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Novel Design of Assistive Technologies Based on the Interconnection of Motion Capture and Virtual Reality Systems to Foster Task Performance of the Ageing Workforce

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Abstract: Demographic changes, increasing life expectancy, and increasing healthy life expectancy lead to an increasingly ageing workforce. This condition has a growing impact on the workforce in today's industries. However, old workers are not a burden for companies and industries. They are a fundamental part of the industrial ecosystem due to the consistency of their human factors, namely their large knowledge, experience, and decision-making ability. For this reason, the ageing workforce must be incorporated and engaged through the introduction of digital age technologies to improve their working conditions and extend their active life. This paper focuses on a novel design of assistive technologies based on the interconnection of motion capture (MoCap) and virtual reality (VR) systems as a driver for the improvement of the task performance of the ageing workforce. We intend to explore how this technological tool can help and enhance the work of the ageing workforce. For this, we study two different areas of application: the training, learning, and communication of the older workers and the ergonomic analysis and workplace design for the ageing operators. In the end, a pilot study is proposed to apply this technology in real work environments.

Keywords: ageing workforce; virtual reality; motion capture; training; learning; workplace design

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1. Introduction

Population demographic transformations are causing changes all over the world [1]. The ageing of populations that has taken place across the world presents a direct impact on workforces, and consequently on the employability rate of older operators. This means that there has been a growth in the number of elderly individuals in companies and industries who actively remain in the workforce. It is predicted that by 2030 the rate of workers aged 55–64 is expected to be more than 30% of the workforce in several countries [2]. The ageing workforce is one of the biggest challenges that human beings are facing today because there are still no clear, detailed, and shared strategies to take corrective and preventive measures to reduce its impact on production industries [1,3]. Nevertheless, recently, general requirements and guidelines for an age-inclusive workforce were published in the ISO 25550:2022 for ageing societies, which have the potential of adding value for organizations, workers, communities, and other stakeholders, with a specific focus on older workers [4].

Older workers experience a reduction in their work capacity due to the negative impact of age, musculoskeletal pain, and inappropriate ergonomic exposure [5]. In addition, ageing workers exhibit less adaptability to innovation and information and communication technologies, as well as a relative loss of their physical strength. Studies show that age negatively affects response time, being almost double compared to younger individuals, but does not affect accuracy, for example in a hammering task [6]. Other studies demonstrate significant differences between age groups in posture during object lifting after prolonged exposure to sitting work. In this scenario, older people have a much more reduced total range of motion [7]. However, these older workers are considered a vital resource for companies and industries for their human and cultural heritage [1]. Nevertheless, although humans are an essential key to modern and digitalized production systems, special attention needs to be paid to the ageing workforce. Thus, it is possible to actively integrate them into the factories and companies with the use of technologies, such as virtual reality, augmented reality, exoskeletons, and collaborative robots, which can help and assist the ageing operator during work tasks [2].

However, in various work situations, working conditions such as safety, well-being, operational risks, and operator productivity can be effectively improved by applying a collaborative user-centered approach, also known as human-centric manufacturing [8,9]. The digitalization of industry and its transformation process is a challenge of Industry 4.0 associated with the Fourth Industrial Revolution. This represents a great potential for innovation but with an impact on the role of the operator who is increasingly involved in intelligent activities and decision-making processes [5,6]. With industrial development, the physical effort performed by operators during their work has been reduced, since workers are now supported and assisted by machines. In contrast, the cognitive skills of human beings and their decision-making ability add important value and are extremely necessary for production processes [10]. Therefore, the current debate is about the cost-effectiveness of new technologies and their advantages for work development versus the empowerment of the workforce as it must be prepared and trained to handle these new technologies and the complexity and speed that production requires nowadays [6].

The application of new technologies in different work environments becomes a focus for improving working conditions as these technologies act as assistance systems for workers, simplify human-machine interaction, and enhance the physical and cognitive abilities of operators [6,8]. Virtual reality and motion capture are wearable technologies that may include inertial immersion units (IMUs), force sensors, and surface electromyography (EMG) [11]. Virtual reality is a real-time interactive computing technology that enables the creation and integration of any virtual environment. This technology allows users to manipulate and perform actions in cyberspace, becoming active participants, no longer just observers [12,13]. Some studies have shown that exercising with VR can reduce fatigue, stress, and depression and can provide relaxation, which is reflected in a positive point for older people when using this new technology [13]. In addition, wearable technologies, such as smartwatches and wristbands, are present in our daily lives that simply display health statistics and trends. That is, they are devices that provide real-time feedback that incorporates biosensor systems that continuously monitor the physiological state of the user, such as heart rate and rhythm, and skin temperature, among others [14]. These new technologies are emerging exponentially as useful tools for user performance and working condition improvements, risk monitoring and assessment, and the design of new workspaces in industrial environments [11,15–17].

2. Materials and Methods

The main debate between the technological advances in industries and the growing demographic challenge regarding the ageing workforce leads to numerous questions. From the issues concerning the cost-effectiveness of applying these technologies in industrial environments to the adaptation of the workers to the emerging innovative technologies, especially the older operators. This paper focuses on motion capture systems with virtual reality systems. Thus, our research question is: how can this technological tool help, enhance, and improve the work of the ageing workforce?

To respond to this, a survey of scientific papers with different applications of these technologies for possible industrial environment applications and, if possible, targeting the ageing workforce was conducted. The following keywords were used: "Ageing Workforce", "Older Worker", "Virtual Reality", "VR", "Mocap System", "Motion Capture", and "Wearable Sensors" in the following databases: ScienceDirect, Scopus, and Web of

Knowledge, with Boolean operators applied. The following database search string was used: ((“Ageing Workforce”) OR (“Older Worker”)) AND ((“Virtual Reality”) OR (“VR”) OR (“Mocap System”) OR (“Motion Capture”) OR (“Wearable Sensors”)). In addition, only scientific articles written in English and whose publication date was within the last 5 years, i.e., 2018–2022, were selected. From the search, 86 articles were obtained from Science Direct, 13 articles from Scopus, and 7 from Web of Science, totaling 105 articles. After that, 1 article was excluded because it was unavailable for full read text. Of the remaining 104 articles, the articles duplicates or triplicates were excluded. Thus, a total of 94 remained for analysis. The next step was the exclusion by reading the titles and the abstracts. Only 20 papers were eligible for the current study’s purpose, being analyzed and included in this paper. With this small number of scientific articles focusing on the particular use of these technologies in work environments highly dependent on the ageing workforce, it was necessary to use the system of “snowballing” to be able to obtain scientific data that could be relevant to the work [18]. A total of 37 articles were used for the construction and development of this paper. The results obtained were analyzed and sectioned into 2 main research area groups according to their purpose of use, which will be addressed in the following sections.

Finally, for future research, a pilot study proposal is presented where this tool can be applied to analyze the differences between younger and older workers. Thus, some conclusions could be drawn regarding their adaptation and involvement at work and, consequently, their levels of work satisfaction with health and safety improvements.

3. Results and Discussion

3.1. First Analysis and Creation of the Lines of Research

Through the database created with the completed search, the first verification was to analyze the main keywords of the studies used in this research work. For this, a database with all the information was used and applied in the software, called VOSviewer 1.6.17. It allows for generating bibliometric maps with the main relations and interconnections of the keywords [19,20]. The VOSviewer Map represented in Figure 1 was created through a fractional counting of the occurrence of the keywords of the articles’ index.

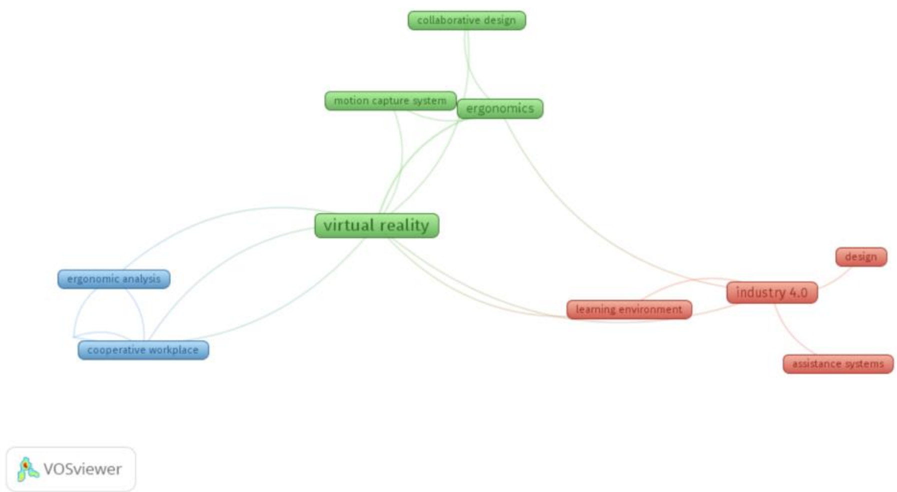

Figure 1. VOSviewer Map of keywords’ occurrence.

The keywords that had a high occurrence and which had fundamental interconnections for the study were “Virtual Reality”, “Industry 4.0”, “motion capture system”, and “cooperative workplace”, which are interconnected and linked to others, such as “design” and “collaborative design”, “ergonomics” and “ergonomic analysis”, “learning environment” and “assistance systems”. They are organized into three groups, as represented in Figure 1, through different colors: “Virtual Reality” as green, “Industry 4.0” as red, and "cooperative workplace" as blue. It is important to mention that the interconnection and the overlapping of the themes in the different clusters are highlighted. This proves the dependency and the need for interconnection of all these research areas. Thus, as an example, for the creation and development of cooperative workplaces, it is necessary to consider the ergonomic analysis and a collaborative design application for operator assistance systems with Industry 4.0 technologies. These clusters and relations of keywords allowed the section of the following chapters as research lines that influence the operator and especially the ageing workforce.

The lines of research chosen are in line with other investigations. Alves, Lima, and Gaspar (2022) [2] concluded that the application of digital technologies in human-centred production systems to assist industrial environments with high sociodemographic challenges, i.e., with the ageing workforce, is very small and still underdeveloped. Therefore, this work follows a line of research that focuses on training, communication, and learning that fits with the management strategies for the ageing workforce of Calzavara et al. (2020) [21]. A second line of research of ergonomic analysis and design of new workplaces follows the framework of technological solutions as worker assistance by Giakoumis et al. (2019) [22] and Mark, Rauch, and Matt (2021) [23]. Training and continuous learning and the application of digital technologies are some of the strategies that can boost and improve the involvement of ageing workers. Thus, in the first research line, "virtual reality systems" for the creation of learning, training, and communication environments are discussed. In the second research line, "virtual reality and motion capture systems" for the design of new workplaces and ergonomic analysis are discussed.

3.2. Research Area 1: Training, Learning, and Communication

Virtual reality (VR) is one of the Industry 4.0 technologies that allow for a decrease in design and production costs, maintain product quality, and overcome technical demands of complexity and efficiency. VR is a widely used tool in teaching and learning, such as teaching students to simulate safety scenarios. However, to acquire better results and to bring benefits, it is essential to apply it in real-case scenarios for real-time data collection and physical motion capture [12].

The use of VR's immersive capabilities in learning processes allows the discovery of new knowledge, the possibility to perform experimental tasks that would be impossible to perform or practice in the real world, and to obtain appropriate knowledge and skills in real-life situations [24]. Therefore, this technology is a great substitute for the real-life environment where safety concerns can be reduced and minimized and is therefore suitable for training new workers [12]. In the future, more adoption of the training-by-technology technique is intended to promote industry collaboration and involvement in the Immersive Learning Program [25]. Furthermore, learning in VR-based environments varies depending on the technology design intent, functionality, and learning objective, but is facilitative because it potentiates learning through repetitive exploration and practice in a risk-free learning environment [24].

Virtual reality has been shown to enhance the cognitive learning process in different social areas and everyday skills, namely in tasks such as shopping, cooking, cleaning, and in vocational training, improving the skills, and behaviors of the users [26]. In addition, it has also been applied to motor coordination and balance training systems for older people to prolong their physical ability [13]. Regarding the application of VR-based training, virtual reality technology has been employed in manufacturing, construction, and military operations, and can also be used in more sensitive areas such as medicine and medical surgery to assess trainee skills. In addition, for high-risk industrial environments, such as maintenance line workers, who are subjected to and involved in workspaces with high-risk factors, VR can be used to create virtual environments of complex situations to train workers and help them to acquire risk prevention knowledge [24]. Therefore, it can be said that virtual reality training systems (VRTS) can be an effective and safer alternative than traditional training for high-risk work environments [24]. For example, the application of virtual reality as a screening tool for the cognitive health of aviation pilots has been studied to prevent and manage critical risks in older pilots [27].

On the other hand, VR-based training systems can also be coupled with teleoperated robotic systems in which the user gives commands to the collaborative robot to perform the work task virtually [10]. Other strategies that have been developed to counteract isolation and social distancing when applying virtual reality systems is the use of embedded systems with networked communication robots, a "Chatbot", in which they provide the information needed for task development or contain a database of information about the work area [28]. Another way is the projection visualization of the virtual environment being studied so that co-workers can intervene and collaborate as a team [29].

3.3. Research Area 2: Design of Workplace and Ergonomic Analysis

The factories of the future aim to optimize their production processes, and their sustainability and give the worker a central role at work. This is fundamental to a human-centered approach where the operator is a crucial element in the industrial ecosystem [9]. Thus, the workplace of the future allows a decrease in the physical load of operators, reducing ergonomic risks and improving Occupational Health and Safety (OHS). In addition, these improvements enhance greater productivity, better working conditions, and worker well-being [30]. To enable this, various digital technologies and methodologies have been applied to analyze and evaluate operators' physical and cognitive conditions [31].

However, nowadays, the prevalence of occupational diseases and risks, associated with the overload of workers and the possible development of musculoskeletal disorders, is a huge problem and an important indicator of the working conditions of today [11]. This is because the human body is the main engine for performing work activities and tasks within the industrial environment. Therefore, monitoring work activities to preserve the physical well-being of workers is critical [9]. One way to help workers to prevent occupational diseases and help the promotion of health and well-being in the workplace is to measure and monitor work exposure with sensor technology applications [32]. Moreover, as an example, the use of wearable inertial measurement units (IMUs) is growing among researchers and practitioners as these devices have a low cost, are easy to use, and outperform traditional observation assessment methods (which are subjective and lengthy) [33]. There are different and diverse methods and techniques for analyzing IMU data sensors, but most of them are prevalent for upper limbs, with a smaller number existing for lower limbs or the whole body [34]. Studies have adopted an approach using IMU sensors to develop a tool for on-site balance monitoring of construction workers, coupled with a mobile application to link the data collected by the IMU. Thus, it is possible to proactively identify workers at a higher risk of falls [35]. In addition to posture assessment, IMU sensors have also been used for performance analysis regarding load lifting motion and movement speeds [36].

Initial studies applied IMU sensors with EMG sensors for the evaluation of physical effort and biomechanical overload to the whole body for ergonomic risk assessment [37]. Then, the application of different sensor technologies has been implemented in workplaces for measuring and monitoring the adopted working posture and physical fatigue, in which the collected data can be provided in real-time to the worker. Feedback from this measurement can help workers to act depending on the data obtained and alert operators to occupational risks and incorrect work postures [32]. An example of an application is the use of a motion analysis system that is based on the integration of motion capture technology (MoCap) with software designed to observe and analyze the human body while performing tasks/activities in the industrial workplace [38]. MoCap systems can be based on inertial technology and optical technology with and without markers. MoCap systems that utilize inertial technology are composed of small inertial sensors that are placed and spread over the body. A gyroscope, magnetometer, and accelerometer are integrated into each sensor to record the three geometric axes. As for optical MoCap systems, these can be applied using markers that are also placed and spread along the body. In this situation, a set of cameras will detect the position of the markers and create a three-dimensional action space. The markers for optical MoCap systems can be active or passive, i.e., active markers, usually LEDs, emit their light, while passive markers are spheres coated with retroreflective materials to be detected by an infrared emitter. Marker-less optical MoCap systems have become promising, as they use cameras without the need to place markers (in the case of optical MoCap) or sensors (in the case of inertial MoCap), allowing and freeing the operator to perform his tasks and functions as normal [38]. A MoCap system allows for the creation of a digital copy of the operator in real-time, virtually representing the human skeleton and its movements. Thus, it is possible to accurately track over time the position and orientation of the operator in a workspace [30]. The MoCap system provides quantitative data in an automated way for the productive and ergonomic analysis of the operator during his work, namely the analysis of tasks in terms of execution time and space used, body movements, and also ergonomic data according to international ergonomic indexes such as the Ovako Work Posture Analysis System (OWAS) [39], the Rapid Entire Body Assessment (REBA) [40], and The National Institute for Occupational Safety and Health (NIOSH). Thus, through this tool, it is possible to analyze and design workplaces in terms of worker productivity, health, and well-being [38]. Studies have adopted non-intrusive, automated motion capture methods for assessing physical fatigue in construction workers, allowing to improve worker resistance to physical fatigue in construction tasks and to alert and raise awareness among managers to consider the fatigue of their workers [41].

On the other hand, the combined use of motion capture and virtual reality has been reported as a dual tool to improve workplace design as it allows fast and reliable measurements and ergonomic assessments [30] and can bring economic benefits [11]. This tool can be applied at various stages of the product life cycle, from concept to design, in pre-production, and even for the innovation of a manufacturing system. Many automotive and aerospace industries are applying MoCap with VR for real-time evaluation and streamlining of the pre-production phase. This joint system allows the building and testing of a virtual prototype of the workplace and the performing of numerous measurements in a short period to optimize the ergonomic design of a workplace [11]. A practical application example is the use of wearable sensors consisting of IMU and EMG sensors to monitor muscle strains and postures during the execution of a pick-and-place task in the automotive industry for ergonomic evaluation in parallel with Rapid Upper Limb Assessment (RULA) [42] indices. Through the VR system combined with EMG sensors and an accelerometer, it is possible to experiment with different workplace configurations and show in real-time the EMG-based ergonomic assessment within the immersive virtual environment to evaluate cooperative workplaces from an ergonomic point of view [43]. Similarly, the VR-Ergo Log system consists of the integration of a MoCap system with an immersive VR device and a heart rate monitoring system that allows the evaluation of possible future configurations of the actual workplace, considering execution time, ergonomics, and worker fatigue [44]. Another paper focused on the development of a prototype tool called ErgoSentinel which, through software, allows the continuous and detailed analysis of posture in real-time and offline. This tool, working in real-time, enables it to overcome the limitations of observational methods and immediately detect and correct incorrect operator posture [45]. More recent studies show that this type of evaluation can be conducted with several workers simultaneously, namely, the WEM Platform, which allows a progressive analysis and evaluation of the ergonomic indices in real-time simultaneously with operators carrying out collaborative tasks [46,47].

3.4. Challenges

After reviewing the studies that use the MoCap-VR system, one of the major limitations is the small number of participants in the studies, namely older workers, as well as the limitation of the number of workers that can use the system at the same time [46]. In addition, most of the developed studies resort only to initial simulations and with little application in real-case scenarios. Another limitation of the use of this system is its cost, and its cost-effectiveness for industries, especially small industries, must be analyzed.

On the other hand, several studies report that the use of this system can influence the operators [44], namely during use and the experiment the users experience symptoms like sickness, disorientation, nausea, sweating, and headaches leading to vomiting [48]. Studies show that most uses of wearable inertial sensors prove to be comfortable and do not cause distraction or overload to operators. However, their use becomes more distracting for the workers in cyclical work activities and work with older operators. Thus, the concern of collecting information on the physical exposure of workers to this equipment becomes important, as personal and work characteristics lead to increased variability in perceptions of discomfort and distraction [49]. On the other hand, the industrial use of virtual reality has given special attention to VR sickness. It is important to prioritize studies that analyze the causes of these effects and the possible measurement of symptoms after its use in a reliable way. The most common causes for VR disease are directed towards hardware such as devices and viewing modes, content such as graphic realism and rendering, and human factors such as demographic characteristics (age, gender, and health history) [50]. With the use of biometric sensors and motion capture systems in real cases, i.e., with human applications, ethical issues regarding workforce privacy arise. One of the future challenges will be to assess these ethical concerns regarding these privacy issues and the human and workers' rights when they are monitored.

One challenge for the ageing workforce present in industries is lifelong learning and training. To allow for a more effective and efficient integration, universal design principles can be used, creating simple and intuitive systems, perceptible information, tolerance for error, and flexibility in use. The core principles of Universal Design for Learning are focused on the educational experience and therefore can be applied to workers. The first principle, engagement, is aimed at motivating and supporting the operator; the second principle, representation, is how the content is presented; finally, the third principle, action and expression, represents how the learning is demonstrated and evaluated [51].

In the future, special attention will have to be paid to the interaction of these digital technologies with the ageing workforce. A major challenge is how the relationship between technology and the older operator will be formed, from the implementation of these digital devices in the industrialized environment with the presence of elderly workers to the barriers that may arise due to the difficulties of training and acceptance of the ageing workforce with the latest high-tech devices. The ageing workforce can be actively integrated into companies and industries by exploiting the heterogeneity of human resources and the respective individual skills and competencies of older workers. Notably by exploiting the experiences, knowledge, and decision-making capacity of ageing operators, as well as their social and interpersonal skills, a more dynamic working environment is enabled. Thus, with the introduction of heterogeneous and rotating work teams, the training and continuous learning of older operators will be boosted and improved [2].

3.5. Future Research

For future research, we suggest the practical use of this system (MoCap-VR) in a real case study, as illustrated in the scheme of Figure 2. This work will be developed in the metallurgic industry sector, which is characterized by repetitive and highly specialized work. First, and according to the OECD data and other studies [2,22], two groups of workers are defined: a group of young workers (20–54) and another of ageing workers (the older workers present in the industry under study—55–64).

Next, through the motion capture system, using sensors and commercial software, real working conditions will be evaluated, that is, data regarding the posture and movements of the operator in the execution of a work task will be collected and evaluated. In the first analysis, an ergonomic assessment will be conducted and a comparison between the study groups will be carried out. At this first point, workers can be warned if they have harmful ergonomic postures.

In the second phase, both groups involved in the study will have training sessions to be adapted to the virtual reality system. A virtual work environment like the real workplace is created for further analysis. In this second stage of the work, conclusions can be drawn regarding the ability to adapt and accept the new technologies of Industry 4.0, comparing the groups with different age groups.

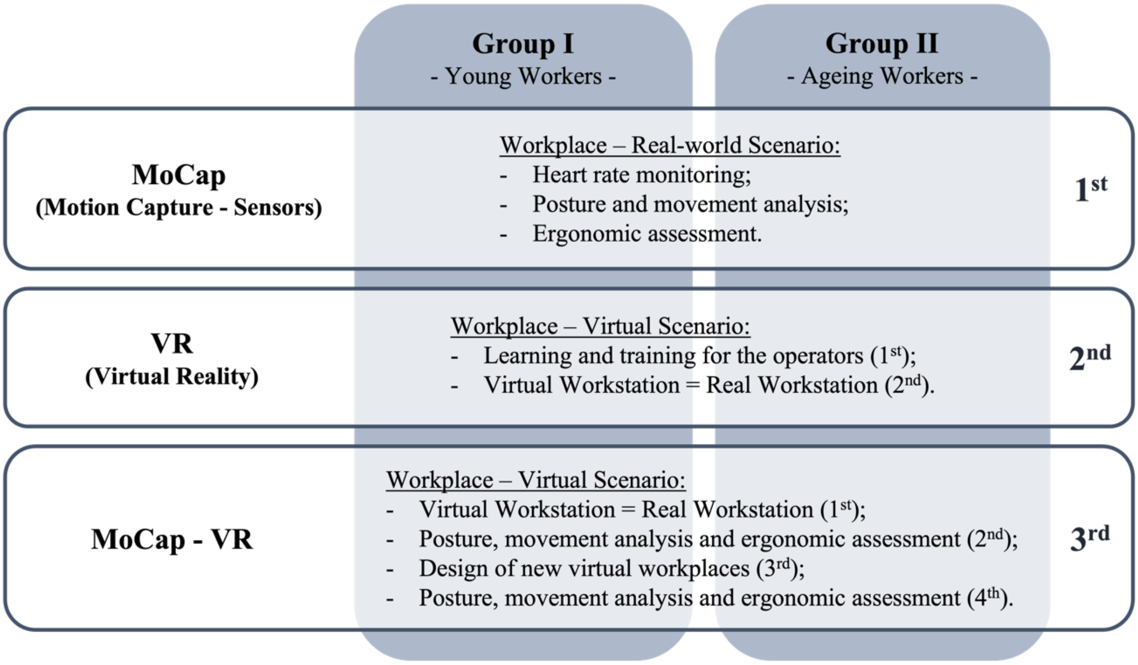

Figure 2. Schematic representation of the pilot study.

Finally, and with the simultaneous use of the MoCap—VR system, we will proceed again to the analysis of the posture and movements of the operator in the execution of a work task in a virtual scenario similar to the real world of work. This step could serve as a "control" group since the differences in working conditions between performing the task in a virtual versus real workplace could be verified. Similarly, the process could be repeated for new virtual workplaces designed to improve the individual and ergonomic conditions of the operators.

In the end, a comparison can be conducted between younger and older workers according to ergonomic aspects, work capacity, and well-being at work. In this way, workplaces can be adjusted to the capabilities and characteristics of the ageing workforce to ensure their health and safety and to extend their working life, with real-time responses.

4. Conclusions

The ageing workforce is a growing concern in companies and industries. Therefore, measures and strategies must be taken to secure older operators in the industrial environment, prolonging their active life. Thus, workplaces must provide health and safety for the operator, in terms of ergonomics and well-being. To facilitate this, the use of motion capture systems and virtual reality systems has been explored to improve working conditions by improving learning and training techniques, measuring, and evaluating the postures and body movements of the operators, and simulating work environments that provide better working scenarios, especially for older workers. This article summarizes in two major research areas the application of the MoCap—VR system: learning, training, and communication and, on the other hand, the design of new workplaces and ergonomic evaluation. Thus, the use of a virtual reality system with motion capture can become a useful technological tool that can help and improve the work of the ageing workforce. From its application in learning and training processes to methodologies and techniques of analysis to ergonomic assessment that can improve the working conditions of elderly operators. Due to the limitations found in the analyzed studies, such as the small number of participants in the studies and the few existing real cases with the ageing workforce, a schematic proposal for a future application in a real case is presented. Initially, commercial software will be applied, and later, if possible, specified and adjusted software for the work completed by the operators will be created. To perform a first comparative study between older and younger workers, a preliminary study with a smaller number of workers and one department should be conducted. In this first evaluation, the equipment will be adjusted, and management and workers will be open to the development of the work. Then, the spectrum of workers will be extended to different departments of the industry to include as many as possible operators. Thus, work environments can be adjusted and improved in real-time, according to the capabilities and characteristics of the ageing workforce, to ensure their health and safety and to extend their working lives.

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