Safety in Mines Research Advisory Committee

Final Project Report

Virtual Reality Simulators for Rock Engineering related training

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Executive Summary

Virtual reality (VR) has been investigated by SIMRAC and CSIR Miningtek as a means of providing an enhancement to current training methods that will lead to more effective hazard awareness training programmes. A VR training simulator developed under a previous SIMRAC project (SIMGEN 203) was used to evaluate VR as a training medium in comparison with a conventional mine training programme.

Groups of trainees were separately evaluated after completing either a conventional training programme or an additional VR based training session. Results confirm findings of the previous SIMGEN 203 project in that the relevance, trainee comprehension and trainee recognition of images and objects in the VR simulator are at a high level. Trainees also voiced their preference for the VR medium over other training media, including video.

A number of shortcomings in the standard video based approach are highlighted and suggest that opportunities exist for VR based approaches to provide improved methods of hazard awareness training. VR offers a more stimulating training approach whereby trainees actively participate in the learning process and the practical application of their knowledge can be evaluated in a safe environment.

Virtual reality based training simulators are capable of providing relevant and improved training delivery in the mine training environment as an enhancement to current training methods.

Preface

This project is effectively a continuation of the SIMGEN 203 project, which ran during 1995 and 1996, and this report should be read in conjunction with the final report for SIMGEN 203 (Squelch, 1996). The purpose of the current project is to further investigate the potential of using VR as a training medium, to make a preliminary assessment as to its effectiveness and to make a comparison with the current training method.

Acknowledgements

Gratitude is expressed to SIMRAC for financial support of project GAP 420.

The author gratefully acknowledges the assistance of the management and staff of the Elandsrand Gold Mine and Training Centre who provided access to facilities and trainees for evaluation purposes. Particular thanks go to Mr Rudy van Rensburg, Mr Willie Brits, Mr Jackson Salakufa, Mr Mac Lion and Ms Maria Wesi for accommodating the daily schedule interruptions and facilitating the attainment of the project objectives. The participation of the trainees in the exercise is also gratefully acknowledged.

The work of Mrs Helen Parsons and Mr Knox Phala of Interlinear Projects in the gathering and analysis of data is gratefully acknowledged.

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1 Introduction

During 1995 and 1996 the SIMGEN 203 research project investigated virtual reality (VR) technology and the possibility of applying this to mine training, in particular to hazard identification training (Squelch, 1996). In the course of the SIMGEN 203 project, a prototype virtual reality hazard identification training simulator was developed and tested. The evaluations of this simulator were conducted at the Elandsrand Training Centre and indicated a high level of relevance and acceptance with the target groups of underground workers.

The 1997 project makes a preliminary investigation into the potential training benefit to be obtained from VR based simulators. This has been pursued by conducting simulator training sessions with a representative selection of underground workers and comparing this to a different group of workers only exposed to the standard classroom training method.

1.1 Research problem statement

Although the initial SIMGEN 203 project indicated an encouraging response from trainees in terms of their acceptance and understanding of the system, the issue of training potential was not directly addressed. The current project is therefore concerned with investigating to what extent a VR simulator can provide improved training over and above the conventional classroom training.

1.2 Objectives and aims of this study

The project enabling output is stated as:

> *Assess the potential benefits that the application of virtual reality could have on the effectiveness and efficiency of worker training programmes in the South African gold and platinum mining industries.*

1.3 Research design

1.3.1 Research context

The study sets out to investigate whether or not the use of virtual reality training simulators can improve on the current quality and worker retention of underground hazard awareness training. A secondary aspect was to determine the acceptability of the computer and VR as a learning medium, and to identify limitations of the simulator content and VR as a training medium.

1.3.2 Research design

The approach taken, to investigate and quantify the issue of whether improved hazard awareness training could be achieved through use of a VR simulator, was to compare training sessions conducted in the classroom with sessions conducted on the VR simulator. An independent industrial psychologist (Interlinear Projects) was contracted to perform this evaluation, and their results and findings are incorporated in this report.

It was not possible to conduct a *quantitative* comparison between the two training media, VR and video, because the disparity in content of the two training programmes would have necessitated the impractical formulation and presentation of customised video and lecture content to match that of the VR simulator. The relevant sections of the classroom programme covering the equivalent hazards to the VR programme were however rescheduled so that they were all presented one after the other.

As with the previous SIMGEN 203 project, Elandsrand gold mine was chosen as the test site at which the evaluation process would take place. Permission was obtained from the mine to have access to trainees passing through the Training Centre on the return-from-leave refresher training courses as subjects in the evaluation exercise.

1.4 Development of the study

Section 1: Introduction and background.
Section 2: Research methodology
Section 3: Research procedure
Section 4: Results
Section 5: Discussion
Section 6: Conclusions and recommendations

2 Research methodology

The stated project methodology is as follows:

1. *Conduct and evaluate hazard identification training sessions with target group of underground workers using Virtual Reality simulator already developed under project SIMGEN 203. Elandsrand Gold Mining Company is proposed as test centre.*
2. *Review test centre's current hazard identification training methods and their effectiveness and compare to simulator training evaluation.*
3. *Final report and recommendations.*

In terms of the actual investigation this methodology was translated into the following six steps:

1. Identifying learning elements for comparison
2. Devising the experimental design
3. Developing a suitable instrument for testing and recording
4. Collecting the data
5. Analysing the information
6. Compiling the report

2.1 Elements to be investigated

Key elements to be tested for recognition and comprehension amongst the virtual reality and video sample groups were identified as the interpretation of certain visual aspects of the medium and knowledge of hazards.

2.1.1 Virtual reality elements

Key visual elements in the virtual reality programme were identified as the four icons employed to represent the remedial actions, and eight pictorial elements depicting key aspects of the workplace.

The four icons represent the activities of:

- barring down
- installing support
- stopping the scraper winch
- testing for gas (methane)

The eight pictorial elements, selected in order to assess whether the subjects perceived graphic representations of the workplace to be real, were:

- pack
- support (timber stick)
- electrical substation
- prop (mechanical and hydraulic)
- scraper winch
- drill
- working face
- reef

The remaining key aspects were knowledge of hazards, in particular fall of ground, scraper winches and methane.

2.1.2 Video elements

Key elements of the video based training were the visual images in the videos themselves and knowledge of hazards. While no specific items in the videos were targeted, the issue was rather one of overall comprehension of the scenarios being portrayed. Again, knowledge of hazards, in particular fall of ground, scraper winches and methane, was sought.

2.2 Experimental design

The principles applied in the experimental design allowed for the assessment of:

- prior knowledge levels
- determination of comprehension of:
  - concepts
  - language, in terms of level and vernacular
  - visual literacy
- ability to transfer skills learned
- retention levels in the short term, i.e. four weeks

Two groups of 30 subjects were chosen to participate in this investigation. One of the groups experienced training via the medium of virtual reality, the other was trained using the mine's standard video based approach. Both of the groups were subjected to prior knowledge testing.

To allow for attrition in the samples between the training and the follow-up testing periods, additional subjects were selected for each group.

Several biographical variables were investigated to determine their impact on the subjects' performances. Two of these variables - education and job category - are of primary importance as they are the most likely to affect subjects' levels of visual literacy and their ability to recognise job-specific information.

Consequently, the samples drawn were not regular, stratified samples, but were restricted to those subjects working in the underground environment in jobs where the course content would have specific application.

Matching of the samples was performed for the two primary variables of:

- education level
- job group

2.3 Testing and recording

A questionnaire was developed to capture the data in this investigation. A blend of closed- and open-ended questions was included to provide both quantitative and qualitative data for analysis. The questionnaire was administered by means of an interview.

All interviews were conducted on an individual basis in the language of the subject's choice. The duration of the interviews varied between 20 and 30 minutes. The background to the investigation was clearly explained to each subject and all employees were assured of confidentiality of response. The data collected during these interviews was subjected to appropriate non-parametric statistical analysis and to content analysis.

2.4 Data collection

Data was collected in three phases:

- pre-test
- post-test
- follow-up test

The pre- and post-tests were conducted immediately prior to and after training respectively. The follow-up test took place four weeks after training to determine information retention levels.

3 Research procedure

For each of the two training methods under investigation, a separate evaluation and interview system (i.e. questionnaire) was devised; these were kept as similar as their diverse nature permitted. The drawing up of the evaluation questionnaire was undertaken by an independent industrial psychologist (Interlinear Projects) and the associated interviews were conducted by an expert interviewer provided by the independent psychologist.

3.1 Virtual reality training simulator sessions

For the purposes of this evaluation exercise, the VR training simulator was set up in an office at the Elandsrand Training Centre in the configuration shown in Figure 3.1. Trainees were individually pre-tested regarding their knowledge of underground hazards, then shown and questioned regarding their interpretation of the images presented in the VR simulator. Each trainee was then given instruction in the use of the joystick and allowed some time to move around the stope world. After this, the trainee was asked to “walk” up the dip gully, go into the top strike gully, head for the stope face and go down the face to the bottom strike gully. The trainee was told that, while following this route he was to look out for hazards, and stop and inform the interviewer when he saw one. The interviewer then asked the trainee to describe what the hazard was and to perform the necessary corrective action. After each hazard was identified and corrected the trainee was asked to continue with the exercise. If the trainee failed to identify a hazard and instead triggered the hazard, the interviewer asked the trainee to explain what had happened. After the trainee had encountered all four hazards, he was asked some post-test questions by the interviewer and that concluded the first phase of the simulator training evaluation process.

The second phase of the process was for the same interviewer to visit each of the tested trainees at their place of work underground and, with the aid of printed colour screen images, ask questions to determine the retention and understanding of their simulator training experience.

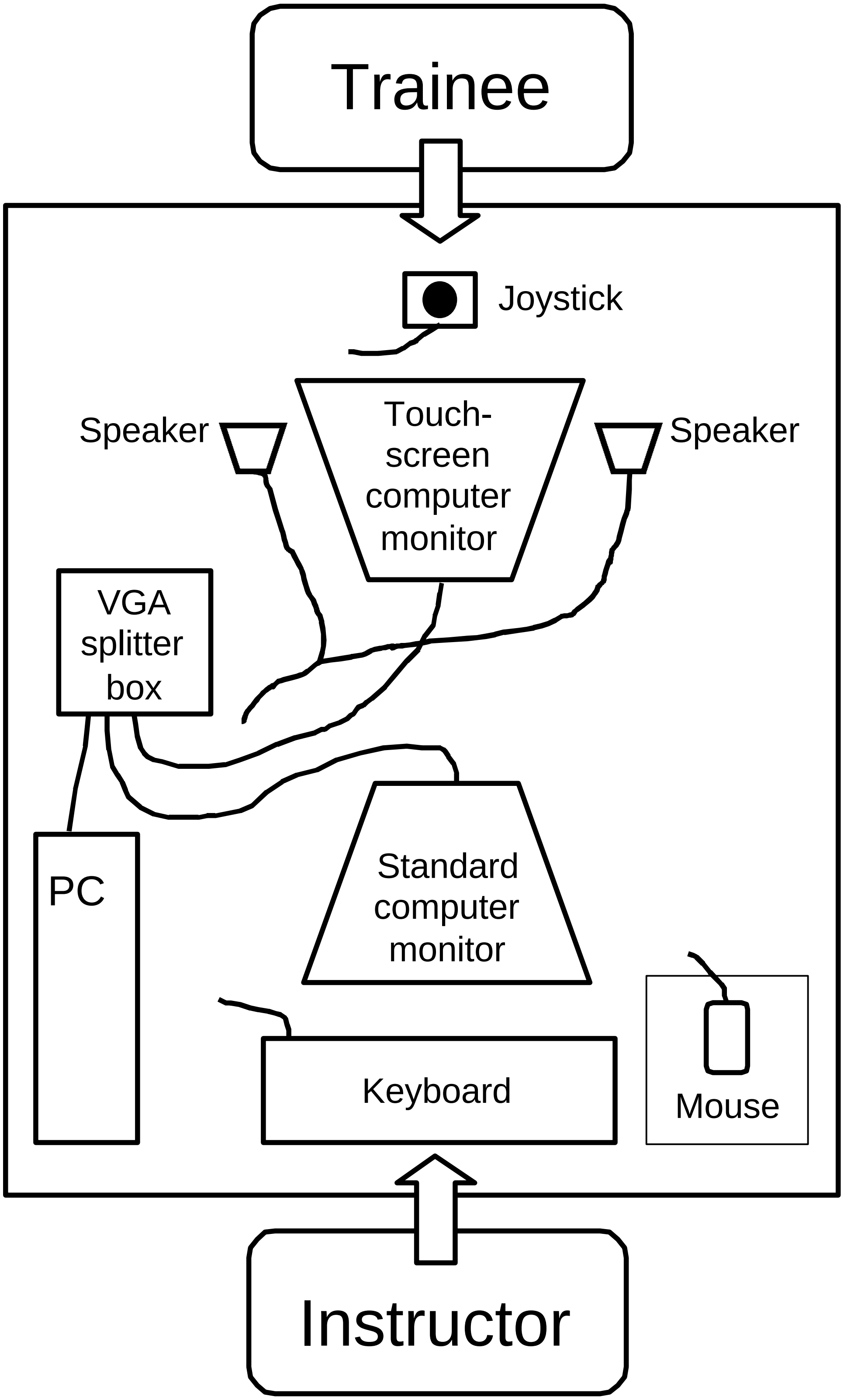

Figure 3.1 *VR stope simulator's operational configuration*

3.2 Classroom training sessions

The existing return-from-leave classroom training programme in operation at the Elandsrand Training Centre consists of two days of lectures, videos and discussion sessions. The fall of ground and scraper winch safety aspects of the training programme relevant to the current study are addressed through the showing of three videos and after-viewing discussion sessions.

This classroom training programme was used for the control study aspect of the investigation. It was, however, necessary to re-schedule the three relevant videos to a single time slot in the morning classroom session in order to facilitate the monitoring and interview process. The sample group of trainees was selected, from those present at the training centre each day, to match as closely as possible the distribution of job grades and functions in the VR training group. A further selection criterion was that no trainee should have been previously exposed to the VR simulator.

The selected trainees were individually interviewed prior to the start of the classroom training programme for a pre-test session to determine their knowledge level regarding the relevant hazard aspects. The interviewer sat in during the viewing of the videos and the discussion sessions in order to observe the trainees' reactions and participation. A post-test interview was held with each of the trainees at the end of the day's training programme to determine the level of understanding and learning attained by the trainees. As in the case of the VR training sample, these trainees were all re-interviewed in a follow-up session at their place of work to determine the longer-term retention of their training.

4 Results

The results of this investigation have been grouped according to the following subject areas:

- Biographical information
- Recognition and comprehension of visual material
- Knowledge levels
- Attitude towards the training medium

All data was cross-tabulated against the biographical variables to determine whether these factors were responsible for any specific directions in the results. Education levels and job groups were particularly examined. No significant differences were found to exist in any of the analyses performed across biographical variables. Where significant differences were isolated in analysis, these results have been highlighted.

4.1 Biographical information

Several biographical variables were investigated to determine their impact on the subjects' performances. Two of these variables - education and job category - were determined to be of primary importance. Frequency analysis shows the virtual reality and video samples to be well matched on these attributes.

The final sample sizes were:

- virtual reality sample = 31
- video sample = 32

The biographical profiles of the two samples are presented below under the relevant variable headings. Unless otherwise indicated, all figures are expressed as percentages.

4.1.1 Length of service at the mine

Statistically significant differences exist between the two samples in terms of their length of service at the mine (Figure 4.1). Of the subjects comprising the virtual reality sample, over 40 per cent have worked at the mine for more than seven years. In the case of the video sample, almost 30 per cent of the subjects have been employed at the mine for less than three years.

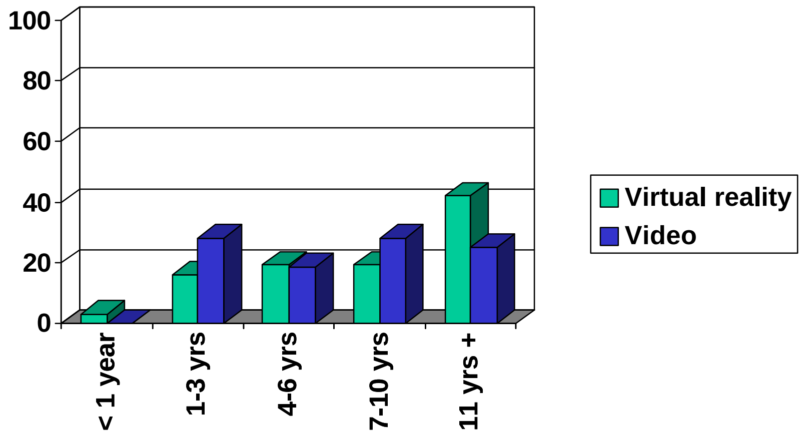

Figure 4.1   Length of service at the mine

4.1.2 Length of service in the mining industry

Similar differences exist between the samples in respect of their experience in the mining industry (Figure 4.2). Three quarters of the virtual reality subjects have a service record longer than seven years.

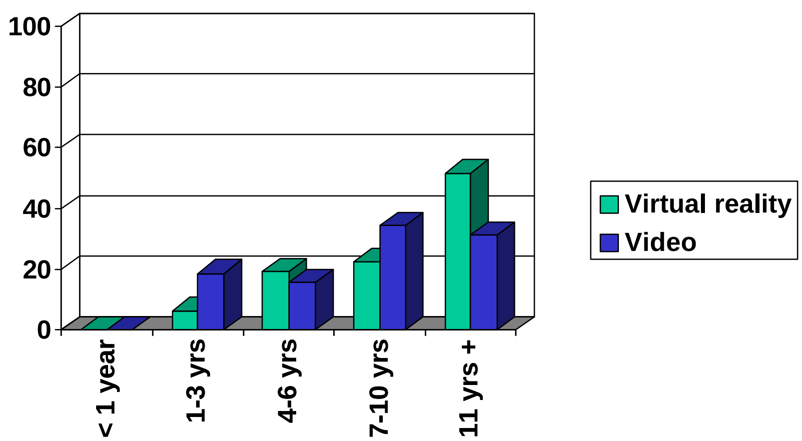

Figure 4.2   Length of service in the mining industry

4.1.3 Category of job

Job category is one of the primary variables used to determine differences in the response levels of the subjects, and it was important that the samples be as closely matched as possible in this regard (Table 4.1). Although the job categories of driller, winch operator and locomotive driver have been superseded by multi-tasking, some subjects still refer to the former categories as they best describe the main focus of their day-to-day tasks. Data analysis was performed using these categories in their separate sub-sets and also as a combined grouping with multi-tasking but no significant results were found.

The samples are closely matched on the job category variable.

Table 4.1 Distribution of job categories in each sample group

Job category	Virtual reality sample	Video sample
Engineering and Services	1 (3.23 %)	3 (9.38 %)
Labourer	5 (16.13 %)	2 (6.25 %)
Team Leader	4 (12.90 %)	5 (15.63 %)
Multi-task	11 (35.48 %)	10 (31.25 %)
Driller	3 (9.68 %)	1 (3.13 %)
Winch operator	3 (9.68 %)	7 (21.88 %)
Locomotive driver	4 (12.90 %)	4 (12.50 %)

4.1.4 Job grade

The virtual reality and video samples are well matched on the variable of job grade (Figure 4.3).

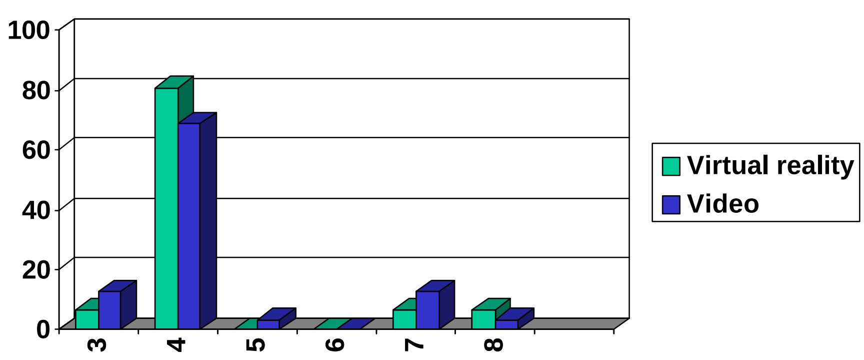

Figure 4.3 Job grade of subjects

4.1.5 Age

The average age of the subjects in the video sample is significantly younger than those of the virtual reality sample (Figure 4.4). This correlates with the greater length of service reported by this sample.

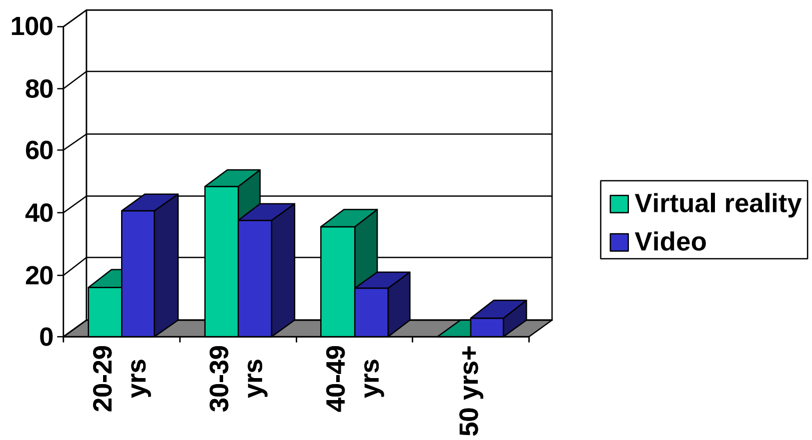

Figure 4.4 Age of subjects

4.1.6 Home language

There are significantly higher proportions of Shangaan-speaking subjects in the video sample and Xhosa-speaking individuals in the virtual reality sample (Table 4.2).

Table 4.2 Home language of subjects

Home language	Virtual reality sample	Video sample
Sesotho	10 (32.26 %)	11 (34.38 %)
Xhosa	10 (32.26 %)	4 (12.50 %)
Zulu	1 (3.23 %)	3 (9.38 %)
Siswati	5 (16.13 %)	2 (6.25 %)
Pedi	0	1 (3.13 %)
Setswana	1 (3.23 %)	2 (6.25 %)
Venda	0	1 (3.13 %)
Shangaan	4 (12.90 %)	8 (25.00 %)

4.1.7 Level of education

Level of education is one of the primary variables used to cross-tabulate the results of this study (Figure 4.5). The differences in education levels between the samples are not significant.

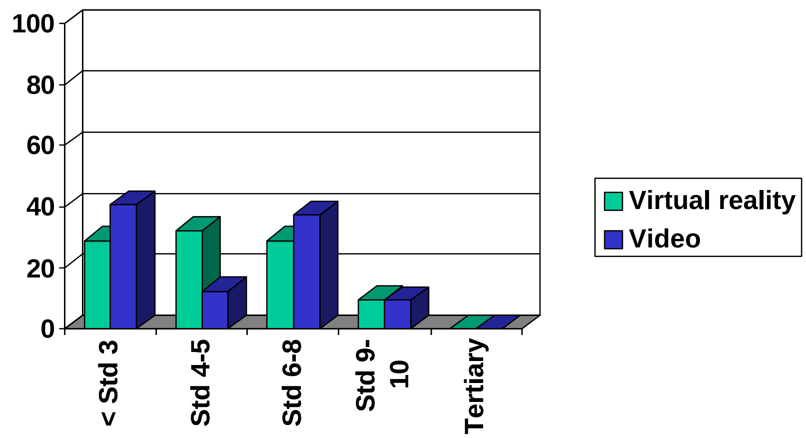

Figure 4.5 Level of education of subjects

4.2 Recognition and comprehension of visual material

Several aspects of the visual material contained in both the virtual reality and the video training programmes were tested for recognition and comprehension. The results are presented under the following headings:

- icons
- pictorial elements
- incidental recognition of visual material
- general views of visual material

4.2.1 Icons

During the virtual reality training programmes a series of four hazards is presented to the trainee. The trainee is required to demonstrate the appropriate action to be taken by selecting one of four icons that represent specific courses of action.

These icons were presented to the virtual reality sample in the pre- and follow-up test situations.

The four icons represent the actions:

- bar down
- install support
- stop winch
- test for gas

The icons representing ‘barring down’ and ‘installing support’ were immediately recognisable, without coaching, to all subjects in the virtual reality group. The ‘stop winch’ icon recorded high recognition prior to training and an extremely high score at follow-up testing (Figure 4.6).

The ‘test for gas’ icon was not easily recognisable to the subjects and, although all subjects understood its purpose immediately after training, at follow-up testing the level of recognition had fallen (Figure 4.6).

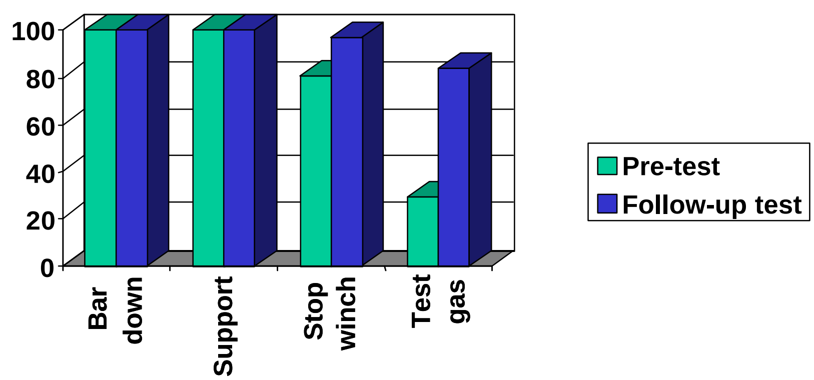

Figure 4.6   Comprehension of icons by virtual reality sample

4.2.2   Pictorial elements

Eight pictorial elements depicting key aspects of the workplace were selected for recognition testing. These elements were:

Set 1:
- pack
- support (timber stick)
- electrical substation
- prop (mechanical and hydraulic)

Set 2:
- scraper winch
- drill
- working face
- reef

The visual representations of the underground elements selected for testing were easily recognised by the subjects in the virtual reality sample (Figure 4.7 and Figure 4.8). Pre-test levels were all above 90 per cent and four weeks later, at follow-up testing, all subjects recalled the visuals accurately.

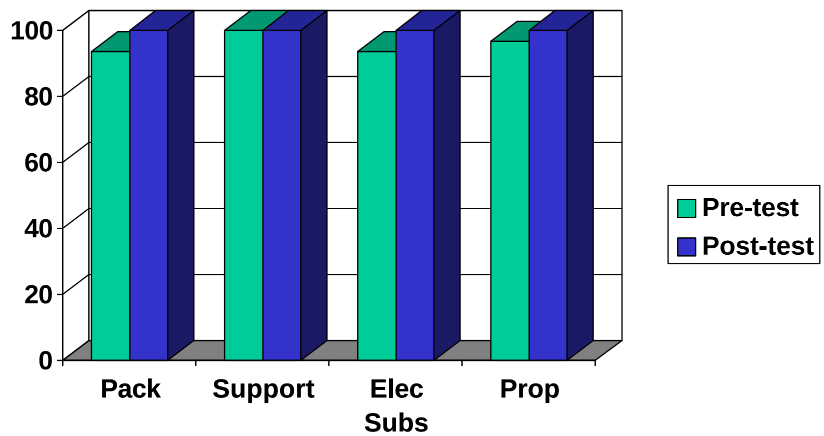

Figure 4.7 Recognition of pictorial elements by virtual reality sample-Set 1

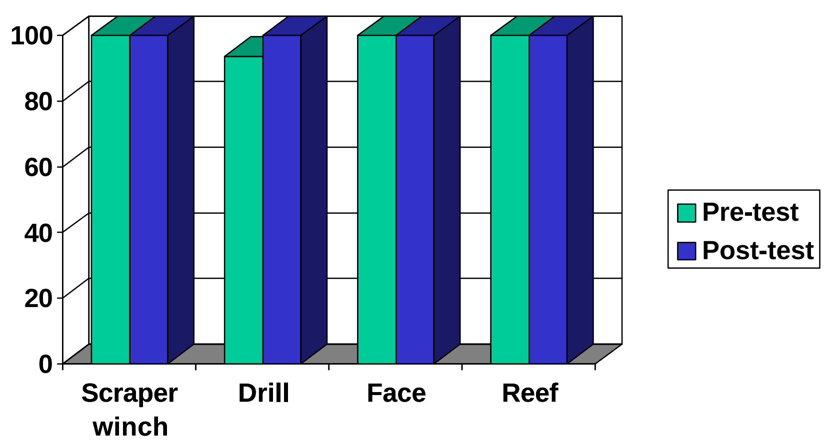

Figure 4.8 Recognition of pictorial elements by virtual reality sample-Set 2

4.2.3 Incidental recognition of visual material

Included in the virtual reality training programme is a visual representing a man using crutches. No emphasis is placed on this picture and the subject's attention is not deliberately drawn to it. None of the virtual reality subjects were exposed to this visual during the pre- or post-test situations.

At follow-up testing, the subjects were asked whether they recalled having seen this visual before. A high level of recall was exhibited by the subjects (Figure 4.9).

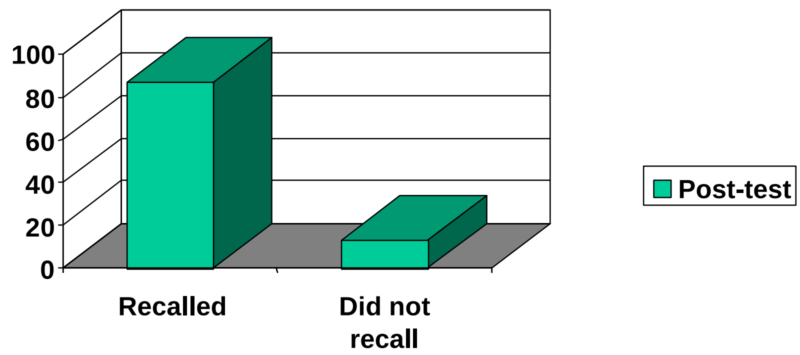

Figure 4.9 Recall of 'man on crutches' visual by virtual reality sample

4.2.4 General views of visual material

Both groups of subjects were asked to evaluate the ease with which they were able to understand the visual material in their respective training programmes. The evaluations were made against a five-point scale (Figure 4.10 and Figure 4.11).

No extremes of view were recorded and both sample groups indicated high levels of ease of comprehension.

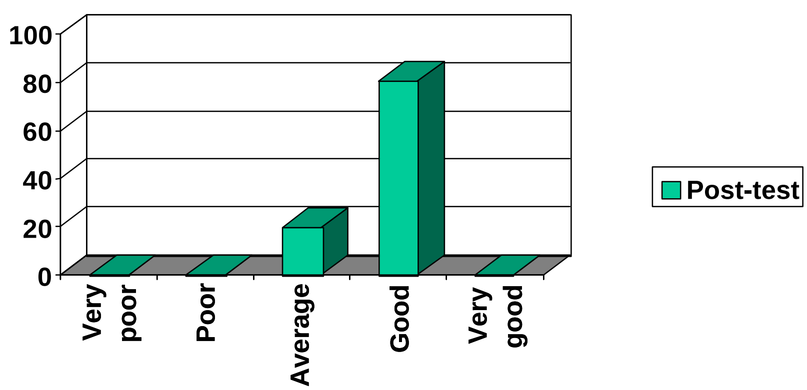

Figure 4.10 Ease of understanding visual material by virtual reality sample

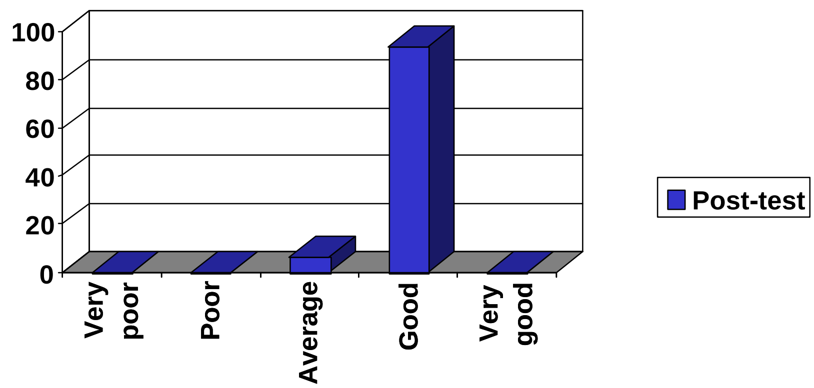

Figure 4.11 Ease of understanding visual material by video sample

Subjects in both sample groups were asked to indicate the level of realism they felt to be depicted in the visual material contained in their respective programmes. The evaluations were made against a five-point scale (Figure 4.12 and Figure 4.13).

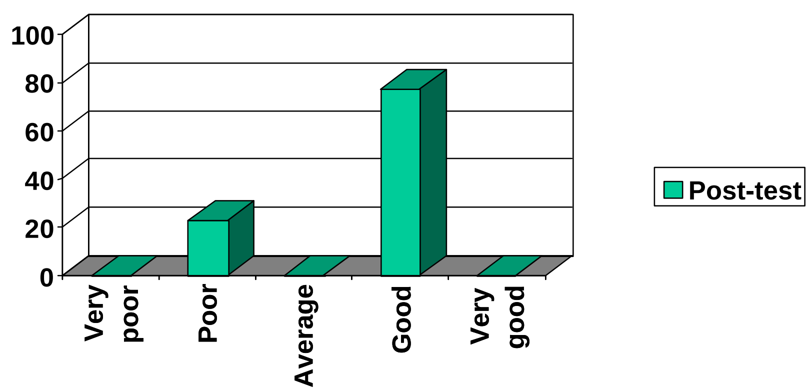

Figure 4.12 Perceived level of realism in visual material by virtual reality sample

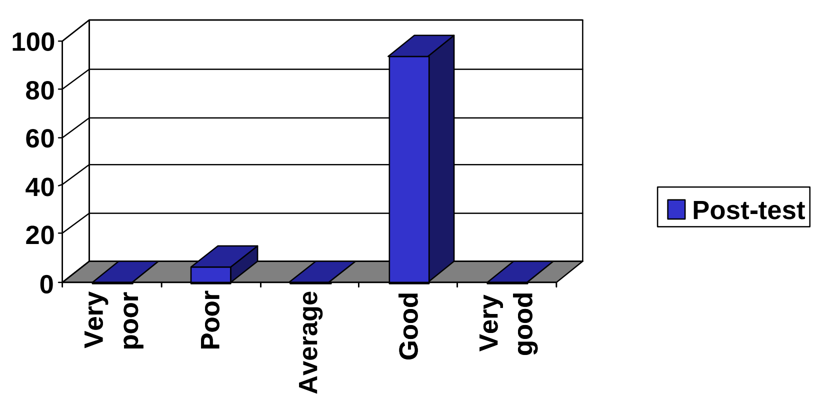

Figure 4.13 Perceived level of realism in visual material by video sample

No extreme views were expressed and both sample groups indicated that they considered the respective visual material to be a realistic representation.

Subjects in the video sample expressed satisfaction with the level of detail shown in the material. Those subjects who responded negatively to this question supported their views by saying that only the scenes immediately before and after accidents were shown. The accident itself was not depicted and so it was not possible to see what had really happened.

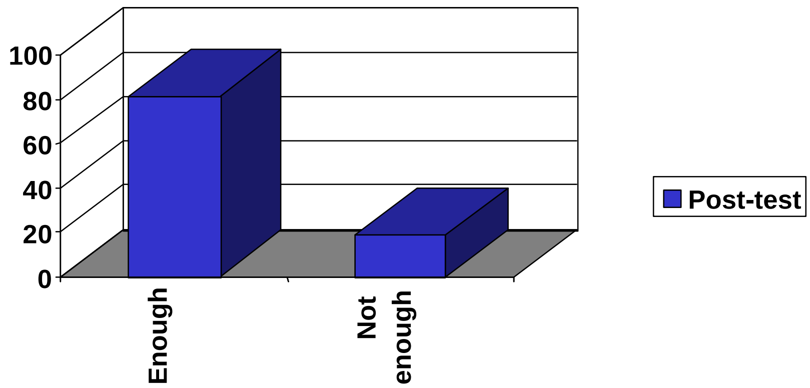

Figure 4.14 Opinion of detail provided in visual material by video sample

4.3 Knowledge levels

The virtual reality training programme emphasises selective hazardous situations in the underground environment. These situations form the focus of this investigation. Consequently, three dangers have been identified as the basis for knowledge testing. These dangers are:

- loose or falling rocks
- scraper winch
- methane

These dangers are depicted in four different hazardous situations in the training programme.

4.3.1 Awareness of selected hazards in pre-test

During pre-testing, both sample groups were asked to list all hazardous situations which they could recall. The responses were analysed according to their recall of the three selected hazards (Figure 4.15).

In the pre-test situation, the virtual reality group showed high knowledge levels of the winch and of loose or falling rocks as dangers. Methane was listed as a danger by less than 40 per cent of the sample.

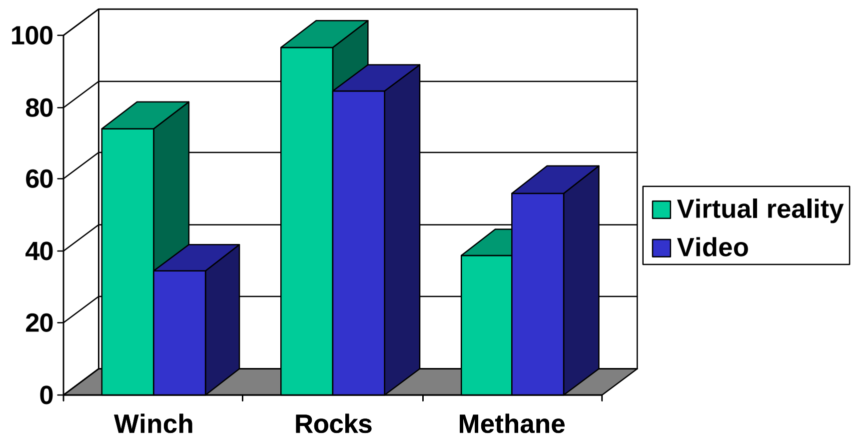

Figure 4.15 Awareness of selected hazards in pre-test

The video sample showed a higher level of knowledge of methane as a hazard but a lower level for the winch and loose or falling rocks as hazards during pre-testing.

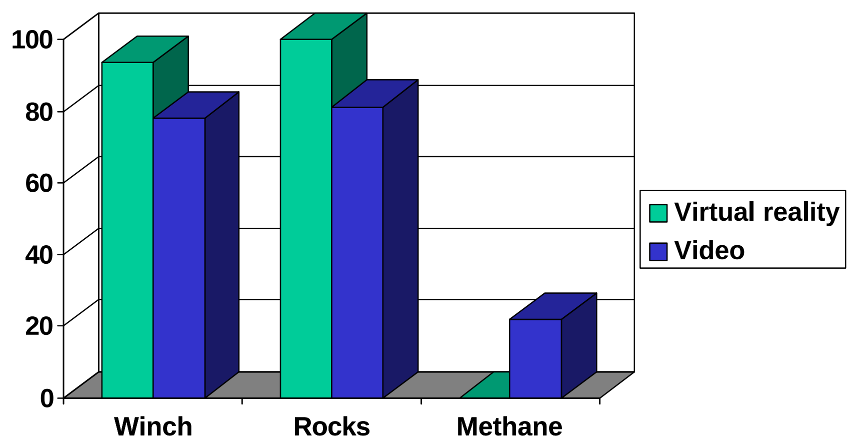

Figure 4.16 Awareness of selected hazards in follow-up test

The same questions were administered to the two samples at follow-up testing. The virtual reality sample group showed an increase in knowledge levels for the winch and loose or falling rocks hazards, but a dramatic decrease in awareness of methane (Figure 4.16).

The responses from the video sample showed an increase in awareness of the winch as a hazard, but a marked decrease in the recall of methane as a danger area.

Knowledge of the correct action to take in the event of any of the three hazards was evaluated for both sample groups (Figure 4.17). The virtual reality group displayed significantly greater knowledge of the actions to be taken concerning a winch. Knowledge of the action to take to determine methane levels is low in both groups, but less than 50 per cent in the case of the virtual reality group.

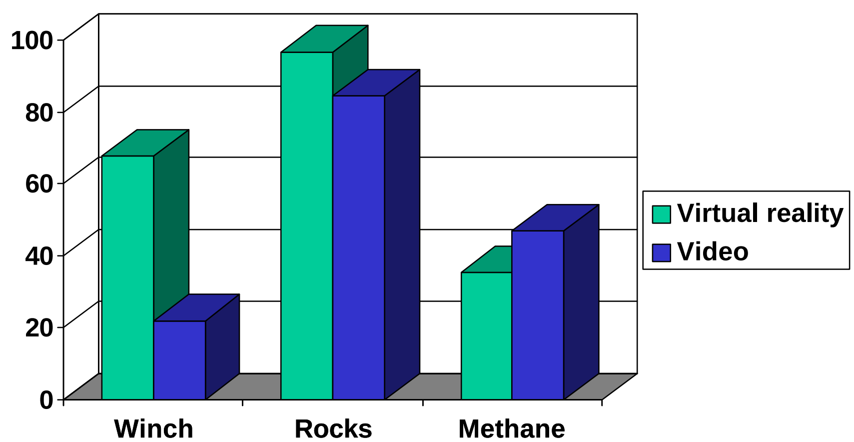

Figure 4.17 Knowledge of correct action to take for hazards in pre-test

The total number of hazards listed by subjects during pre- and follow-up testing was analysed for both sample groups (Figure 4.18 and Figure 4.19).

There is little consistency in the number of hazards cited by either of the two sample groups. Further analysis indicates that the content of the respective training programmes introduced a cueing effect on the subjects. This, combined with the association of the appearance of the interviewer, resulted in the subjects' responses being focused on what they had seen in the programme and not necessarily on their knowledge prior to their exposure to the training programmes.

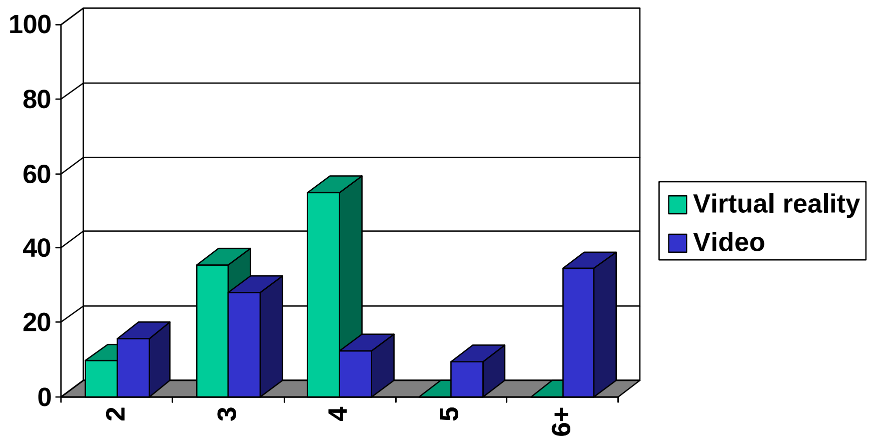

Figure 4.18 Total number of hazards identified in pre-test

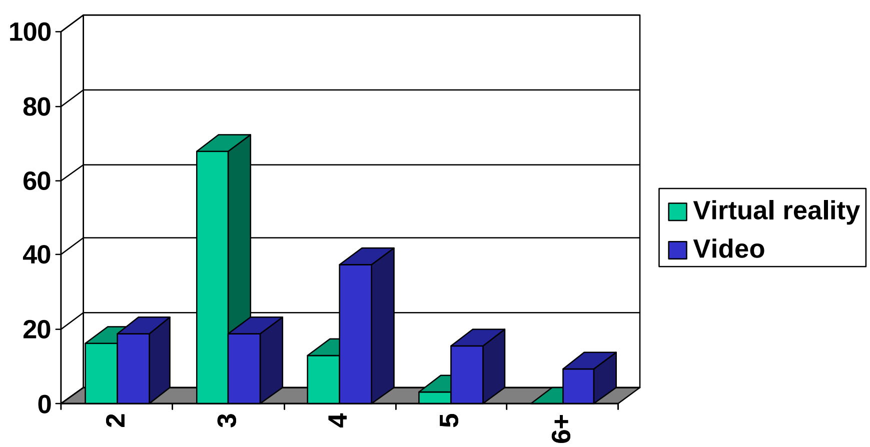

Figure 4.19 Total number of hazards identified in follow-up test

4.3.2 Response to Hazards 1 - 4 during training

Four hazardous situations representing the selected dangers are depicted in the virtual reality training programme. These are:

- Hazard 1 - brow over raise
- Hazard 2 - reef over top strike gully
- Hazard 3 - reef above drilling machine
- Hazard 4 - moving scraper in bottom strike gully

During training, the virtual reality sample group's actions were recorded and their behaviour in respect of each hazard was analysed.

In the case of Hazard 1, the majority of the sample observed the presence of the hazard and stopped before reaching it (Figure 4.20). Less than half of the sample were able to identify the nature of the hazard correctly. Furthermore, even fewer subjects were able to take the correct action.

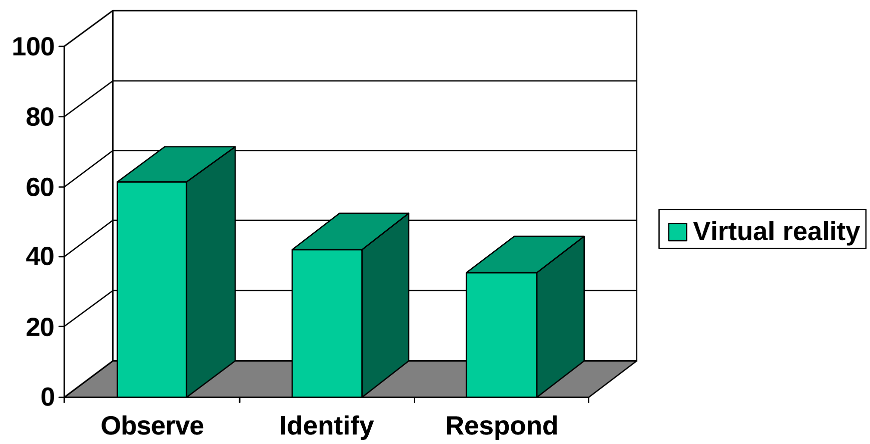

Figure 4.20 Response to Hazard 1 during training by virtual reality sample

When confronted by Hazard 2, a greater proportion of the sample observed the presence of the hazard (Figure 4.21). However, the number of subjects who could correctly identify the hazard and who knew the correct action to take were again considerably lower.

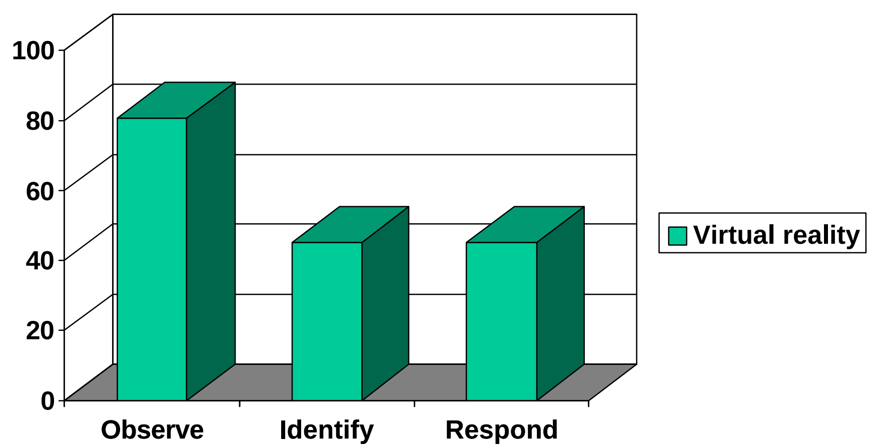

Figure 4.21 Response to Hazard 2 during training by virtual reality sample

The appearance of Hazard 3 elicited higher levels of observation, identification and correct action (Figure 4.22).

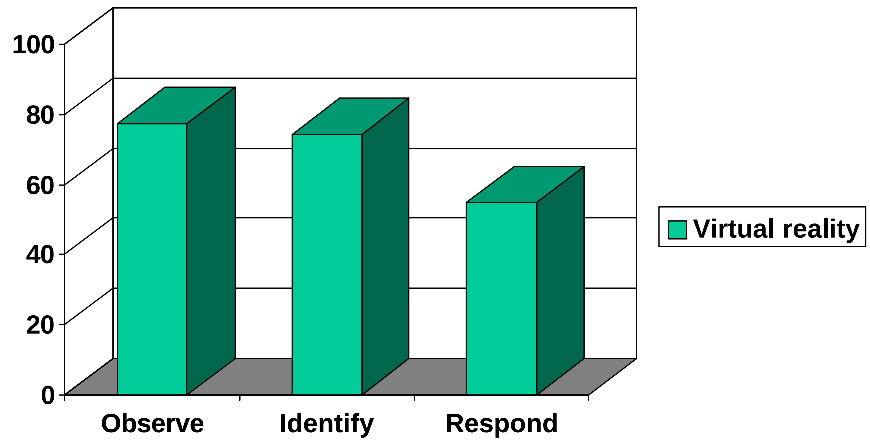

Figure 4.22 Response to Hazard 3 during training by virtual reality sample

Hazard 4 was met with the highest level of observation and correct response (Figure 4.23).

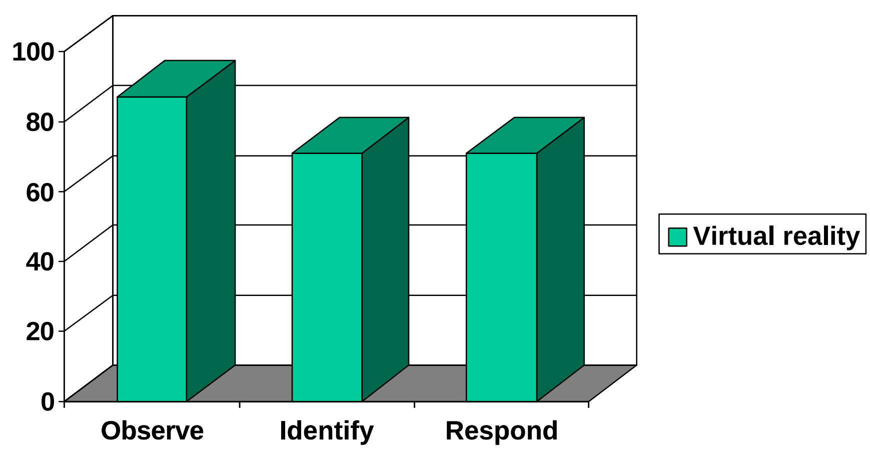

Figure 4.23 Response to Hazard 4 during training by virtual reality sample

4.3.3 Recall of visuals depicting the four hazard situations

During the follow-up testing, four weeks after training, subjects in the virtual reality sample group were presented with visual material depicting the four hazard situations that they had experienced during training.

With the exception of Hazard 2, all subjects recognised and correctly identified the hazards (Figure 4.24). Although Hazard 2 had evoked low responses during training, 80 per cent of the subjects correctly recalled it during follow-up testing.

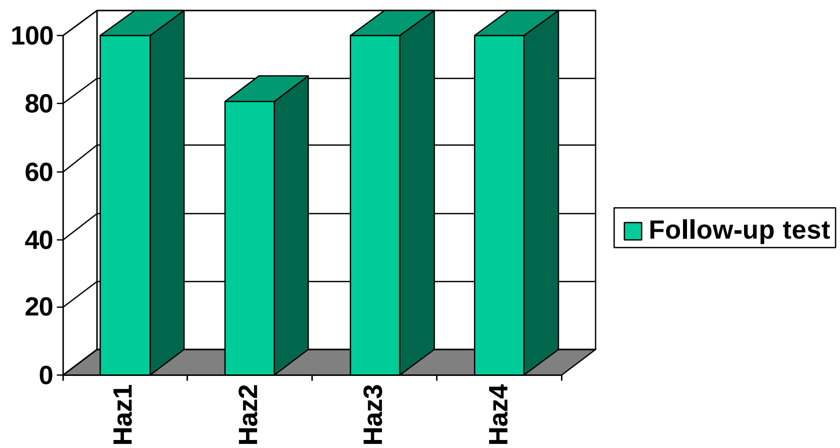

Figure 4.24 Recall of visuals depicting Hazards 1 - 4 at follow-up testing by virtual reality sample

4.4 Attitude towards the training medium

Several variables were tapped to determine the subjects' attitudes towards their respective training media. These variables concerned:

- previous exposure to the medium
- preferred training method
- ease of use
- personal relevance of content
- perceived difficulty of content

4.4.1 Previous exposure to the medium

Exposure to the computer medium is extremely low. Amongst the virtual reality sample, less than one person in five has experienced playing computer games, and over 90 per cent of the subjects have never used a computer before (Figure 4.25).

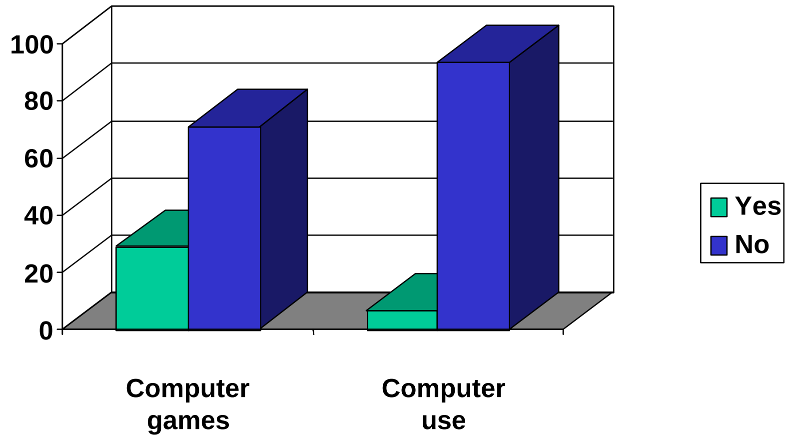

Figure 4.25 Level of previous exposure to a computer by virtual reality sample

Where the video sample is concerned, every subject had viewed these video programmes previously, some as many as five times, but none had been exposed to any other training using video as a medium (Figure 4.26). The virtual reality sample group had also seen these videos during their attendance at previous refresher training courses.

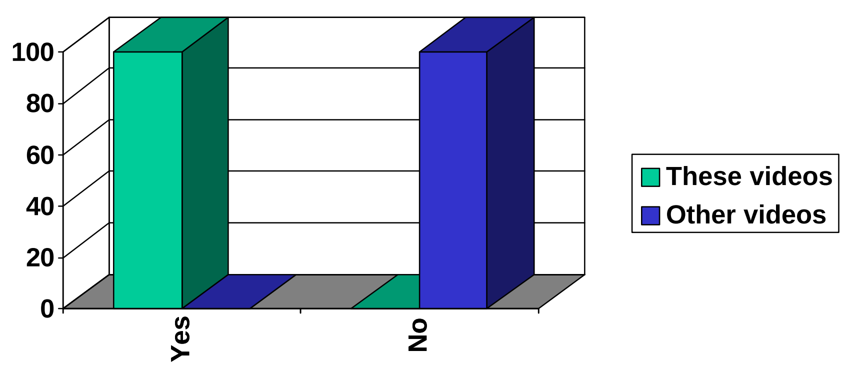

Figure 4.26 Level of previous exposure to video as a training medium by video sample

4.4.2 Preferred training method

Despite the low previous exposure to the computer, the medium received overwhelming support as a good training tool from the virtual reality sample (Figure 4.27).

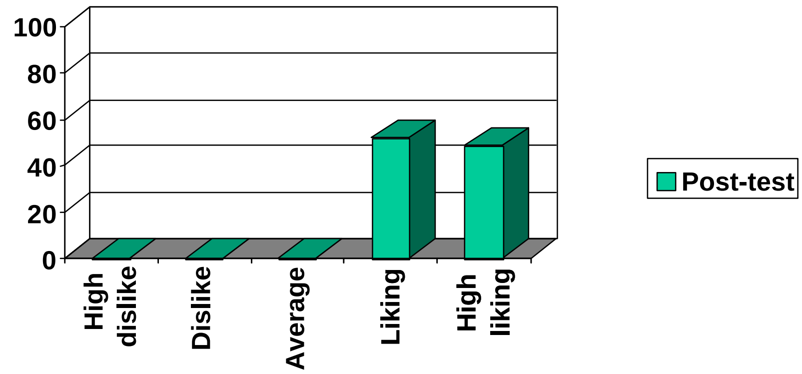

Figure 4.27 Opinion of computer as a training tool by virtual reality sample

Almost all of the subjects preferred virtual reality as a training medium (Figure 4.28).

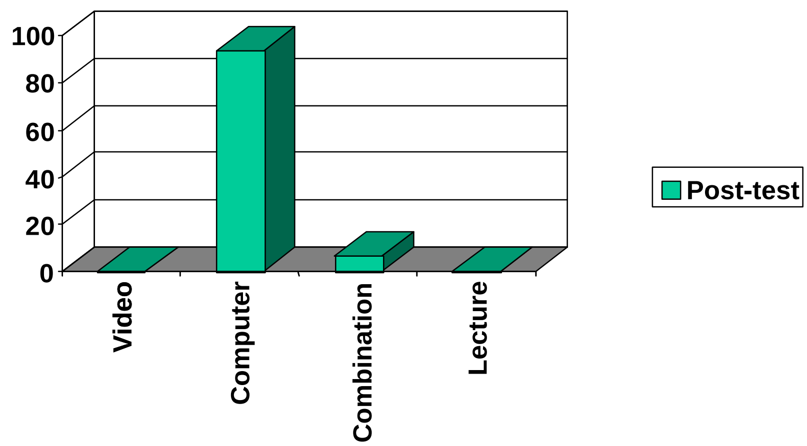

Figure 4.28 Preferred method of teaching by virtual reality sample

Open-ended responses indicated that subjects' self-esteem was raised by exposure to the medium. Some examples of responses are:

> "I like it very much although it needs some improvements. It makes feel that the mine treats me like an intelligent person. The mine is empowering me."

> "With the computer you can see, hear and do as if you are walking underground."

“We get scared to ask questions in a class because sometimes the trainer can embarrass you in front of others. The computer makes you feel at ease.”

“The computer has actual underground pictures and sounds, so it takes your mind to underground. The computer is practical and about reality. In classes we rely on few practicals, just theory only.”

“It is a more practical and up-to-date method training us about our work situations and how to control them. The mine shows that it is highly concerned with our lives and treats us as human beings.”

Nearly all the subjects in the video sample expressed satisfaction with the medium as a teaching method. Observation of the subjects during the video training period revealed seven subjects (22 per cent) to be asleep during the screening of the videos, and a further nine (28 per cent) not to be paying attention to the screen.

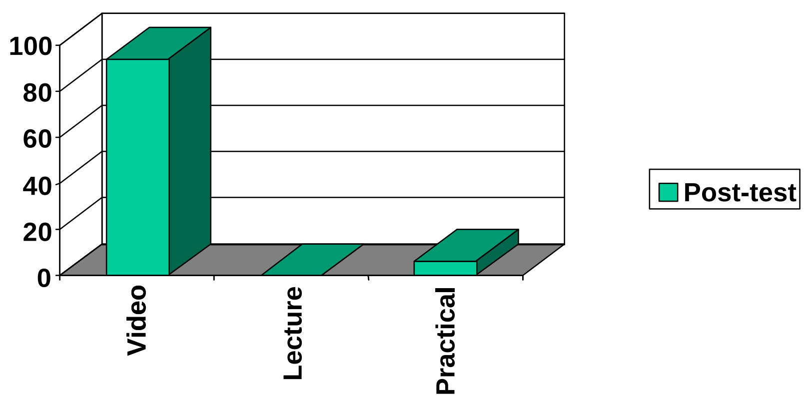

Figure 4.29 Preferred method of teaching by video sample

4.4.3 Ease of use

Despite some initial difficulties in mastering the movement of the joystick, the majority of subjects described it as easy to use (Figure 4.30). Those subjects who did not share this view stated that further practice was needed, but that they did not see the use of the joystick as a barrier to learning.

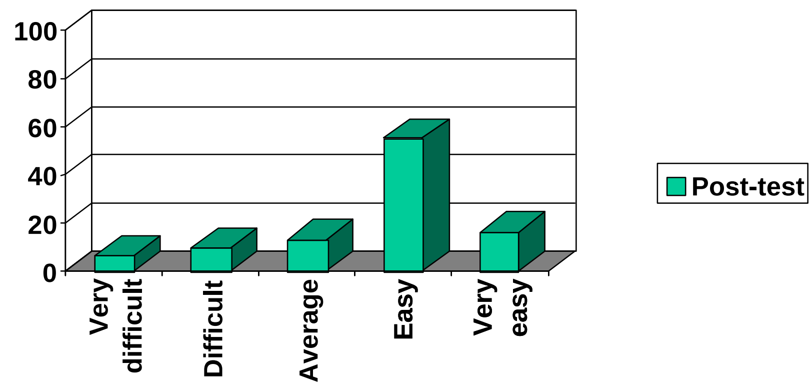

Figure 4.30 Ease of using joystick by virtual reality sample

4.4.4 Personal relevance of content

Significantly more subjects in the virtual reality sample group indicated a high interest in the content of the course (Figure 4.31).

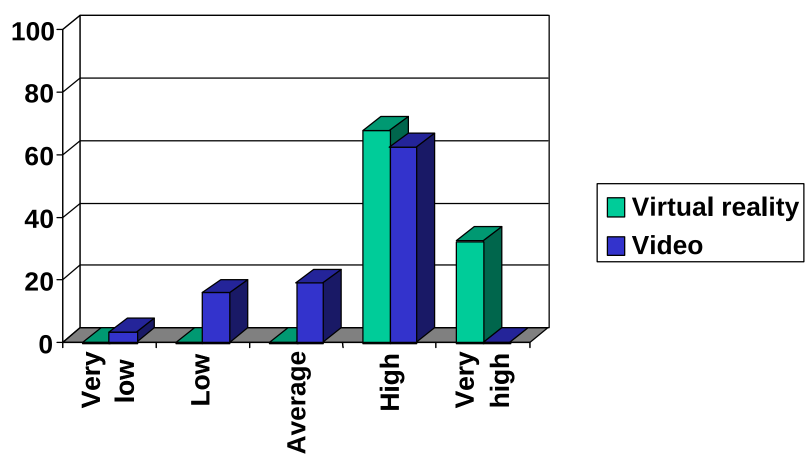

Figure 4.31 Level of personal interest in course content

A wide range of hazardous situations was depicted in the video programmes. The majority of subjects indicated that they consider these situations to be of importance to themselves (Figure 4.32). However, a cause for concern is the 16 per cent of the sample who do not believe these dangers to be of relevance to themselves.

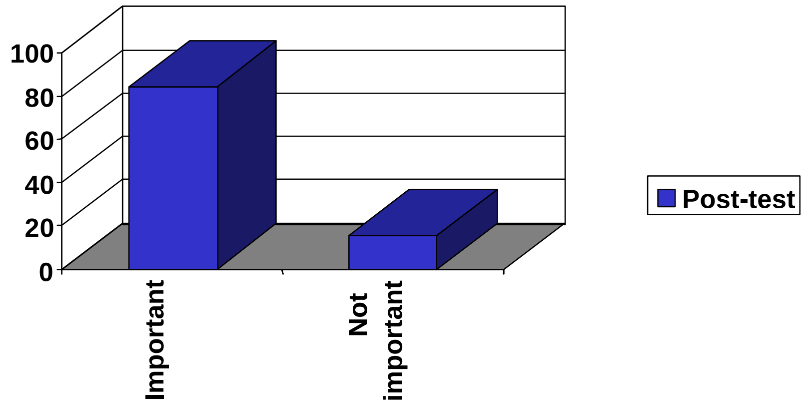

Figure 4.32 Perceived importance of hazards to individual subjects in video sample

Whereas the majority of subjects in the video sample believe that the accidents portrayed in the video programmes could happen to themselves, 22 per cent of the individuals interviewed believe themselves to be protected by virtue of their knowledge of safety rules (Figure 4.33).

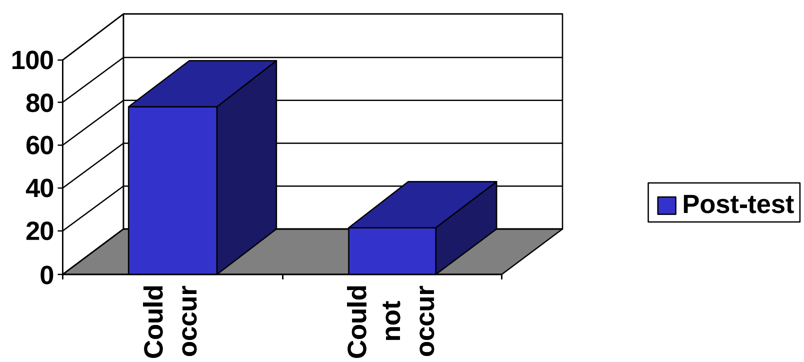

Figure 4.33 Belief that accidents shown in videos could happen to individual subjects in video sample

More than 50 per cent of respondents in the video sample have experienced these accidents occurring to their colleagues (Figure 4.34).

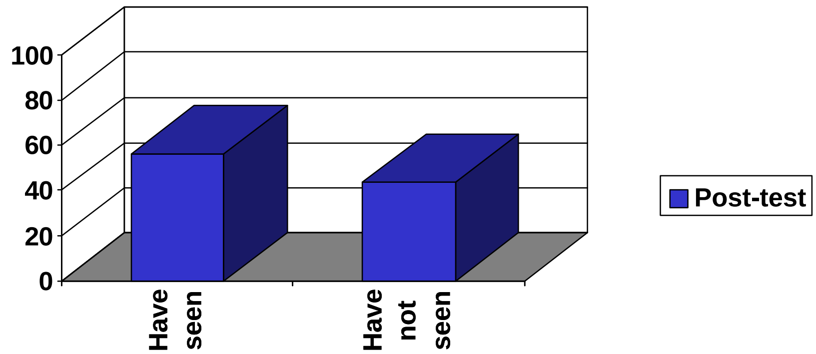

Figure 4.34 Experience of accidents shown in videos occurring to colleagues of individual subjects in video sample

4.4.5 Perceived difficulty of content

The content of the virtual reality course was rated significantly easier than that of the video programmes (Figure 4.35). Only the virtual reality course received a rating of 'very easy' and only the video programmes were rated 'average' and 'difficult'.

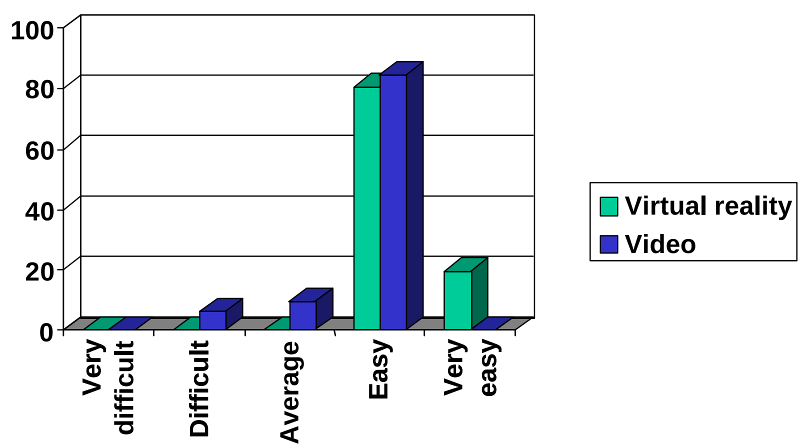

Figure 4.35 Level of perceived difficulty of course content

Subjects were asked to assess the duration of the course in the light of the amount of information that they were presented with (Figure 4.36). A significant number of the video subjects allocated ratings from 'average' to 'very long'.

All subjects in the virtual reality group perceived their respective training programme to be either 'short' or 'very short'.

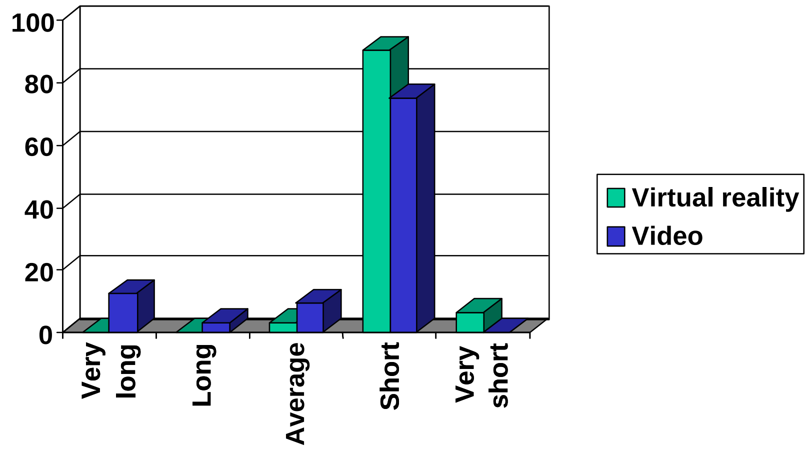

Figure 4.36 Duration of course in relation to amount of content

The sound effects in the virtual reality programme were unanimously evaluated as realistic by the subjects in that sample group (Figure 4.37). In contrast, 19 per cent of the video sample group rated the video sound effects as unrealistic.

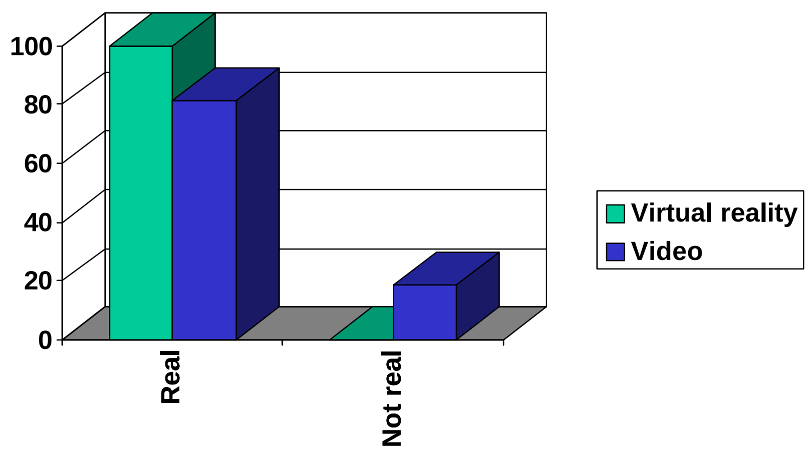

Figure 4.37 Levels of perceived realism of sound effects

The effectiveness of video as a training tool amongst a population with generally low levels of education may be questioned in respect of the 16 per cent of respondents in the video sample group who expressed difficulty in attending to both the video and audio stimulus at the same time (Figure 4.38). Some of the responses from the subjects were:

> "I usually concentrate more on viewing than hearing, even when I'm watching TV."

“I think only of the hazards I see and do not concentrate on listening.”

“They talk too fast and the pictures run too fast too. I just use instinct.”

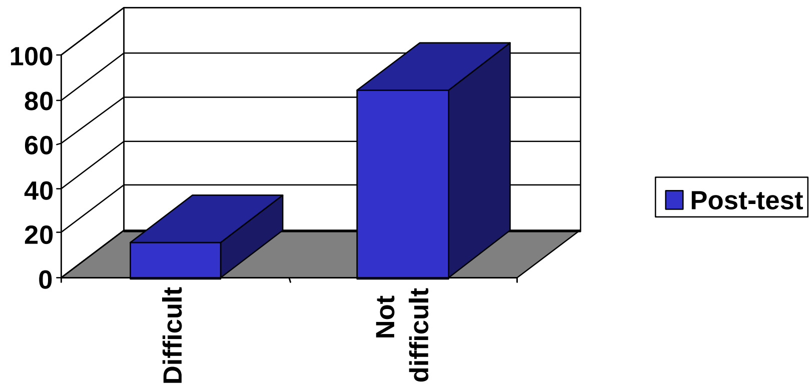

Figure 4.38 Difficulty experienced concentrating on sounds whilst watching picture by video sample

Although cross-tabulations with data on education levels did not show any significant differences on this variable, it should be remembered that the education level of these subjects is generally low on average.

As the main focus of this investigation was the virtual reality training programme, it was not within its scope to investigate this aspect further. However, further research should be undertaken to determine whether the value of video as a training tool is significantly affected by this result.

5 Discussion

The main findings are presented and discussed under the following headings:

- impact of biographical factors
- application of knowledge
- understanding of graphic representations
- types of information suited to the virtual reality medium
- acceptance of computer as a training tool
- impact on management image and industrial relations climate
- training potential
- further investigation

5.1 Impact of biographical factors

Historically in South Africa, biographical variables such as education level, region of origin and language ability have introduced cultural and literacy factors to the learning equation. In this investigation, visual literacy levels and previous exposure to job-related information were expected to impact on the subjects' performance during training.

No such impact was found in relation to any of the biographical variables analysed. The responses to the virtual reality programme appear to be independent of cultural and language values, and of education and experience levels.

In addition, even the age profile differences between the two samples produced no effect on performance. The older age group, which could reasonably be expected to demonstrate a greater resistance to change, constituted the virtual reality sample. The levels of enthusiasm shown by these subjects overrule any suggestion of a reluctance to accept new technology.

This introduces vast possibilities for virtual reality as a training medium in the mining industry. Viewed in conjunction with the fact that it is independent of trainer ability - another identified problem area in the mining industry - it presents opportunities for standardising learning.

5.2 Application of knowledge

An area that does give cause for concern for conventional training, however, is the apparent inability of the subjects to transfer their theoretical knowledge to the practical situation. The high pre-test knowledge levels exhibited by the virtual reality training group (learned through conventional training methods) were not borne out once the subjects were required to take the actions which they had previously quoted. The levels of correct actions fell significantly below the quoted information; the subjects were unable to perform the actions they believed they knew.

This indicates a reliance on rote learning and not on true understanding of application. The virtual reality training programme is able to identify this problem amongst trainees because of its interactive facility. However, with conventional training and the video method currently used at the mine, this problem would pass unnoticed because trainees would achieve acceptable scores on oral or written tests.

The samples drawn are representative of the population for which this type of safety information is critical for everyday working practices. Therefore, it can be expected that the majority of underground workers would exhibit similar difficulties on practical testing.

5.3 Understanding of graphic representations

With the exception of the ‘test for methane’ icon, the visual material presented in the virtual reality training programme was clearly understood by all subjects. The line graphics presented no difficulties in interpretation.

Qualitative information suggests that colours should be made to be more life-like and that a larger screen would help improve the definition of the visual material. Despite these comments, however, little negative impact was observed on subject performance.

5.4 Types of information suited to the virtual reality medium

This investigation examined the teaching of factual information. In this context the virtual reality medium showed considerable promise. Subjects were also exposed to recognition, recall, knowledge application and decision-making via this medium. On these aspects, virtual reality demonstrates a very real potential.

No testing was conducted on the medium's suitability as a conveyor of abstract or complex, detailed information.

5.5 Acceptance of computer as a training tool

All subjects exposed to the virtual reality training medium expressed strong preferences for it as a training medium. The interactive factor played a major role in this assessment. Any difficulties encountered, such as learning to use the joystick or lack of familiarity with the set up were soon overcome. Increased exposure to the system will eliminate these difficulties through practice, and the extension of the medium's use to other training courses is likely to counter any negative responses. Increased performance is also probable because the learning will take place in an environment where obstacles have been reduced or eliminated and which is regarded favourably by the learners.

A favourable attitude to the training medium was identified by Mager (1968), the pioneer of objectives-based learning, as a critical aspect to improved learning and retention. Mager demonstrated that students with a favourable attitude towards the learning situation will remember more of what they have been taught and will willingly learn more.

This process is aided by the use of different media, i.e. visual and auditory, to engage the respective different senses, which result in heightened attention and renewed concentration (Lloyd, 1968). Innovations of this nature become particularly important in training courses that exceed 15 to 20 minutes in length. Psychological research has demonstrated that student performance deteriorates markedly after this time period.

5.6 Impact on management image and industrial relations climate

An unexpected finding of this investigation is the positive impact that the virtual reality training medium can have on the image of management and on the organisational climate. Qualitative information obtained from the subjects' open-ended responses indicates a belief that management is treating them as individuals, human beings and intelligent people. This is the reverse of many of the comments expressed in previous human factor research in the South African mining industry. The belief that management is making an effort to improve life for its workers has the potential for far-reaching impact on the industrial relations climate and the building of trust between management and employees.

5.7 Training potential

The potential of VR for training depends on the VR based content having relevance and meaning for the target group such that their experience imparts some new or refreshes some old knowledge and that this knowledge can be put into practice. A notable feature of VR systems is they provide an interactive and active experience unlike the passive nature of the classroom, and if this feature proves to be useful then a role for VR should be evident.

The high comprehension and recognition levels recorded for the visual and auditory components of the VR simulator indicate that VR is a relevant medium. This is further borne out by the subjects' voiced preference for VR as a training medium and a high personal interest in the course content.

The aspect of knowledge acquisition is evidenced by the VR sample achieving a higher awareness of the main hazards being demonstrated. The poor result for methane, which also decreased in the video sample, is explained by the fact that methane was not actively portrayed as a hazard in either medium. This highlights an important aspect in the design of content in any training medium, whereby the absence of a hazard in that content can be erroneously interpreted by the trainee as signifying its lack of importance. The inclusion of all hazard categories may therefore have to be considered for effective training to occur.

The identification by the VR sample group of the hazards encountered during their sessions showed progressive improvement and these hazards were well recalled during the follow-up sessions.

The reasonably high level of knowledge regarding the corrective actions to be taken for the various hazards that was evident in pre-testing was not translated into correct actions being taken during the VR sessions. This implies that this knowledge, which had been acquired during previous classroom and video training, could not be put into practice. If this is in fact the case, then there is a great opportunity for VR to improve on the current classroom and video form of training by providing a more practical, 'hands-on' form of training. This form of active training should also avoid the tendency of trainees to fall asleep and not pay attention to the training medium.

A further shortcoming of the video material is that a number of trainees did not believe that the accidents portrayed could happen to them, and that they only saw the before and after scenes but not the actual accident and therefore did not understand what had taken place. Again, there is potential for VR based training material to address this by personalising the training experience.

Although no *quantitative* comparison was made between the VR and video training methods, VR would appear to have the potential to provide more effective and relevant training than is currently possible. It is important to remember, however, that it is not intended to replace classroom training with VR simulators, but that a practical, 'hands-on' aspect to training is introduced, whereby a trainee's understanding of hazards and their treatment is put to the test in safe environment.

The operation of the joystick presented some subjects with difficulty, however none rejected it as a means of interaction with the computer and extra practice was considered sufficient to master its use. It is therefore not viewed as an obstacle to successful learning and application of VR but an investigation into a more appropriate alternative could only benefit the long term implementation of VR simulators.

5.8 Further investigation

This investigation was intended as a preliminary assessment of the potential for virtual reality as a training medium in the South African mining industry. The results clearly indicate its worth in the areas in which testing took place. To determine whether the medium has a broader role to play, further investigation in additional areas should be carried out. These areas should be:

- the conveying of conceptual information
- the provision of complex information
- the comparison of controlled learning situations through the development and presentation of specific, comparable course content via different teaching media
- the quantifying of learning and retention levels in the short, medium and long term

6 Conclusions and recommendations

6.1 Conclusions

The current study has made a preliminary investigation of the potential benefits that the application of virtual reality could have with regard to improving the hazard awareness training of underground workers.

The main findings of this study are that:

- responses to the virtual reality programme appear to be independent of cultural and language values, of education and experience levels, and of age.
- an area of conventional training gives cause for concern in that there is an apparent inability of trainees to transfer their theoretical knowledge to the practical situation.
- the visual material presented in the VR programme was clearly understood, with the exception of the gas test icon.
- the VR programme presented content of a sufficiently realistic nature, comparable with the video material.
- VR showed considerable promise in the teaching of factual information.
- trainees were exposed to recognition, recall, knowledge application and decision-making via the VR medium; on these aspects VR demonstrates very real potential.
- trainees expressed strong preferences for VR as a training medium, with the interactive factor playing a key role in this assessment.
- difficulties encountered in operating the joystick were soon overcome and did not detrimentally affect those trainees' experience and enthusiasm.
- a positive image of management was created by the introduction of the VR training medium.

The conclusions arising from this study are therefore that:

- with virtual reality technology it is possible to develop training material with realistic and relevant content for the mine environment.
- virtual reality simulators provide an interactive training medium that will overcome shortcomings in video and classroom based training.

- virtual reality simulators create a training environment in which the application of knowledge is emphasised and evaluated to useful effect and the trainee has more personal involvement.

6.2 Recommendations

To determine whether the medium has a broader role to play, further investigation in additional areas should be carried out. These areas are:

- the conveying of conceptual information
- the provision of complex information
- the comparison of controlled learning situations through the development and presentation of specific, comparable course content via different teaching media
- the quantifying of learning and retention levels in the short, medium and long term

The recommendations arising from this study are that:

- virtual reality training simulators are constructed with maximum relevant visual and auditory content and to portray a wide variety of critical hazards.
- virtual reality training simulators are introduced as an enhancement to current training methods for the training of hazard awareness.
- although not considered to be an obstacle to successful implementation, an alternative interactive device to replace the joystick be investigated.

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