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Towards Sustainable Health and Safety in Mining: Evaluating the Psychophysical Impact of VR-Based Training

Aldona Urbanek [1], Kinga Stecuła [2,*], Krzysztof Kaźmierczak [3], Szymon Łagosz [4], Wojtek Kwoczak [3] and Artur Dyczko [5]

[1] Jastrzębska Spółka Węglowa, Al. Jana Pawła II, 44-330 Jastrzębie-Zdrój, Poland; aldonaurbanek@jsw.pl
[2] Faculty of Organization and Management, Silesian University of Technology, 44-100 Gliwice, Poland
[3] JSW Nowe Projekty, ul. Ignacego Paderewskiego 41, 40-282 Katowice, Poland; kkazmierczak@jswnoweprojekty.pl (K.K.); wkwoczak@jswnoweprojekty.pl (W.K.)
[4] Główny Instytut Górnictwa-Państwowy Instytut Badawczy, plac Gwarków 1, 40-160 Katowice, Poland; slagosz@gig.eu
[5] Państwowy Instytut Geologiczny-Państwowy Instytut Badawczy, ul. Królowej Jadwigi 1, 41-200 Sosnowiec, Poland; artur.dyczko@pgi.gov.pl
* Correspondence: kinga.stecula@polsl.pl

Abstract

Mining involves daily descents underground and enduring dangerous and difficult conditions. Hence, it is very important to use solutions that will reduce the risk in miners' work and ensure the greater safety and comfort of work in accordance with the goals of sustainable development. One way is training using virtual reality. Virtual reality provides greater safety (safe training conditions, the possibility of making a mistake without health consequences, practicing emergency scenarios, etc.) and aligns with the Sustainable Development Goals—particularly SDG 3 (health), SDG 8 (decent work), SDG 9 (innovation), and SDG 12 (sustainable production). However, it is also a technology that has its weaknesses (occurrence of contraindications, side effects, etc.). Therefore, the use of VR-based training should be examined in terms of the well-being and health of training employees. Due to this, this article examines the occurrence of psychophysical complaints during VR training; the tolerance and adequacy of the duration of a 50 min training session in VR was assessed; and the average time needed to adapt to the virtual environment was determined. The VR training was developed as a result of a research project conducted by JSW Nowe Projekty S.A. (ul. Ignacego Paderewskiego 41, 40-282 Katowice, Poland), Główny Instytut Górnictwa—Państwowy Instytut Badawczy (plac Gwarków 1, 40-160 Katowice, Poland), JSW Szkolenie i Górnictwo Sp. z o.o. at Jastrzębska Spółka Węglowa Capital Group (ul. Górnicza 1, 44-335 Jastrzębie-Zdrój, Poland) on the development and implementation of innovative training using VR for miners. The solution was developed in the context of mining's striving for sustainable development in the area of improving working conditions and human safety. The first method used in the study is a survey completed by participants of training courses using virtual reality. The second method is the analysis of trainer observation sheets, which contain observations from training courses. The results revealed that for over 70% of respondents, the need to carry out activities in VR was not associated with fatigue. No average score for psychophysical symptoms assessed by respondents on a scale of 1 to 6 (including disorientation, blurred vision, dizziness, confusion, etc.) exceeded 1.4. The vast majority (85.5%) did not take off the goggles before the end of the training—the training lasted 50 min. This research contributes to the discussion on sustainable industrial transformation by demonstrating that VR training not only improves worker safety and preparedness but also supports development goals through human-centered innovation in the mining sector.

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Keywords: virtual reality; VR training; sustainable training methods; workforce well-being; VR goggles; psychophysical complaints; sustainable safety culture

1. Introduction

In the context of sustainable development and the United Nations' 2030 Agenda, ensuring health and safety at work, particularly in high-risk industries such as mining, is paramount. Mining is an industry characterized by a high degree of risk and factors hazardous to human health and life. The daily underground descents of underground workers make it one of the most dangerous professions. Hence, it is very important to develop and implement in practice methods that reduce the risk of miners' work. One way is training using virtual reality (VR). Thanks to such training, people who will work underground can train in safe and harmless conditions (not going underground). Such technology ensures, on the one hand, the preparation of employees for work underground and, on the other hand, ensures full safety for people who have never experienced working underground. In mining, there are efforts being made to use such solutions, which are aimed at improving the health and safety of employees.

In industries such as mining, VR provides a unique opportunity to conduct realistic and immersive training sessions that can enhance safety and operational efficiency. The study, described in this paper, was conducted at Jastrzębska Spółka Węglowa (Al. Jana Pawła II, 44-330 Jastrzębie-Zdrój, Poland), a major coal mining company, to develop and implement an effective VR-based training program for miners. The training aimed to simulate underground work tasks.

Virtual reality can provide greater safety for mining workers, but there are also other health and safety issues that need to be investigated. In practice, it turns out that not all people can use virtual reality technology [1,2]. On the one hand, there are certain contraindications to using immersive technologies (e.g., epilepsy and a number of other diseases) [3,4] and on the other hand, various ailments related to simulation sickness or motion sickness may also occur during training [5,6]. Therefore, like any technical solution, VR has certain advantages [7–9], but it also has its disadvantages and risks [10–12]. It is therefore very important to approach training using virtual reality with caution.

In other words, it is very important to examine how people training in virtual reality tolerate such training. In the context of sustainable development, both the mental and physical comfort of employees training in VR should be taken care of. It must be highlighted that despite the potential benefits of VR training, concerns remain regarding the psychophysical impact on users, particularly during extended sessions. This research aims to verify these concerns by evaluating the occurrence of psychophysical side effects, such as fatigue, dizziness, disorientation, and others, among participants. Additionally, the study assesses the appropriateness of a 50 min training duration and the time required for participants to adapt to the VR environment.

The novelty of this article is to assess the psychophysical impact of VR training in the mining sector, which is a high-risk work environment that is traditionally difficult to simulate, and which is also conservative in terms of innovative methods. This study presents a pro-worker approach, as innovative methods are often introduced but the participants' opinions (how they felt and how the participants experienced them) are not investigated. It must be emphasized that this is important in the context of caring for the employee and their work environment. In addition, the studies also investigate the individual adaptation time to VR and the possibility of asymptomatic exposure during the training. Furthermore,

this study combines the subjective opinions of the participants with observational data conducted by the trainer to assess both the perceived and observed effects.

Despite the growing number of studies on the use of virtual reality in training in various sectors, there is still a lack of in-depth analyses of the implementation of this technology in the conservative mining environment, especially in Poland. This industry, strongly rooted in tradition and resistance to change, is characterized by distrust of modern technological solutions. The introduction of innovative tools, such as VR training, is often perceived by employees as unnecessary or even frivolous. Meanwhile, the profession of a miner—often performed by people accustomed to conventional work methods—requires safe solutions, thoroughly tested and adapted to their psychophysical specificity. Hence the need for empirical research assessing the impact of VR training on the comfort, safety, and reactions of participants—both physical and mental—which this study proposes. Importantly, few practical studies have empirically evaluated psychophysical impacts of VR training in this industry.

2. Theoretical Background

2.1. Virtual Reality for Trainings

Virtual reality technology has rapidly evolved, offering innovative applications across various fields, including training and education. There is not a very large number of items in the literature indicating practical virtual reality training, although more and more authors write about the use of virtual reality in various industries, and the scope of these trainings is expanding over time. Occupational health and safety training is one of the most important training courses in every enterprise. It turns out that such training, conducted in virtual reality, is the subject of many theoretical studies, as well as practical implementations—as can be read in the literature [13–15]. Moreover, in the literature, there are characteristics of training that take place in virtual reality for military services [16]. Training for both aviation students and future and current employees in the aviation industry is also popular [17,18]. Such training often shows flight simulations or simulations of emergency situations in which the trainee must respond appropriately. Thanks to such training, future aviation staff can be prepared in a more practical way, both technically and mentally, for emergency situations. Another example of training using virtual reality technology may be training in the chemical industry [19]. There are also other training courses in industrial practice, which can often be read about on websites dealing with writing VR applications [20]. Virtual reality training can also be used in areas and industries other than industrial ones, for example, VR training can be used to acquire soft skills [21]. There are also applications for studying foreign languages [22]. Virtual reality is also a good educational tool for students from different fields of study [23–25]. It can be an attractive tool used for education marketing [26]. The topics and scope of virtual reality training can be very varied; it all depends on training needs.

Virtual reality training involves individuals using VR equipment (putting on VR goggles and holding controllers in their hands—although in some new versions, the goggles detect hand movements and controllers are not needed) and performing tasks in a previously prepared application. Such applications usually have several scenarios. The scenarios can have different levels of difficulty and individual modules should be easy to repeat. In practice, this means that it is good for the application to not be too complicated and to be user-friendly in terms of re-approaching the training. From a learning perspective, it is good if the application has several short modules rather than one long module because in the event of making a mistake, the participant does not have to repeat the entire long training, but only needs to work on the given module again. When it comes to applications and their scenarios, various examples can be found in literature and practice. In recent

three years, there has been, for instance, the paper article of [27] which describes a study of the use of virtual reality in pilot training for a private pilot license (PPL). The results show that VR works well for learning theory, pre-flight aircraft inspections, and procedures training, but users experienced isolation and difficulty developing motor skills, which may limit the effectiveness of this method in some aspects of practical training. The study in the article [28] shows VR as a tool for solving accidents in construction through insurance. The literature also describes VR training systems for learning how to assemble and disassemble car engines, designed using the Buick Verano engine as an example [29]. Such training includes replacing engine parts, reusable tools, an intuitive user interface, and the possibility of expanding to other engine models. The application has already been implemented at universities in China and is available as a free executable file and source code, in order to support the development of VR in the automotive industry. Another VR application [30] is used to train medical students in trauma situations, where participants complete a step-by-step simulation that includes diagnosis, treatment of bleeding, and late external fixation. VR can be also used in other medical fields for training purposes [31].

In another article [32], OHS training in high-risk industrial environments is described using the example of the IPLOM refinery in Busalla (Italy). Participants could practice, among other things, operating equipment, responding to emergency situations, and spatial orientation. The first tests showed high user satisfaction and increased self-confidence in crisis situations, which shows the effectiveness of VR in safety training. There are more applications in occupational health and safety training: for railway operators in Sweden (using gamification) [33]; for steel mill workers, where VR is used for the OHS training of employees in a high-risk facility [34]; for simulating hazards and accidents at a construction site [35]; for simulating evacuations and firefighting on ships in accordance with SOLAS standards [36]; for quarry workers in marble mining activities [37]; for electricians and students (the application improves risk awareness and builds a safety culture) [38]; and more. Finally, it should be emphasized that in the context of the future, the ethical and security issues of the data of people who use virtual reality or the metaverse are also important [39]. This issue may not be so noticeable yet, but the rapidly developing technology will make these cyber issues important in daily life.

Although VR applications often present themselves spectacularly both in literature and in practice, their effective implementation requires taking into account the aspect of human–machine interaction (HCI) [40,41]. Users, especially representatives of conservative professions such as mining, may feel resistance and distrust towards new technologies—this is proved in many publications such as [42–44]. Operating VR goggles and the precise manipulation of objects requires an adaptation process, which is not limited to learning the interface, but engages users physically and mentally. From the point of view of ergonomics, and confirmed by biomechanical studies, the weight and way of wearing HMDs can causes stresses on the musculoskeletal system of the head and neck [45] or shoulder muscles [46]. What is more, people staying in VR may experience visual fatigue, nausea, and other symptoms of simulation sickness [47] and motion sickness [48]. The process of adaptation to the VR environment is not only about learning how to control—it is also a matter of determining the optimal exposure time, minimizing side effects, and designing ergonomic interactions, which will allow for the safe and effective use of technology in the training of mining workers.

VR training developed for the mining sector, like applications used in aviation, the chemical industry or healthcare, enables participants to safely practice procedures in high-risk conditions—but in a controlled and repeatable virtual environment. Unlike aviation training (e.g., PPL), which focuses on technical and communication procedures, our training also focuses on the psychophysical impact of the immersive environment on employees,

which is particularly important in underground work. The mining application—like those in the medical industry—enables multiple repetitions of scenarios, which improves the memorization of procedures, without the risk of injury or high costs. Compared to training for construction or metallurgical workers, our application also includes elements of time tolerance analysis and adaptation to the VR environment, which is important for long-term implementation in the sector. Like other high-risk industries (refineries, maritime transport), mining gains a tool for the sustainable development of OHS competences thanks to VR.

2.2. Virtual Reality in Mining—Advatnages in the Context of Sustainable Development

The use of virtual reality training in the mining industry has significant benefits in the context of sustainable development, especially in relation to the UN Sustainable Development Goals (SDGs), such as SDG 3 (good health and well-being), SDG 8 (economic growth and decent work), SDG 9 (innovation, industry, infrastructure), and SDG 12 (responsible consumption and production). First of all, VR training allows employees to be prepared for work in high-risk conditions without having to physically be in a dangerous environment, such as mines [49]. This reduces exposure to hazards, which can lead to a reduction in the number of accidents at work [50].

An additional advantage of using VR training is the possibility of making mistakes without real consequences. In underground work conditions, any mistakes can lead to serious accidents, a threat to life, costly production downtime or even serious damage to health [51]. Thanks to the virtual environment, the participant can repeatedly practice critical scenarios, learn from mistakes and analyze the consequences of their actions in a safe manner, which significantly increases the effectiveness of learning without the risk of real losses [52,53].

In addition, the possibility of repeating procedures multiple times in VR allows for deeper knowledge embedding and the development of muscle memory [54], which is difficult to achieve in real underground work conditions. Training conducted in a traditional way is often limited by time, logistics, and costs, which makes it difficult to practice the same activities multiple times. Virtual reality eliminates these barriers, enabling flexible, individually tailored training anywhere and anytime [20], without affecting the continuity of mine operation. This education model is therefore more accessible and cost-effective while supporting the long-term improvement of employee competences [21].

VR technology, as a training method, can be implemented on a large scale at relatively low unit costs after preparing a training application [55,56]. This form of teaching supports the long-term effectiveness of educational processes in industry and reduces the consumption of resources such as energy, personal protective equipment, or the consumable elements of training infrastructure [57].

Moreover, improving the psychophysical comfort of training participants is part of the corporate social responsibility (CSR) strategy by caring for the well-being of employees. Taking into account their health, safety, and the quality of training is a manifestation of caring for human resources as a key element of the sustainable development of the organization [58]. VR training can therefore be a tool supporting changes towards a more responsible and modern mining industry [59].

3. Materials and Methods

A research project was carried out by JSW Nowe Projekty S.A. (ul. Ignacego Paderewskiego 41, 40-282 Katowice, Poland), Główny Instytut Górnictwa—Państwowy Instytut Badawczy (plac Gwarków 1, 40-160 Katowice, Poland), JSW Szkolenie i Górnictwo Sp. z o.o. at Jastrzębska Spółka Węglowa Capital Group (ul. Górnicza 1, 44-335 Jastrzębie-

Zdrój, Poland) regarding the development and implementation of effective training using a virtual reality environment. Figures 1 and 2 show exemplary views from the developed VR application. Figure 2 shows the visual information that appears to the user during training. This information briefly describes what a dust mask is and what its function is. It also shows quantitative information about other personal protective equipment (PPE) the user has already had.



Figure 1. The exemplary view from the VR application for miners developed for training purposes.

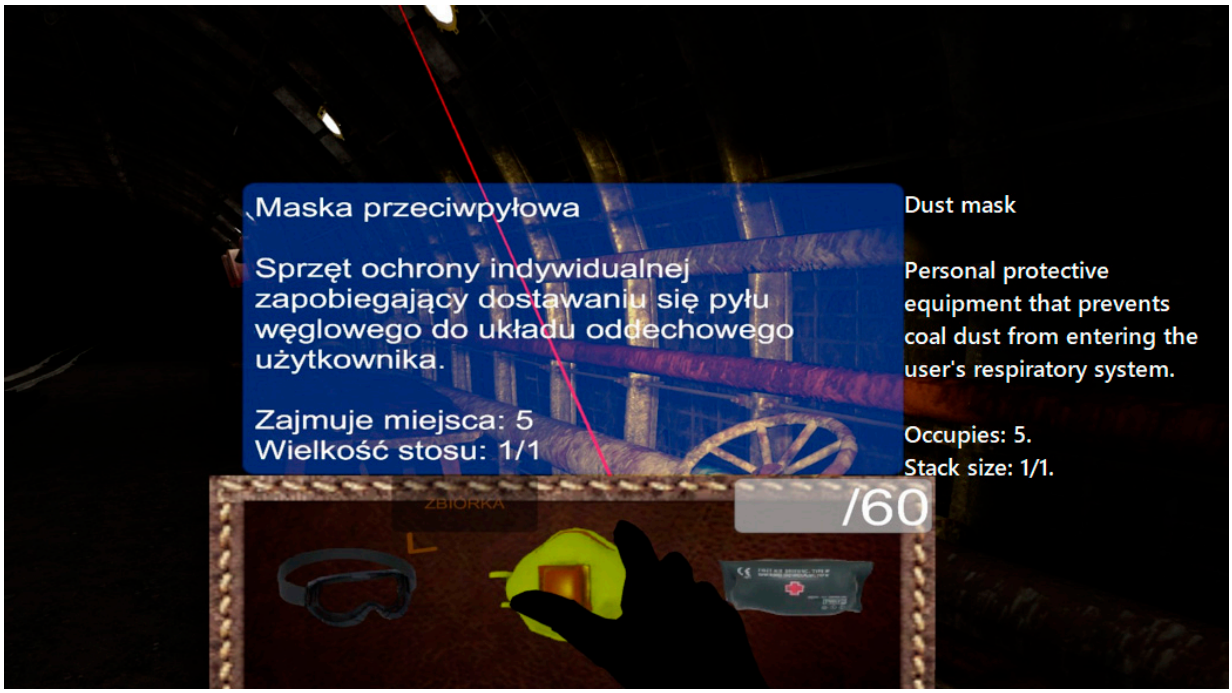


Figure 2. The exemplary view from the VR application for miners developed for training purposes—information about the dust mask.

The research consisted of many stages (Figure 3), and the most important stages included developing a training program using virtual reality and then developing an appropriate VR application.

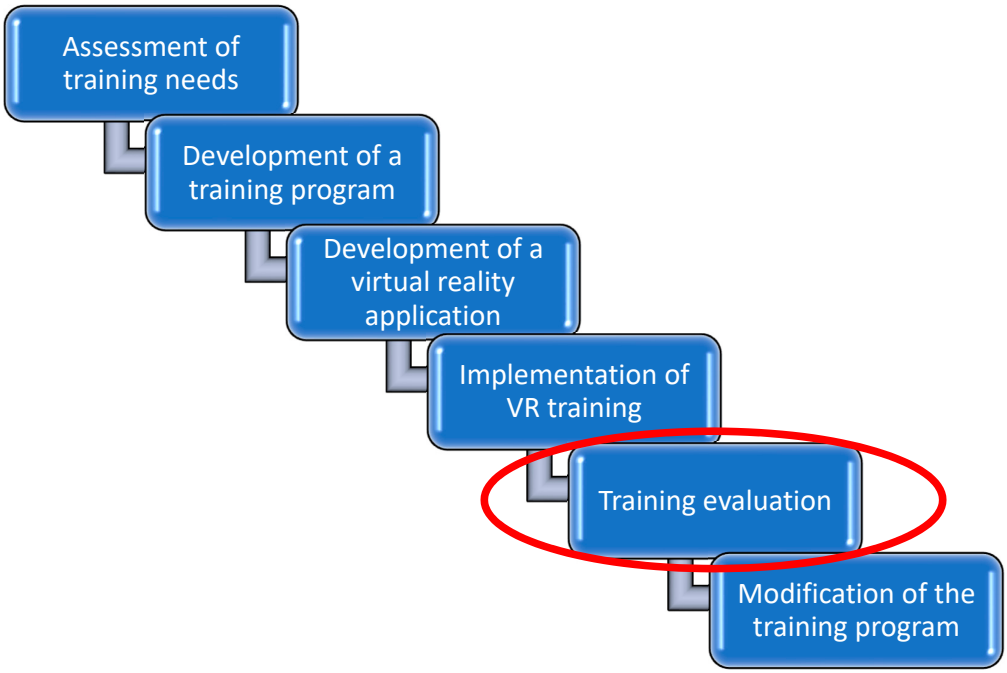


Figure 3. Stages of the research project with the stage marked in red, the results of which are described in this paper.

In the subsequent stage, employees of Jastrzębska Spółka Węglowa (Al. Jana Pawła II, 44-330 Jastrzębie-Zdrój, Poland) and Główny Instytut Górnictwa—Państwowy Instytut Badawczy(plac Gwarków 1, 40-160 Katowice, Poland), underwent a training process, which concerned tasks performed especially in underground work as miners. The place of training was the Pniówek coal mine (Krucza 18, 43-251 Pniówek, Poland) and Główny Instytut Górnictwa—Państwowy Instytut Badawczy (plac Gwarków 1, 40-160 Katowice, Poland). The participants used HTC VIVE Pro VR goggles and controllers. Then the training process was assessed based on various criteria by participants but also by VR training supervisors, who were called "trainers". After completing the training, participants completed surveys. The survey included both open and closed questions. All participants attended the same training.

In general, the participants were asked questions on various topics. There were questions about the assessment of the application, the assessment of individual elements of the training, and also regarding absorbed knowledge. There were also questions about how they felt when using virtual reality and about any problems / complaints that could potentially occur. This article presents only the results of some surveys due to the wide scope of survey research. The training and research were conducted as part of the project "Improving work safety and communication of small work teams using a networked VR environment (SENSE VR)". Additionally, the paper presents the results of trainers' observations that were recorded in trainers' observation sheets. They were concerned with issues directly related to the training, such as reporting psychophysical complaints, technical problems, questions, or other problems by training participants. Trainer observation sheets were completed by employees of JSW Training and Mining who specialize in delivering various types of mining training. They themselves had previously received training in the virtual environment. These individuals had experience in delivering training and had

undergone internal standardization procedures to ensure consistent application of the observation protocol.

The research presented in this article involved 69 participants. The research took place immediately after the training sessions that took place in February 2022. The study participants were miners who were working underground in JSW S.A. Participants represented operators of underground machinery, such as longwall shearers, roadheaders, belt conveyors, beam stage loaders, powered roof supports, and others. The sampling strategy used in this study was convenience sampling. Participants were selected from among employees available at the Pniówek mine (Krucza 18, 43-251 Pniówek, Poland) in Jastrzębska Spółka Węglowa. Training and surveys took place during the period when the developed VR training was being implemented. This method was appropriate given the exploratory nature of the study and the focus on practical implementation in a real industrial context. Inclusion criteria included the following: (1) participants employed or in training within the JSW Capital Group, (2) consent to participate in the study. Exclusion criteria included the following: (1) individuals with known contraindications to VR use (e.g., severe motion sickness, epilepsy). The questions presented in this paper concern the participants' well-being because of virtual reality activity. The survey examines, among others, the occurrence of various symptoms of psychophysical complaints and whether the developed 50 min VR training was appropriate in terms of time for the participants. When it comes to the validation of the survey, the tool underwent expert consultation and VR specialists. Then a pilot test was conducted on the small group to ensure clarity and usability and to check if every question was understandable and clearly formulated. Feedback from the pilot informed the final adjustments.

In this study, the research main objective (O_m), specific objectives (O_s), and objectives in the context of sustainable development (O_{sd}) were set as follows:

- O_m: evaluating the psychophysical impact of VR-based training on participants in the mining sector.
- O_{s1}: examining the occurrence of psychophysical complaints as a result of using virtual reality.
- O_{s2}: evaluating the tolerability and appropriateness of the duration of a 50 min virtual reality training session.
- O_{s3}: determining the mean time needed to adapt to the virtual environment.
- O_{sd1}: Assessment of the impact of VR-based training methods on the health and safety of workers in the mining industry as a contribution to sustainable development (SDG 3 and SDG 8).
- O_{sd2}: Verifying the potential of VR as a sustainable alternative to traditional high-risk training (SDG 9 and SDG 12).

In order to achieve the goals, set in the work, the authors of the research also asked several research questions which were formulated as follows:

- Q_1: What is the level of psychophysical complaints experienced by participants during virtual reality training?
- Q_2: Is there a relation between time spent playing computer games and fatigue after completing virtual reality tasks?
- Q_3: Is the 50 min virtual reality training tiring for participants?
- Q_4: Is the developed 50 min virtual reality training session suitable for participants?
- Q_5: Do participants remove the VR goggles before the training session is completed?
- Q_6: What is the adaptation time for participants in virtual reality training?

4. Results of a Survey

4.1. Characteristics of Research Group

The study included 69 participants who took part in the training. Men made up 84.1% of the group (Figure 4), while 14.5% of participants were women. There were no data available for the remaining 1.4%. The majority of respondents had higher education (60.9%), followed by those with secondary education (34.8%), and a small percentage (2.9%) had basic education. There were no data available for one participant. The largest group consisted of workers with less than 5 years of work experience (44.9%). This was followed by participants with 5 to 20 years of experience (20.3%). Those with 20 to 25 years of experience made up 17.4% of the group, while 15.9% had more than 25 years of work experience.

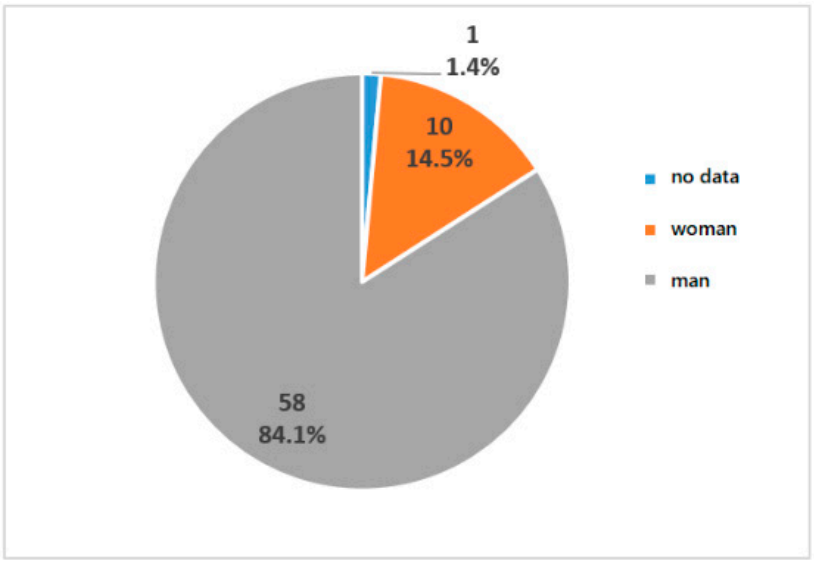


Figure 4. Gender of respondents (N = 69).

Table 1 shows more baseline characteristics of the participants. There is information summarized on gender, education, and work experience.

Table 1. Baseline characteristics of participants.

Parameter	Data/Values
Gender	Man: 84.1% Woman: 14.5% No data: 1.4%
Education	Higher: 60.9% Secondary: 34.8% Vocational: 2.9% No data: 1.4%
Work experience	Over 25 years: 15.9% From 21 to 25 years: 17.4% From 5 to 20 years: 20.3% Less than 5 years: 44.9% No data: 1.4%

The training participants were asked whether they had ever had contact with virtual reality. It turned out that the majority (52.2%) had not used virtual reality before (Figure 5).

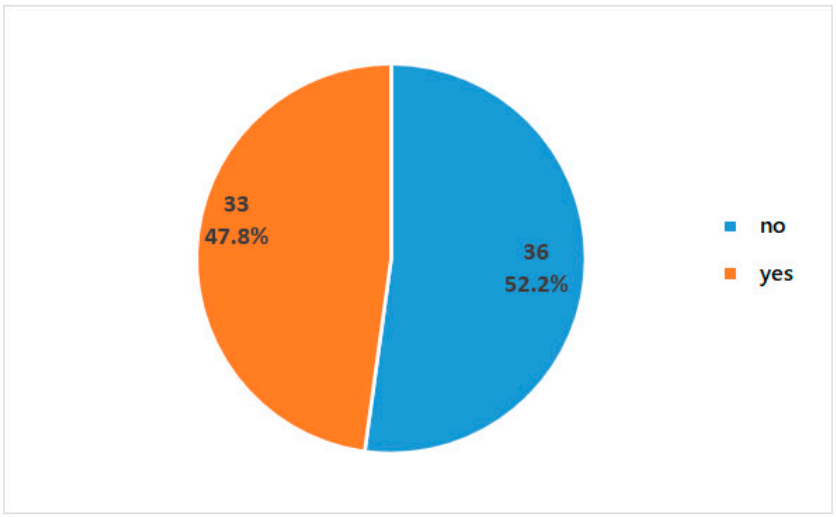


Figure 5. Experience of respondents in VR (N = 69).

Despite quite commonly declared previous contact with VR, over half of the respondents declared that they did not play computer games at all (56.5%). A quarter of the respondents spend up to 5 h a week on such entertainment (26.1%), and approximately one in seven respondents (13.0%) reported playing games for 5 to 30 h a week. Only a small fraction of participants (2.9%) devote more than 30 h a week to gaming. Figure 6 presents detailed data.

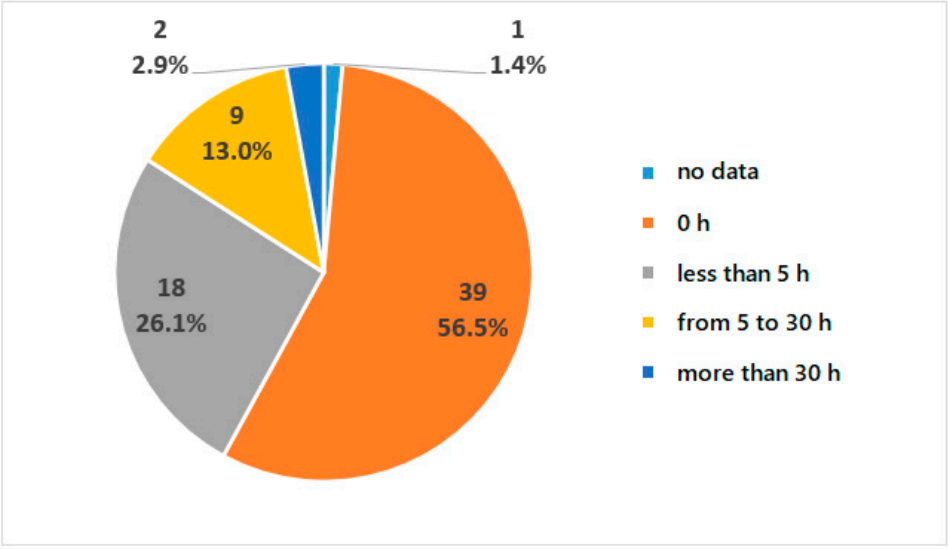


Figure 6. Time spent by respondents on computer games during the week (N = 69).

4.2. Examining Psychophysical Complaints

In the next part of the study, training participants answered questions about experiencing various psychophysical side effects as a result of activity in virtual reality. The first of these questions concerned the feeling of fatigue during training. Experiences related to the use of electronic forms of entertainment and contact with virtual reality translate into a relatively rare feeling of fatigue after completing tasks in VR during training. In the case of over 70% of respondents, the need to carry out activities in a virtual environment was not associated with fatigue. More than 40% of them said that they did not experience this feeling at all. However, every fourth respondent admitted that they felt tired (24.6%). It is also worth noting that for 8.7% of respondents, it was a serious problem, because they

answered "definitely yes" to the question of whether they felt tired. Detailed data are presented in Figure 7.

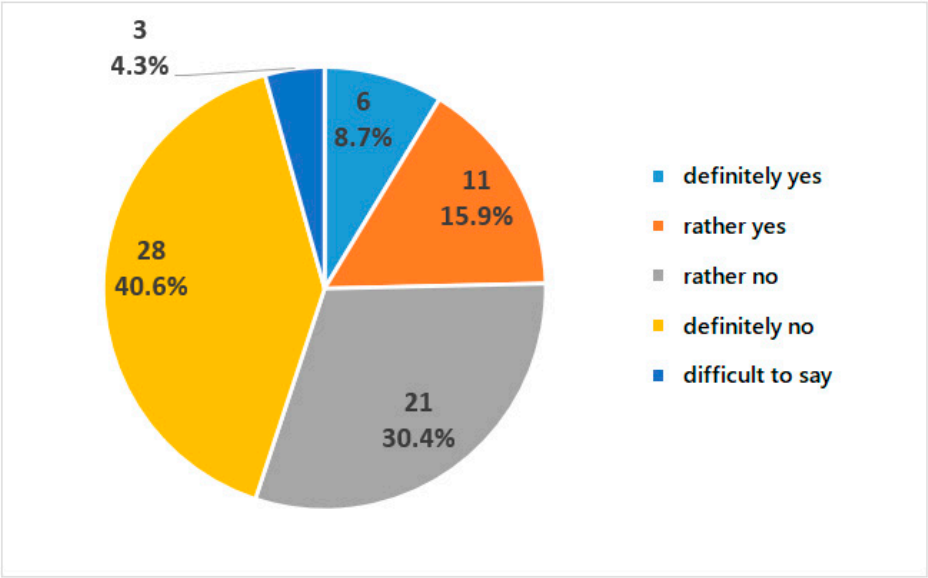


Figure 7. Answers to the question "Did you feel fatigued during training" (N = 69).

In order to complement the analysis presented above, respondents' declarations of fatigue were compared with the time they spend playing computer games. Figure 8 contains a synthesis of the obtained results. The data contained therein indicate that there is no significant correlation between the compiled variables. Contrary to initial expectations, it turned out that a similar level of fatigue from participating in training was declared by people who do not play computer games and those who frequently use this form of entertainment, although the relatively small number of respondents does not allow for categorical conclusions on this matter.

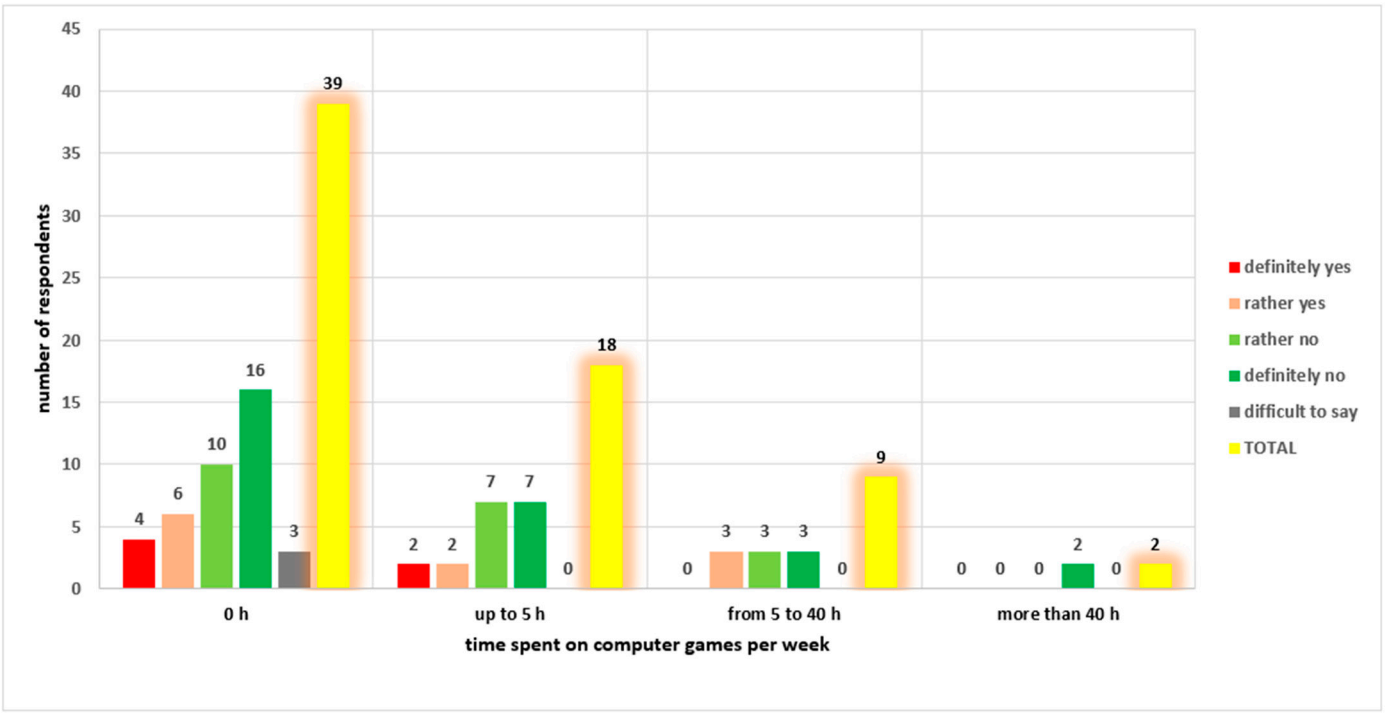


Figure 8. Answers to the question "Did you feel fatigued during training" in the context of time spent playing computer games per week (N = 68) *. * not 69 but 68, as there were no data on one person.

To statistically verify the association between gaming experience and fatigue perception, a chi-square test of independence was conducted. The result was not statistically significant, $\chi^2(12) = 8.87$, $p = 0.714$, suggesting no strong association between time spent playing computer games per week and declared fatigue following VR training. The effect size, measured using Cramér's V, was 0.21, indicating a weak relationship.

Then, all people participating in the training were asked to determine the severity of selected psychophysical symptoms that could potentially appear as a result of activity in virtual reality. The following symptoms were assessed:

- nausea and vomiting,
- visual hallucinations,
- bewilderment,
- balance disorders,
- dizziness,
- blurred vision,
- disorientation and difficulty concentrating,
- other.

The respondents also had the opportunity to supplement the above catalog with other ailments they observed. All symptoms could be assessed by training participants on a six-point scale, where the number 1 meant no symptoms and 6 meant very severe symptoms.

The analysis of the collected questionnaires indicates that the dominant symptom in relation to all the above-mentioned ailments was the lowest degree—1, which indicates the absence of unfavorable symptoms among the training participants.

This conclusion is confirmed by the analysis of average ratings presented in Figure 9. All average ratings obtained indicating the intensity of unfavorable symptoms after removing the goggles should be assessed as very low. The respondents occasionally experienced minor symptoms of disorientation and difficulty concentrating, blurred vision, dizziness, and balance disorders.

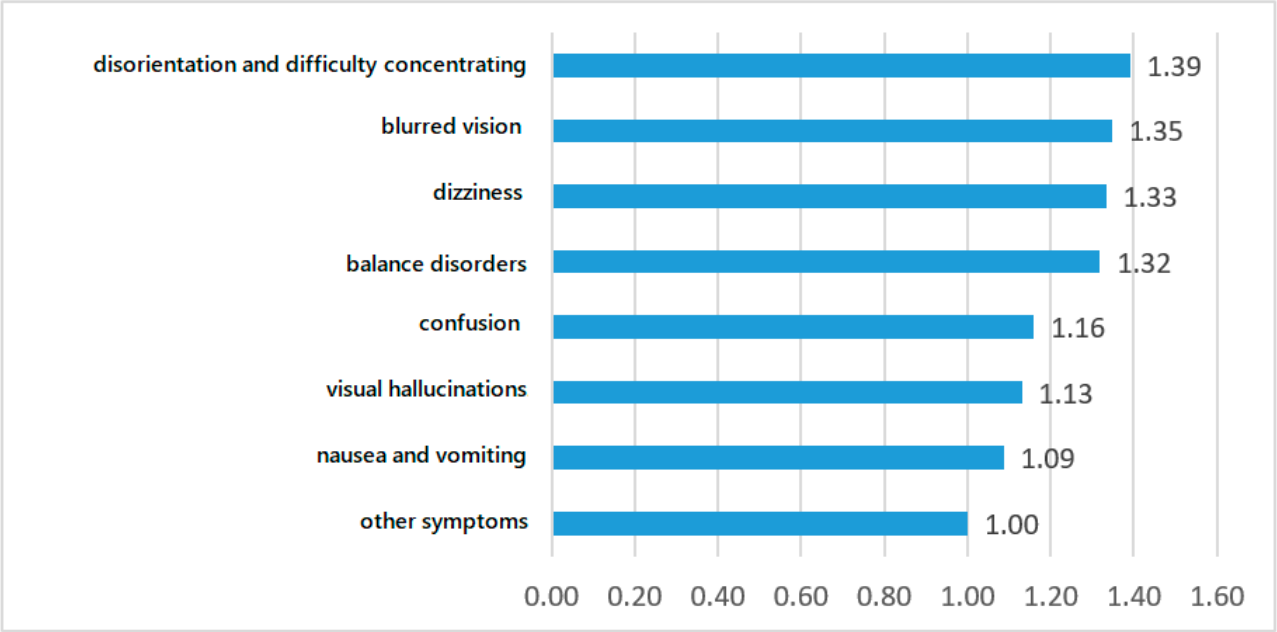


Figure 9. Psychophysical complaints related to participation in training—average grades; the scale from 1 to 6 (N = 69).

As mentioned earlier, in addition to survey research, the so-called observation sheets were also a method used in the research. The trainers, who supervised the participants

during the virtual reality training, maintained an observation sheet. They provided assistance to the trainees and ensured their safety and health throughout the training session. During the implementation of the VR training, a total of 4 trainers participated in the study. Each of them was responsible for a group of about 15–20 employees. This allocation was intended to ensure close supervision of the participants, the possibility of the ongoing observation of reactions, and a quick response in the event of any discomfort or questions from employees.

Table 2 presents the trainers' conclusions regarding the occurrence of psychophysical symptoms observed or reported by the training participants. Analysis of the observation sheets showed that the most common psychophysical symptom was dizziness, followed by headache, balance disorders, and visual acuity problems—such problems occurred after removing the goggles. There have also been sporadic cases of confusion and nausea. One person also reported feeling load on their head/arms due to the weight of the headset/controllers. One person also reported visual hallucinations after completing the training session.

Table 2. Occurrence of psychophysical complaints after taking off the VR goggles—trainers' observations.

Psychophysical Complaints	Number of Respondents Reporting
dizziness	7
headache	5
balance disorders	4
blurred vision	4
confusion	3
nausea	2
head/arms load	1
visual hallucinations	1

It can be noticed that even when seven participants reported to trainers the symptom of dizziness, the average grade for it was 1.33, which is low. Therefore, we can conclude that this problem was not very noticeable. It can happen that sometimes while using VR, there may be slight dizziness, but participants reported and informed trainers about the appearance of headaches. However, they did not state that it was severe dizziness that would make it difficult to conduct the training. It is worth emphasizing that five people reported headaches, which, however, were not directly assessed by the participants in the survey (but could appeared under "other symptoms"). This is important information: in subsequent studies, this factor should also be included as a separate factor, because the occurrence of headaches was not predicted in the survey earlier. This is important because during use, the impact of stimuli on the eyes, as well as the weight of the goggles, may affect the occurrence of headaches. Balance disorders were assessed at an average score of 1.32, while only four people reported this symptom to their trainer. However, it turns out (from the trainers' diaries) that such a disorder was also very mild. Such a symptom was reported but was not assessed by the trainer as something that was problematic and interfered with the training. When using goggles, being in virtual reality, a slight balance disorder may also sometimes occur due to technical factors related to the application. The blurred vision was rated at an average of 1.35 and four people also reported this symptom. The reason for the blurred vision may be different—sometimes it is related to the individual vision defect of the participant, and sometimes it may result from technical problems of the application that may show a blurred image for some time. But it may also result from the equipment. This third reason did not occur in the case of this training because only a few people reported such symptoms—which means that they were related either to a short occurrence of a technical problem or to the participant's vision defect. At the

moment, virtual reality goggles do not have a large field of adjustment when it comes to the individual vision defects of participants. However, it is worth mentioning that technology is developing and in newer models there are already possibilities to adjust the lenses and their spacing. Then, confusion was also reported by three people with a rating of 1.16. Two people reported nausea to the trainers. This is also important information because it was not directly assessed in the survey. In the next study "nausea" will definitely be included as a separate factor so be evaluated. Interestingly, one person reported problem of "head/arms load", which means that for this person, wearing the goggles was simply too heavy. One person also reported visionary hallucinations to the trainer, but they were assessed as temporary after removing the goggles and passed quickly.

Trainers also observed that many participants pointed out the lack of sense of time during VR training. This means that the training was engaging and conveyed the feeling of the so-called immersion. This is extremely important in the context of learning and the memorization process.

It is also worth emphasizing that the participants were eager to sit down right after the training. However, it can be said that this was normal because rest is recommended after a 50 min training.

In turn, physical symptoms such as fatigue or dizziness most often appeared after the training, i.e., when returning the goggles to the researchers. It can be generally said that the VR application was prepared in such a way that training in it was relatively adaptable and did not cause any serious side effects to the participants.

On the other hand, although symptoms such as dizziness or hallucinations were reported by only a few participants, they deserve special attention due to their potential impact on user safety. This is especially true for high-risk industries such as mining. For example, seven participants reported dizziness to their trainers, but the average self-assessment was relatively low (m = 1.33 on a 5-point scale) and the trainers did not consider these symptoms as serious. Nevertheless, even mild dizziness can disrupt engagement in training or impede the performance of virtual tasks requiring spatial orientation. From an occupational health and safety perspective, this is very important. Further research is needed on the application: improving it, especially in terms of the technical aspects (images, movement, light stimuli). Headaches were another notable issue: five participants reported them to their trainers, although the survey tool did not include "headache" as a separate symptom category. This is a limitation that highlights the need for more comprehensive symptom tracking in future studies. Headaches can result from prolonged exposure to visual stimuli, improper headset fit, or the weight of the device, suggesting the importance of ergonomics and optical design in VR equipment [60]. One participant reported visual hallucinations after training. Although these were temporary and quickly subsided after removing the headset, they should not be dismissed. Even rare perceptual distortions can indicate a mismatch between sensory input and brain processing—a phenomenon known as "cybersickness" [61]. In occupational settings, such reactions may impair situational awareness or increase the risk of accidents, especially if VR training is used shortly before real-world tasks. As such, although symptoms such as dizziness, blurred vision, or hallucinations were not common in this study, their safety implications require further investigation. Future protocols should include pre-training screening, adaptive exposure times, and break schedules, especially for older users or those unfamiliar with immersive technologies. Additionally, nausea and headaches should be explicitly included in symptom assessment tools to provide a more accurate risk profile for VR use in industrial training environments.

4.3. Examining Time Spent on VR Training

In the next part, the respondents were asked whether they took off their goggles before completing the training. The training lasted 50 min. It turned out that the vast majority (85.5%) did not take off the goggles before the end of the training (Figure 10). People who took off their goggles (14.5%) were asked about their reasons for doing so. The responses included indications of hardware and software problems (five cases), followed by excessive severity of psychophysical symptoms (two cases). Additionally, one person indicated dissatisfaction with the experience in VR and another pointed to external interference.

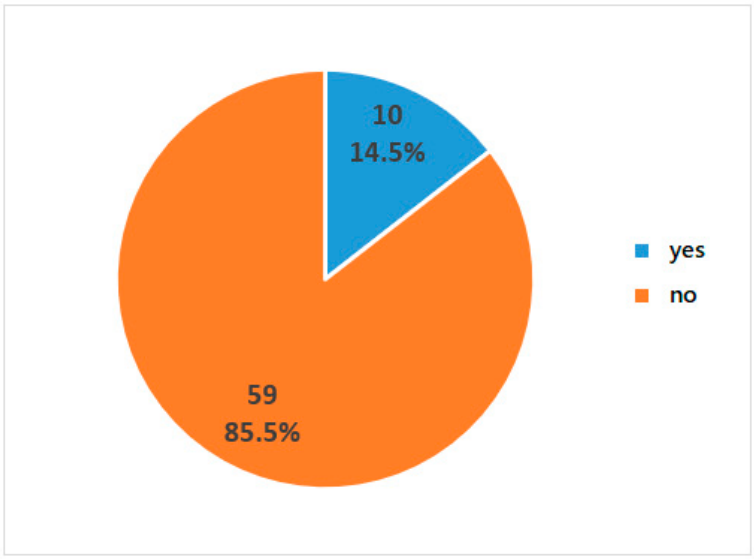


Figure 10. Answers to the question "Did you take off VR goggles before the end of the training" (N = 69).

Based on the research, it can be concluded that a 50 min virtual reality training is appropriate in the context of the time spent in virtual reality. The research can also be supplemented with conclusions drawn from the trainers' observation sheets.

The analysis of the notes in these documents allowed us to draw the following conclusions:

- the average time for training participants to adapt to the VR environment was 9 min;
- most often, after 5 min, people taking part in the training adapted to VR technology;
- the range of adaptation times was quite large: the shortest time recorded was 1 min and the longest was 30 min;
- VR goggles were most often removed after the training was completed (i.e., after 50 min);
- there were cases of the premature stopping of using the VR goggles: the shortest time spent in virtual reality was 7 min;
- the average time spent wearing the goggles was long—it amounted to 47 min.

4.4. Discussion of the Results and Findings

It should be emphasized that the research presented in this article and its results are original and unique in the context of Polish mining. An analysis of available literature and industry sources indicates that among Polish entities related to the mining sector (i.e., entities involved in hard coal mining or the production of mining machines), although there are declarations regarding the use of virtual reality technology in training, there are no scientific publications presenting empirical data from such implementations. In particular, no research has been made available so far on the assessment of VR training by participants, nor on its impact on psychophysical aspects related to the adaptation to

this technology in difficult working conditions. Therefore, the implemented project and its results fill a significant research gap and constitute a breakthrough towards the modern, safer, and more effective training of mining staff using modern digital tools. When it comes to other results in other than JSW mining entities, there is just a little information on the topic similar to our studies. First of all, in Polska Grupa Górnicza (PGG), virtual reality is used for occupational and safety training. These initiatives are described in the following website: [62]. However, there are no scientific papers with a description of these phenomena, nor with the results of research on the evaluations of such OHS trainings in PGG. On another website, the following can be read: "so far, one scenario has been created, and it concerns the operation and maintenance of a conveyor belt" [63]. This means that PGG is also attempting to use virtual reality for training in the operation of underground mining machines, but in this case too there is no confirmation of this in scientific articles. On the Internet, there is a news item from 2025, where it can be read that PGG is developing training for miners [64]. However, there are no details on the real usage. On the same website, it can be read that KGHM (copper and silver mining) will also follow the same idea and, based on the developed scenarios in PGG, it will consider using training for its workers. As for the next large entity involved in hard coal mining in Poland, Bogdanka, there are no scientific articles or websites found on the Internet that would refer to the use of virtual reality for this entity. The only article that refers to the use of 3D models in mining in Bogdanka is an article by Dyczko [65], and although it does not explicitly address the topic of virtual reality, the technique is mentioned in the text as an important one. To sum up, in light of the available sources and literature, there are no published scientific studies in Poland that would empirically analyze the use of virtual reality technologies in mining training and their impact on participants, which makes the research presented in this article unique and pioneering in the national context.

Another reflection worth discussing is related to the hardware and application of virtual reality. One of the factors influencing the possible occurrence of psychophysical ailments is the technical quality of the application and VR equipment. Certain aspects of the application design—such as the intensity and frequency of movement in the virtual environment or too dynamic changes in perspective—could have influenced the occurrence of symptoms such as dizziness, balance disorders, or headaches. These problems are of course constantly being fixed, because with technological progress, designers and graphic designers are able to develop applications of increasingly better quality. In addition, based on research, observations of participants, and conversations with them, the designers also receive feedback, which will contribute to improving certain technical aspects in the next version of the application. Another issue is the weight of the goggles and the limited possibilities of adjusting the lenses to individual vision defects. In this respect, changes are also being considered, because with the progress of technology, newer types of VR goggles appear on the market, which increasingly allow for the adjustment of the goggles' parameters to the individual needs of the user. For example, Meta Quest Pro goggles, or others, unlike HTC VIVE, allow the user to change the lens spacing. Thanks to this, there is a chance that the ability to adjust the spacing of lenses in VR goggles can have a positive effect on the comfort of seeing objects in virtual reality, which in turn can help reduce ailments such as headaches. The individual adjustment of optical settings to the user's eyesight is an important element of VR system ergonomics, which can significantly improve the training experience, especially in professional groups not used to using this type of technology.

In summary, the results of the research conducted indicate several practical implications for the design and implementation of VR training in the mining industry. Firstly, it is important to further improve the ergonomics of VR devices—especially in the area of lens

adjustment, the adjustment of fastening straps, and a reduction in the weight of the goggles, which can reduce the occurrence of physical discomfort such as headaches or neck strain. Secondly, it is necessary to introduce a short adaptation phase before the actual training, including familiarizing the participant with the operation of the equipment, the virtual environment, and basic interactions. Such an initial protocol can significantly increase the user's comfort and the effectiveness of learning. The subject of consideration and further research will also be the introduction of a short break during the training. Although the results showed that a 50 min training was a good amount of time for the training, it is worth considering the possibility of dividing the training into smaller parts—and examining whether such a scenario would not minimize the occurrence of psychophysical complaints.

5. Conclusions

This study explored the psychophysical impact of a 50 min virtual reality training session on participants engaged in tasks related to underground mining at Jastrzębska Spółka Węglowa (Al. Jana Pawła II, 44-330 Jastrzębie-Zdrój, Poland). The findings offer valuable insights into the feasibility and effects of using VR as a training tool in this context.

The study revealed that most participants did not experience significant psychophysical side effects from the VR training. The most commonly reported symptoms were mild, including slight dizziness and occasional disorientation. Serious symptoms such as nausea and visual hallucinations were rare. The analysis of trainers' observation sheets corroborated these findings, indicating that while minor complaints were noted, they did not significantly impede the training process.

The planned VR training was generally well-tolerated by participants. The majority did not remove their VR goggles prematurely, suggesting that the session length was appropriate. The average time spent in virtual reality was 47 min and it was well-tolerated. Only a small fraction of participants reported significant discomfort that led to early termination of the session. It must be highlighted that it is impossible to plan VR training down to the minute. Some people will perform training activities faster, others slower. It depends on individual skills and predispositions. The study examined a 50 min session, and the result confirms that this duration in VR is proper for training. By analyzing this result in the context of occupational health and safety, as well as the 45 min lessons commonly used in schools, it can be concluded that it is recommended to develop 45 min training sessions in VR as trainees may finish the training sooner or later than the planned 45 min. However, 45 min training sessions in virtual reality can be recommended based on the conducted research.

Participants exhibited a relatively quick adaptation to the VR environment, with the average adaptation time being around 9 min, which was he average time of adaptation to the VR environment, i.e., the moment when the participant independently and efficiently navigated and manipulated objects. This time was noted by the trainers in the observation sheet. It was counted on a stopwatch. It was the average result of all times for all participants. This rapid adaptation suggests that the VR technology and the training program were effectively designed to engage users without causing significant initial discomfort.

The study highlighted the high level of engagement and immersion achieved during the VR training. Many participants reported losing track of time, indicating that the VR environment successfully captured their attention and facilitated a deep focus on the training tasks.

Overall, the study concludes that VR training is a viable and effective method for preparing employees for tasks in challenging environments such as underground mining. The minimal psychophysical complaints, quick adaptation times, and high levels of engagement support the use of VR as a practical training tool. Future research could focus on

optimizing the VR training program further and exploring its long-term benefits on job performance and safety.

The 69 employees participating in the study represent a small percentage of the total number of people employed underground in the JSW Group, which includes several mines in Poland. However, the study was preliminary and was purposely limited to one mine, where the application was implemented first. The aim was to conduct preliminary tests and collect psychophysical data in a controlled, limited sample. These preliminary tests were conducted in the Pniówek mine initially. Although the sample was not representative of the entire population of miners, it provides important information to improve the application and prepare broader studies in the future.

Research indicates that VR technology can be an effective training tool in mining in Poland, especially in improving work safety and employee engagement. However, the practical implementation of such solutions requires appropriate organizational preparation and the consideration of adaptation barriers. This is particularly important in the context of older people, people with contraindications to using VR goggles, and less technically savvy employees. The results may be useful for mine managers, health and safety managers, and training departments who are considering innovative methods of educating employees in high-risk conditions. However, the research is limited by the small and deliberately selected sample and the fact that tests were conducted only in one of the mines initially, which limits the possibility of generalizing the results. In the future, it is recommended to extend the research to other plants and analyze the long-term impact of VR training on employee behavior.

This paper provides a discussion on sustainable transformation in the industry by showing that VR training can improve the safety of workers and help them be prepared for underground dangerous work and can also support long-term development goals through using innovation in mining.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The original contributions presented in the study are included in the article; further inquiries can be directed to the corresponding author. The data presented in this study are available on request from the corresponding author.

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References

1. Wiederhold, B.K.; Wiederhold, M.D. Side Effects and Contraindications. In *Virtual Reality Therapy for Anxiety Disorders: Advances in Evaluation and Treatment*; American Psychological Association: Washington, DC, USA, 2005.
2. Undurraga-Tschischow, M.J.; Sales-Avila, A.; Fierro-Larenas, M.J.; Lama-Andrade, S.; Suarez-Vergara, P.; Muñoz-Monari, B.; Mena-Iturriaga, M.J. Contraindicaciones y efectos adversos de la realidad virtual inmersiva como herramienta terapéutica: Revisión de alcance. *Fisioter. Bras.* **2025**, *26*, 2018–2061. [CrossRef]
3. Yang, L.; Morland, T.B.; Schmits, K.; Rawson, E.; Narasimhan, P.; Motelow, J.E.; Purcaro, M.J.; Peng, K.; Raouf, S.; DeSalvo, M.N. A prospective study of loss of consciousness in epilepsy using virtual reality driving simulation and other video games. *Epilepsy Behav.* **2010**, *18*, 238–246. [CrossRef]
4. Simón-Vicente, L.; Rodríguez-Cano, S.; Delgado-Benito, V.; Ausín-Villaverde, V.; Delgado, E.C. Cybersickness. A systematic literature review of adverse effects related to virtual reality. *Neurología* **2024**, *39*, 701–709. [CrossRef]
5. Sedhom, R.; Megaly, M. It might be virtual, but the effect is real. *Int. J. Cardiol.* **2023**, *390*, 131207. [CrossRef]
6. Kim, H.K.; Park, J.; Choi, Y.; Choe, M. Virtual reality sickness questionnaire (VRSQ): Motion sickness measurement index in a virtual reality environment. *Appl. Ergon.* **2018**, *69*, 66–73. [CrossRef]
7. Bibri, S.E.; Jagatheesaperumal, S.K. Harnessing the Potential of the Metaverse and Artificial Intelligence for the Internet of City Things: Cost-Effective XReality and Synergistic AIoT Technologies. *Smart Cities* **2023**, *6*, 2397–2429. [CrossRef]
8. Zhang, M.; Zhang, Z.; Chang, Y.; Aziz, E.-S.; Esche, S.; Chassapis, C. Recent developments in game-based virtual reality educational laboratories using the microsoft kinect. *Int. J. Emerg. Technol. Learn.* **2018**, *13*, 138–159. [CrossRef]
9. Stecuła, K.; Wolniak, R.; Aydın, B. Technology Development in Online Grocery Shopping—From Shopping Services to Virtual Reality, Metaverse, and Smart Devices: A Review. *Foods* **2024**, *13*, 3959. [CrossRef]
10. Xu, Z. Analysis of the advantages and disadvantages of virtual reality technology in gaming. *Lect. Notes Educ. Psychol. Public Media* **2023**, *14*, 157–161. [CrossRef]
11. Saparova, A.B. Virtual reality or dangerous entertainment? Язык в сфере профессиональной коммуникации.—Екатеринбург **2021**, 564–568.
12. Kaimara, P.; Oikonomou, A.; Deliyannis, I. Could virtual reality applications pose real risks to children and adolescents? A systematic review of ethical issues and concerns. *Virtual Real.* **2022**, *26*, 697–735. [CrossRef]
13. Makransky, G.; Klingenberg, S. Virtual reality enhances safety training in the maritime industry: An organizational training experiment with a non-WEIRD sample. *J. Comput. Assist. Learn.* **2022**, *38*, 1127–1140. [CrossRef]
14. Joshi, S.; Hamilton, M.; Warren, R.; Faucett, D.; Tian, W.; Wang, Y.; Ma, J. Implementing Virtual Reality technology for safety training in the precast/prestressed concrete industry. *Appl. Ergon.* **2021**, *90*, 103286. [CrossRef]
15. Norris, M.W.; Spicer, K.; Byrd, T. Virtual reality: The new pathway for effective safety training. *Prof. Saf.* **2019**, *64*, 36–39.
16. Pallavicini, F.; Argenton, L.; Toniazzi, N.; Aceti, L.; Mantovani, F. Virtual reality applications for stress management training in the military. *Aerosp. Med. Hum. Perform.* **2016**, *87*, 1021–1030. [CrossRef]
17. Fussell, S.G.; Truong, D. Preliminary results of a study investigating aviation student's intentions to use virtual reality for flight training. *Int. J. Aviat. Aeronaut. Aerosp.* **2020**, *7*, 2. [CrossRef]
18. Fussell, S.G. *Determinants of Aviation Students' Intentions to Use Virtual Reality for Flight Training*; Embry-Riddle Aeronautical University: Daytona Beach, FL, USA, 2020; ISBN 9798684691430.

19. Fracaro, S.G.; Chan, P.; Gallagher, T.; Tehreem, Y.; Toyoda, R.; Bernaerts, K.; Glassey, J.; Pfeiffer, T.; Slof, B.; Wachsmuth, S. Towards design guidelines for virtual reality training for the chemical industry. *Educ. Chem. Eng.* **2021**, *36*, 12–23. [CrossRef]
20. Stecuła, K. Review of Virtual Reality Applications Applied in Industrial Practice. *Silesian Univ. Technol.* **2023**, *187*.
21. Xie, B.; Liu, H.; Alghofaili, R.; Zhang, Y.; Jiang, Y.; Lobo, F.D.; Li, C.; Li, W.; Huang, H.; Akdere, M. A review on virtual reality skill training applications. *Front. Virtual Real.* **2021**, *2*, 645153. [CrossRef]
22. Symonenko, S.; Zaitseva, N.; Osadchyi, V.; Osadcha, K.; Shmeltser, E. Virtual reality in foreign language training at higher educational institutions. In Proceedings of the 2nd International Workshop (AREdu 2019), Kryvyi Rih, Ukraine, 22 March 2019; Sun SITE Central Europe: Aachen, Germany, 2020.
23. Hussein, M.; Nätterdal, C. The Benefits of Virtual Reality in Education—A Comparision Study. Bachelor's Thesis, University of Gothenburg, Gothenburg, Sweden, 2015.
24. Pottle, J. Virtual reality and the transformation of medical education. *Futur. Healthc. J.* **2019**, *6*, 181. [CrossRef]
25. Soliman, M.; Pesyridis, A.; Dalaymani-Zad, D.; Gronfula, M.; Kourmpetis, M. The application of virtual reality in engineering education. *Appl. Sci.* **2021**, *11*, 2879. [CrossRef]
26. Stecuła, K. Identifying Diverse Uses of Virtual Reality in Higher Education and Exploring Perceptions of VR in the Chosen Field. *Silesian Univ. Technol.* **2023**, *181*. [CrossRef]
27. Ehambaranathan, E.; Murugasu, S.; O'Connor, S. Leveraging VR in the Age of the Metaverse: Opportunities and Challenges in Private Pilot Licence Training. *J. Airl. Oper. Aviat. Manag.* **2024**, *3*, 8–17. [CrossRef]
28. Silva, M.; Allis, C.; De Silva, C. Potential of virtual reality (VR) technology for safety training and accident prevention in construction. In Proceedings of the 12th World Construction Symposium, Colombo, Sri Lanka, 9–10 August 2024; p. 840.
29. Lan, G.; Lai, Q.; Bai, B.; Zhao, Z.; Hao, Q. A virtual reality training system for automotive engines assembly and disassembly. *IEEE Trans. Learn. Technol.* **2023**, *17*, 754–764. [CrossRef]
30. Teng, P.; Xu, Y.; Qian, K.; Lu, M.; Hu, J. Case-Based Virtual Reality Simulation for Severe Pelvic Trauma Clinical Skill Training in Medical Students: Design and Pilot Study. *JMIR Med. Educ.* **2025**, *11*, e59850. [CrossRef]
31. Alarcon-Urbistondo, P.; Perez-Aranda, J.; Casado-Molina, A. Key determinants of intention to use virtual reality in medical training. *Virtual Real.* **2024**, *28*, 90. [CrossRef]
32. Toyoda, R.; Russo-Abegão, F.; Glassey, J. VR-based health and safety training in various high-risk engineering industries: A literature review. *Int. J. Educ. Technol. High. Educ.* **2022**, *19*, 42. [CrossRef]
33. Haj-Bolouri, A.; Katende, J.; Rossi, M. Gamified immersive safety training in virtual reality: A mixed methods approach. *J. Work. Learn.* **2024**, *36*. [CrossRef]
34. Molek-Winiarska, D.; Chomątowska, B.; Gregorczyk, R. The use of Virtual Reality technology in employee safety and health training. *A case study of an enterprise from the smelting industry. Eduk. Ekon. I Menedż.* **2023**, *69*. [CrossRef]
35. Alsalmi, H.; Khamis, K.; Diab, E. Virtual reality technology to raise awareness of occupational hazards on construction sites. *Ecol. Saf.* **2024**, *18*, 270–286. [CrossRef]
36. Hamed-Ahmed, M.H.; Fraga-Lamas, P.; Fernández-Caramés, T.M. Towards the Industrial Metaverse: A Game-Based VR Application for Fire Drill and Evacuation Training for Ships and Shipbuilding. In Proceedings of the 29th International ACM Conference on 3D Web Technology, Guimarães, Portugal, 25–27 September 2024; pp. 1–6.
37. Pireddu, A.; Innocenti, A.; Lusuardi, L.M.; Santalucia, V.; Simeoni, C. The Impact and Effectiveness of Virtual Reality Applied to the Safety Training of Workers in Open-Cast Mining. *Int. J. Environ. Res. Public Health* **2025**, *22*, 151. [CrossRef]
38. Pribadi, A.P.; Rahman, Y.M.R.; Silalahi, C.D.A.B. Analysis of the effectiveness and user experience of employing virtual reality to enhance the efficacy of occupational safety and health learning for electrical workers and graduate students. *Heliyon* **2024**, *10*, e34918. [CrossRef]
39. Al-Kfairy, M.; Alrabaee, S.; Alfandi, O.; Mohamed, A.T.; Khaddaj, S. Navigating Ethical Dimensions in the Metaverse: Challenges, Frameworks, and Solutions. *IEEE Access* **2025**, *13*, 79996–80018. [CrossRef]
40. Hoc, J.-M. From human–machine interaction to human–machine cooperation. *Ergonomics* **2000**, *43*, 833–843. [CrossRef]
41. Boy, G.A. *The Handbook of Human-Machine Interaction: A Human-Centered Design Approach*; CRC Press: Boca Raton, FL, USA, 2017; ISBN 131702947X.
42. Xheko, S.A. Exploring Employees' Resistance Towards the Creation of an Executable Process Model for Innovation Adoption in Mining. Master's Thesis, University of the Witwatersrand, Johannesburg, South Africa, 2024.
43. Ediriweera, A.; Wiewiora, A. Barriers and enablers of technology adoption in the mining industry. *Resour. Policy* **2021**, *73*, 102188. [CrossRef]
44. Chiguvi, D. The challenges faced by management in managing employee resistance to change in the mining sector. *Int. J. Dev. Sustain.* **2022**, *11*, 202–209.
45. Knight, J.F.; Baber, C. Effect of head-mounted displays on posture. *Hum. Factors* **2007**, *49*, 797–807. [CrossRef]
46. Chen, Y.; Wang, X.; Xu, H. Human factors/ergonomics evaluation for virtual reality headsets: A review. *CCF Trans. Pervasive Comput. Interact.* **2021**, *3*, 99–111. [CrossRef]

47. de Winkel, K.N.; Talsma, T.M.W.; Happee, R. A meta-analysis of simulator sickness as a function of simulator fidelity. *Exp. Brain Res.* **2022**, *240*, 3089–3105. [CrossRef]
48. Chattha, U.A.; Janjua, U.I.; Anwar, F.; Madni, T.M.; Cheema, M.F.; Janjua, S.I. Motion sickness in virtual reality: An empirical evaluation. *IEEE Access* **2020**, *8*, 130486–130499. [CrossRef]
49. Van Wyk, E.; De Villiers, R. Virtual reality training applications for the mining industry. In Proceedings of the 6th International Conference on Computer Graphics, Virtual Reality, Visualisation and Interaction in Africa, Pretoria, South Africa, 4–6 February 2009; Association for Computing Machinery: New York, NY, USA, 2009; pp. 53–63.
50. Grabowski, A.; Jankowski, J. Virtual reality-based pilot training for underground coal miners. *Saf. Sci.* **2015**, *72*, 310–314. [CrossRef]
51. Simpson, G.; Horberry, T. *Understanding Human Error in Mine Safety*; CRC Press: Boca Raton, FL, USA, 2018; ISBN 1315549190.
52. Abotaleb, I.; Hosny, O.; Nassar, K.; Bader, S.; Elrifaee, M.; Ibrahim, S.; El Hakim, Y.; Sherif, M. An interactive virtual reality model for enhancing safety training in construction education. *Comput. Appl. Eng. Educ.* **2023**, *31*, 324–345. [CrossRef]
53. Patterson, J. Human Error in Mining: A Multivariable Analysis of Mining Accidents/Incidents in Queensland, Australia and the United States of America Using the Human Factors Analysis and Classification System Framework. Ph.D. Thesis, Clemson University: Clemson, SC, USA, 2009.
54. Farrell, W.A. Learning becomes doing: Applying augmented and virtual reality to improve performance. *Perform. Improv.* **2018**, *57*, 19–28. [CrossRef]
55. Hilfert, T.; König, M. Low-cost virtual reality environment for engineering and construction. *Vis. Eng.* **2016**, *4*, 2. [CrossRef]
56. Islam, M.K.; Brunner, I. Cost-analysis of virtual reality training based on the virtual reality for upper extremity in subacute stroke (VIRTUES) trial. *Int. J. Technol. Assess. Health Care* **2019**, *35*, 373–378. [CrossRef]
57. Paszkiewicz, A.; Salach, M.; Dymora, P.; Bolanowski, M.; Budzik, G.; Kubiak, P. Methodology of implementing virtual reality in education for industry 4.0. *Sustainability* **2021**, *13*, 5049. [CrossRef]
58. Salah, B.; Abidi, M.H.; Mian, S.H.; Krid, M.; Alkhalefah, H.; Abdo, A. Virtual reality-based engineering education to enhance manufacturing sustainability in industry 4.0. *Sustainability* **2019**, *11*, 1477. [CrossRef]
59. Urbanek, A.; Stecuła, K.; Kaźmierczak, K.; Łagosz, S.; Welenc, H.; Dyczko, A. Virtual Reality-based Training for Miners: An Assessment from Participants' Perspective. *Silesian Univ. Technol.* **2024**, *197*. [CrossRef]
60. Stanney, K.; Fidopiastis, C.; Foster, L. Virtual reality is sexist: But it does not have to be. *Front. Robot. AI* **2020**, *7*, 4. [CrossRef]
61. Rebenitsch, L.; Owen, C. Review on cybersickness in applications and visual displays. *Virtual Real.* **2016**, *20*, 101–125. [CrossRef]
62. Polska Grupa Górnicza Wirtualna Rzeczywistość w Służbie BHP. Available online: https://www.pgg.pl/strefa-korporacyjna/aktualnosci/451/Wirtualna-Rzeczywisto%C5%9B%C4%87-w-S%C5%82u%C5%BCbie-BHP (accessed on 30 June 2025).
63. netTG. pl PGG: Górnicy w Wirtualnych Wyrobiskach. Available online: https://nettg.pl/gornictwo/154864/pgg-gornicy-w-wirtualnych-wyrobiskach (accessed on 30 June 2025).
64. WNP. pl PGG do Szkolenia Górników Wykorzystuje Metody z Gier Komputerowych. KGHM też chce z nich skorzystać. Available online: https://www.wnp.pl/energia/energetyka/pgg-do-szkolenia-gornikow-wykorzystuje-metody-z-gier-komputerowych-kghm-tez-chce-z-nich-skorzystac,927248.html (accessed on 30 June 2025).
65. Dyczko, A. *Mining 4.0—Towards an Intelligent Deep Mine of the Future*; Wydawnictwo IGSMiE PAN: Krakow, Poland, 2023.

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