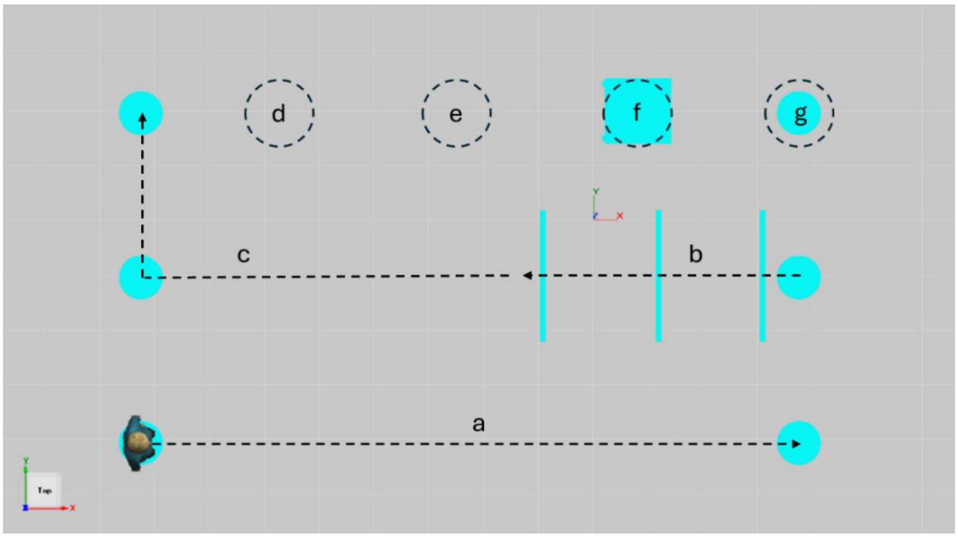

Figure 2: Polygon circuit with 3 dynamic actions (a, b and c) and 4 static postures (d, e, f and g).

Throughout the test, the Mocap sensor was used to record data on the movements, which are useful for ergonomic evaluation in post-processing. Three results from three different evaluations are presented below. For the sake of simplicity, these are labelled as follows:

- PS Simulation: this evaluation is carried out using Siemens' Process Simulate software by creating avatars, as explained in the next section.
- PS Mocap: This assessment is carried out using the PS software, with data recorded by the Mocap system.
- Unity Mocap: this assessment is carried out using Unity modules designed to process the data recorded by the Xsens system.

4. ERGONOMICS EVALUATION

This section describes the evaluation carried out. In the first step, human avatars are created for the PS simulation. To ensure greater inclusivity, four different avatars are created, two female and two male. Each avatar is chosen with a height and weight in the 50th percentile, but with different ages: one is 25 years old, the other 40 years old. As shown in Fig. 3, the 50th percentile corresponds to a height of 163 cm and a weight of 63 kg for women and a height of 175 cm and a weight of 79 kg for men. All other characteristics are set to the default values provided by the software. Once the avatars are created, the next step is to recreate the virtual environment by inserting various obstacles and objects and assigning tasks to the avatars. For the static postures, it was necessary to manually adjust some body angles.

Fig. 4 shows the different steps performed by the avatar during the simulation.

Using the same software, an empirical analysis can be performed on the Mocap system to obtain the PS Mocap score. The software enables communication with various motion capture devices, including the Xsens system. The same communication can be achieved via a special

Unity plugin that allows the user to send and receive information with the MVN software. Fig. 5 shows the two environments.

Figure 3: Human Avatar characteristics used in Process Simulate.

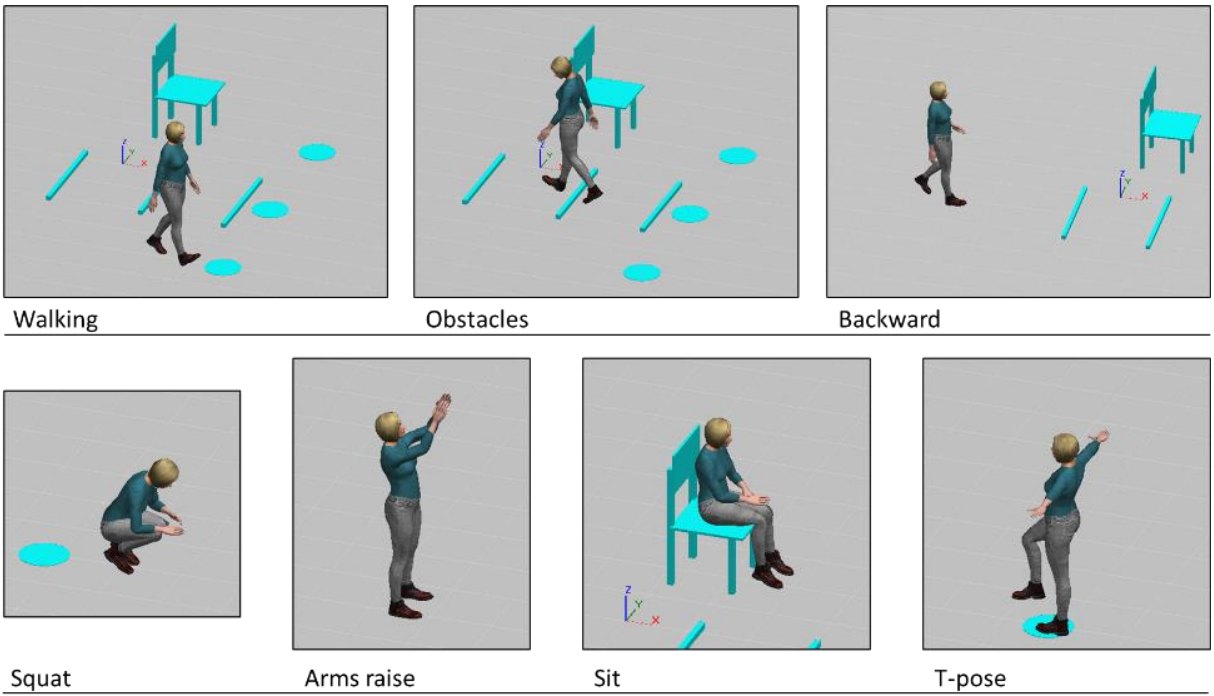

Figure 4: Simulated steps of the 'polygon circuit'.

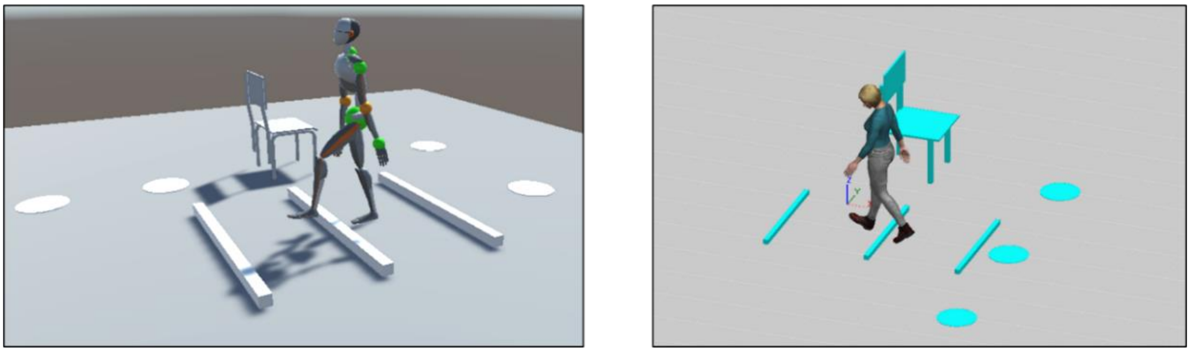

Figure 5: The virtual Unity 3D environment (on the left) and the Process Simulate environment (on the right).

5. RESULTS

As the Process Simulate license restricted the analysis, the ergonomics evaluation only includes the RULA and OWAS indices. In this section, various comparisons of the results are shown, both in tabular form and in diagrams. Regarding the four human avatars proposed for the simulation (two male and two female), the evaluation results obtained are very similar to each other; therefore, only one result is reported in the following section.

First of all, it is important to distinguish two different types of actions analysed:

- **Dynamic actions** (walking, obstacle, backward walking): The ergonomic index is evaluated frame by frame and then averaged over the entire duration of the action. As explained above, Process Simulate does not provide a final averaged index, so this assessment is done manually. However, since the OWAS index consists of several sub-indices that fluctuate rapidly over time, calculating the average proved to be unreliable. For this reason, only the RULA index for dynamic actions is calculated.
- **Static actions** (squatting, arm raising, sitting, T-posture): The ergonomic index for static actions can be easily assessed using observational methods traditionally used by ergonomists for ergonomic assessments. Therefore, in addition to the comparison between the two software systems, a comparison was also made with the index calculated manually using the RULA and OWAS tables.

5.1 Dynamics

Fig. 6 shows the analysis carried out for each dynamic action performed. In particular, it compares the average errors obtained in the evaluation of each subject (see Fig. 7) and the final results between the Mocap system and the simulation (Table II).

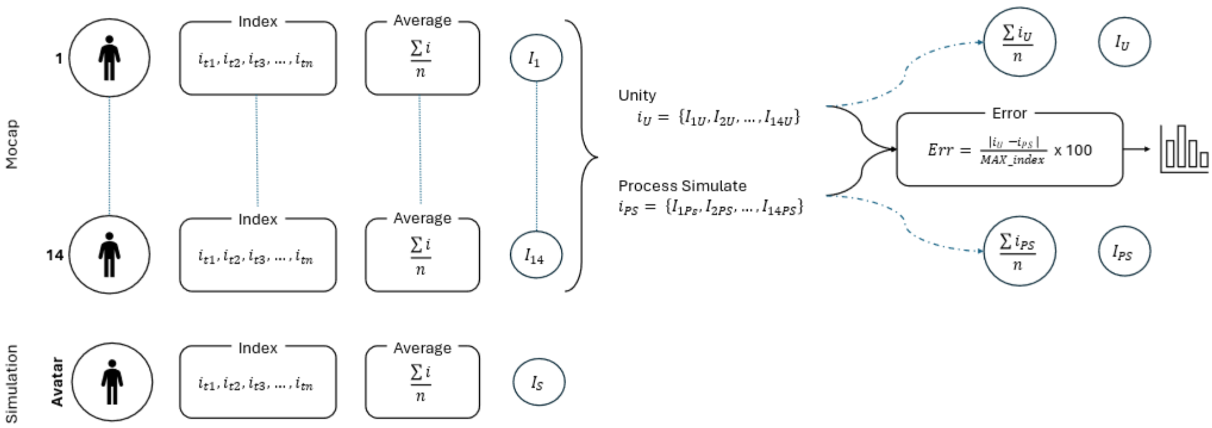

Figure 6: Ergonomics analysis for dynamic actions.

The graph shows that in most cases the average error between the evaluation system performed by Process Simulate and the Unity module with the Mocap system is less than 20 %.

Table II shows the comparison between I_S, I_{PS} and I_U (see Fig. 6), respectively the average of the index obtained from the evaluation in PS simulation (I_S), PS Mocap (I_{PS}), and Unity Mocap (I_U).

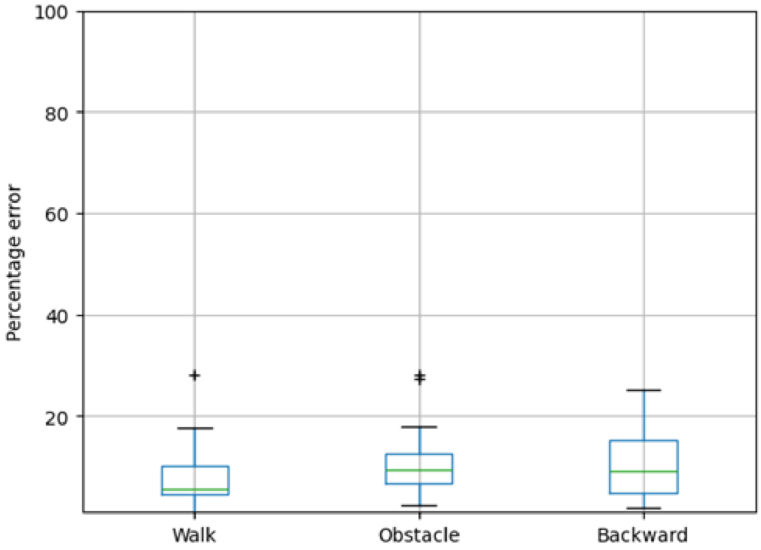

Figure 7: Ergonomics analysis for dynamic actions.

Table II: RULA comparison between analytical and empirical analysis for dynamic actions.

RULA (1-7)	**Walk**	**Obstacles**	**Backward**
Process Simulate '*simulation*'	2.21	2.15	2.00
Process Simulate '*mocap*'	3.20	3.47	3.72
Unity '*mocap*'	3.01	3.02	3.11

5.2 Static

In static evaluation, a single value is evaluated at the moment the position is reached. The average error between the evaluations of the Mocap system is calculated for both the RULA index (see Fig. 8 a) and the OWAS index (see Fig. 8 b).

The consistency of the results between the different avatars indicates that the results are robust and are not significantly affected by minor variations in the anthropometric data. This consistency speaks to the reliability of the simulation method used in this study.

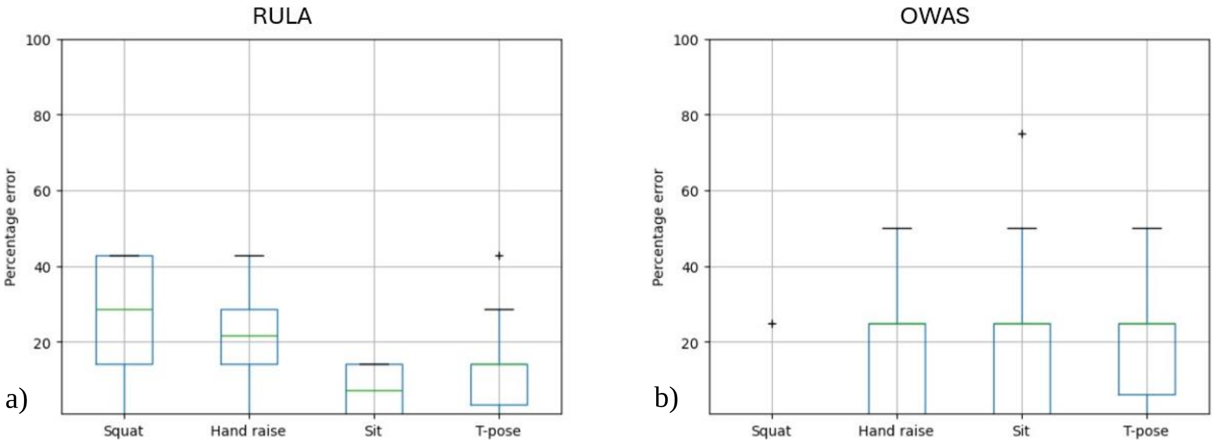

Figure 8: a) RULA and b) OWAS percentage error in static evaluation using the Mocap system.

For the final comparison with the index obtained from the analytical simulation, the results are presented in Table III for the RULA index and in Table IV for the OWAS index. The tables also contain the "observed value", which is the result of a manual assessment with paper and pencil based on the observation of the analysed position.

Table III: RULA comparison between analytical and empirical analysis for static actions.

RULA (1-7)	Squat	Hand raise	Sit	T-pose
Observational	3	5	2	3
PS 'simulation'	3	5	3	3
PS 'mocap'	5.1	5.5	3.2	4.0
Unity 'mocap'	3.25	4	3	3.07

Table IV: OWAS comparison between analytical and empirical analysis for static actions.

OWAS (1-4)	Squat	Hand raise	Sit	T-pose
Observational	3	1	1	1
PS 'simulation'	3	2	1	1
PS 'mocap'	3.1	1.8	1.9	1.8
Unity 'mocap'	3	1	1	1

6. DISCUSSION

Like the presentation of the results, the discussion is also divided into dynamic and static actions. In addition, further considerations are made in section 6.3 'General considerations'.

6.1 Dynamics

The percentage error shown in Fig. 7 between the assessments performed with Mocap systems using the two software platforms may be due to the fact that the average for Process Simulate is calculated manually, adding a subjective element to the assessment. Nevertheless, the table shows that the final average scores are in the 3–4 range of the RULA index. This value is higher than the value determined by the analytical assessment (Table II), which is in the 2–3 range. The difference is mainly due to the fact that the simulation models a typical walking pattern without taking into account possible disabilities of the test participants. Some participants had difficulty walking and occasionally assumed positions that are not typical for a healthy person. As a result, the final ergonomic index is slightly higher.

6.2 Static

Fig. 8 shows significant differences between the Mocap assessments performed by the two systems. Before analysing this aspect, it is important to determine which assessment is more reliable. For static position evaluations, the Process Simulate simulation can be considered the gold standard (Tables III and IV).

As expected, the observational evaluation performed manually with pen and paper largely agrees with this gold standard. The only two differences are observed in the seated position for the RULA index and in the raised arm position for the OWAS index. These differences are primarily due to the subjective nature of the assessment of certain body regions. A more detailed analysis revealed slight discrepancies in the assessment of the arm angle for the seated position and the trunk angle for the position with raised arms. When comparing these ratings with the Unity Mocap results, it becomes clear that the values are quite close to each other. The small differences are due to the subjects adopting a slightly different position to the mannequin used in the simulation. However, the Process Simulate Mocap evaluation yielded different results. These discrepancies, particularly in the assessment of the squat with the RULA index, are due to tracking errors that were not correctly reproduced in the Process Simulate software. Occasionally, the mannequin assumed unusual postures that deviated from the actual recorded positions.

6.3 General consideration

The first consideration concerns the time required for the ergonomic assessment with the tools used. The 'PS simulation' involves modelling and creating the virtual environment required to interact with the mannequin, such as adding a chair to simulate a seated position. This step is time-consuming, making 'PS simulation' the most time-consuming method compared to the other two approaches. Some studies are investigating a specific tool to reduce this time and increase the productivity of the simulation expert [25].

'PS Mocap' and 'Unity Mocap' are quite similar in this respect; they only require the activation of communication with the Mocap system used (in this case the MVN software) and the selection of the index to be evaluated. With the Unity solution, however, the programming skills required and the time required to develop the evaluation modules must also be taken into account. In contrast, no special knowledge is required for Process Simulate, although, as already mentioned, the license limits the assessment to a few ergonomic indices. In addition, the open-source nature of Unity provides opportunities for further innovation and customization, enabling researchers and practitioners to develop bespoke solutions that can be tailored to specific ergonomic challenges. This flexibility is particularly beneficial in rapidly evolving industrial environments where standardized solutions may not suffice. Finally, both Process Simulate and Unity support integration with virtual and augmented reality systems.

7. CONCLUSION

This study compares two methods of ergonomic assessment in an industrial setting: one analytical and one empirical. For the empirical methods, two approaches were evaluated: a human digital modelling software called Process Simulate and a custom solution developed using the open-source software Unity. To ensure a clear and effective comparison, a well-defined test protocol was created that included various simple actions (three dynamic and four static). To broaden and diversify the results, both healthy participants and those with mobility impairments were included in the evaluation. The comparison revealed advantages and disadvantages for each approach in terms of reliability of results, assessment time and other factors.

Future research should investigate the integration of additional motion capture systems and ergonomic indices, as well as the development of more user-friendly interfaces, which will consequently lead to more extensive studies and appropriately arranged workplaces [26]. These advances will help bridge the gap between sophisticated analytical tools and practical applications in the workplace and ensure that ergonomic assessments remain both rigorous and accessible to a wide range of users.

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