Proceedings of the 7th WSEAS International Conference on Automation & Information, Cavtat, Croatia, June 13-15, 2006 (pp11-16)

Virtual apnoea diving

mr.sc. IVAN DRVIŠ
Faculty of Kinesiology
University of Zagreb
Horvačanski zavoj 15
CROATIA

mr.sc. DARKO KATOVIĆ
Faculty of Kinesiology
University of Zagreb
Horvačanski zavoj 15
CROATIA

prof.dr. NATAŠA VISKIĆ-ŠTALEC
Faculty of Kinesiology
University of Zagreb
Horvačanski zavoj 15
CROATIA

Abstract: Applicability of virtual reality technology in simulation of the variable weight discipline conditions, i.e. deep-sea apnoea diving, was examined. A diving simulator was designed that combines computer designed virtual undersea environment and a mechanical structure that helps divers ascend. Relations with the two diving disciplines performed in a pool, static apnoea and dynamic apnoea, were established.

Key-Words: - virtual reality, simulation, diving, variable weight, static apnoea, dinamic apnoea

1 Introduction

At the Faculty of Kinesiology in Zagreb, researchers conducted study about usability of apnoea dive virtual reality simulator in order to reduce mortality rate and diving accidents among divers as well as to establish threshold limit of the divers' capabilities.
There are several definitons of virtual reality (VR). Newquist (1992) defines virtual reality as a technology combining computer and sensor mechanism that creates simulated, interactive, computer controlled environments and sensations. VR technology has been developing at a high rate in the past few years and has found a purpose in many fields of science. Sport and entertainment have soon found a way to apply VR in creating virtual environments with various training simulators such as bicycle ergometres, treadmills, ski simulators, rowing ergometres and similar equipment usually found in fitness and wellness centres. Each of these devices has a modified mechanism that creates necessary information about tactile stimulus where the VR visualisation system immerses the user into a lifelike virtual environment thereby making the experience more satisfactory for the user.
The more serious approach to VR in sport can be found in research of kinesiologists. VR technology helps considerably during training process in various sport activities. There are numerous examples of VR technology being applied in sport kinesiology: baseball throws [2] (Hamilton, 1992), skydiving training simulator [5], the NEC downhill ski simulator [4] (Li, 1993), research on the effect of perceptive stimuli [6] on human movement (Tong, Marlin, Frost, 1995), the VR test for the evaluation of cognitive capabilities and selection of skydivers [7] (Viskić-Štalec, Katović, 2001) etc.

Proceedings of the 7th WSEAS International Conference on Automation & Information, Cavtat, Croatia, June 13-15, 2006 (pp11-16)

Working at the SAP (Swimming Across the Pacific) project [1], Fels et al. designed a swimming simulator. The body movement of the participant in the simulation is tracked via sensors while the HMD helmet generates a virtual image of a swimming pool. Preliminary tests suggest that the system is capable of creating a genuine swimming experience.
In the last decade, breath-hold diving has become very popular, both as a recreational activity and a competitive sport, with more and more people participating in it. In proportion with the popularity of the sport, the number of diving accidents has also been rising, which is indicative of the need for prevention and more significant approach to a systematic study of the level of success in breath-hold diving disciplines from the point of view of medicine and kinesiology.

2 Problem Formulation

The possibility of replacing the real world with the virtually created one has been confirmed on more than one ocassion. But one thing still remains unclear, and that is the exact relation between the two worlds. This research is focused on the relation of the real and the virtual in one kinesiologic discipline. It was in what measure the variable weight diving simulator can help evaluate capabilities of divers in real conditions.

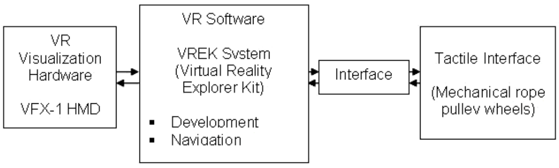
2.1 The diving simulator

A simulator was designed so all the measurements can be taken in the virtual, not real undersea environment, so the examinee's life was in no danger. The HMD helmet and a personal computer were connected with the mechanical part of the simulator that enabled a tactile experience of the dive via electronic interrelay.
The computer, with a suitable software support, enabled the creation of various VR environments here the examinee could be subjected to all sorts of challenges. In our case a software called VREK – Virtual Reality Explorer Kit, by Themekit, was used. Basic models required to create a virtual undersea and above-sea environment were created with the VREK MindFormer module. Special attention was given to their complexity to avoid later complications regarding too many training sites and disruption of speed rate at which the final simulation was carried out on account of the environment overload. The same module was used to add animation effects to the objects in order to make the virtual environment as real as possible.
Tactile sense was included in order to make the experience of diving as real as possible. The structure of the simulator had a weight grip, the same as the virtual one, which was "pulling" the diver into the depth. Mechanical rope pulley wheels were also a part of the structure. When pulling the rope, the examinee experienced a sensation similar to the one when ascending for real. The depth of the dive as well as the speed at the which the diver could see the designations in the virtual undersea environment pass by were synchronized with the pulling of the rope (Fig. 1). In that way a greater degree of reality was achieved.

Fig. 1. Virtual dive on mechanical rope pulley wheels

The final synchronisation of objects in the virtual undersea and above-sea environment was achieved via VREK MindSetter module. Interaction of the objects in the simulation as well as the interaction between the examinee and the simulation was regulated by a complex system of positioning of the objects and event triggers that regulated the degree of reality and synchrony with the actual event that was being simulated. Working at this level of the simulation required an additional improvement of the virtual environment's scenery due to the limited resources of the programme and its final solutions which were not up to the demands of the project (for example, we did not use the stereoscopic image because of its reduced resolution, we reduced the number of static and animated objects in the scenery due to the disruption of speed rate at which the simulation was carried out, etc.). The final stage in constructing the technically oriented part of the simulation included connecting the external devices intended for the interaction with the virtual environment and their synchronisation. HMD (Head Mounted Display) VFX-1 helmet and a mechanical pulley system with an added electronic interrelay were used. The resolving power of the helmet was 640x480, with a maximum of 256 colours appearing on two displays the size of 0.7 inches. The helmet had integrated sensors to track the position and the orientation of the examinee's head. The pulley system with an added electronic interrelay was adapted to transform the actual movement of the rope into a signal recognised by the computer as a joystick. The transformed information could in that way be recognized by the VREK application and synchronised with the simulation (Fig. 2).

Fig. 2. Virtual apnoea diving – System diagram



2.2 The course of research

After the assignment was explained to the examinee, the examinee was placed in front of the pulley structure within the reach of the rope. With a frozen initial image of the simulation the examinee adjusted the eyepieces on the helmet so that the resolution of the image and the space between the eyepieces met the examinee's needs. A noseplug prevented the examinee to breathe through nose. With the simulation set in motion, the examinee was dynamically led by a camera (head movement was possible) which took the examinee above the dive spot and the virtual scenery of the above-sea environment (islands, animated sailboats, dive platform). At this point of the simulation the examinee was adjusting to the specific visualisation equipment and virtual scenery with the help of a supervisor.

Upon coming in front of the dive platform, the examinee was informed by the supervisor about the remaining time needed for the ventilation and psychological preparation for the dive. A countdown followed, and at the moment of the transition to the undersea environment, the examinee inhaled a maximum amount of air, held breath and with a closed mouth observed the dive-in scene in which he was participating, while the depth designations on a virtual rope were passing him by. After the examinee assessed that he had reached the depth from which he could ascend without taking in air, he pulled the rope on the pulley system and simulated ascent[1]. When the examinee reached the virtual surface, the simulation was halted and the results were recorded (the maximum achieved depth in metres).

2.3 Sample of the examinees

70 third-year students of the Faculty of Kinesiology in Zagreb were taken as a representative sample in the research on apnoea diving in virtual undersea environment. The students were selected during the entrance exam and subjected to years-long training in various practical courses within college education programme as well as within various sport activities outside college curriculum, and were chosen for the research on account of their desirable psychosomatic characteristics.

2.4 Variables

Three variables were used in the research. Two of them were calculated on the basis of the measurements carried out in the pool, and the third one was calculated in the VR simulator. At this stage of the simulation it was not technically possible to keep track of the pressure growth according to the depth achieved, which would help determine capabilities of reaching the maximum depth, just like in real dive. It was concluded that the simulator was most probably the best for determining the capabilities of divers in dynamic and static (apnoea diving). That is why the following two variables were chosen: dynamic apnoea and static apnoea. The results of the static apnoea were affected by the functional state of the body, ability to slow down metabolism, mastery of breathing and relaxation techniques during preparation, mental stability, motivation, etc. The results of the dynamic apnoea were affected by physical shape, ability of the body to function normally while fighting the body toxins, good diving technique, the choice of optimal diving

[1] The correlation between the speed of the dive and the ascent in actual conditions was established and synchronized with the speed in the virtual environment

speed in relation to individual characteristics, motivation, etc.
Variables calculated in a pool:
Dynamic apnoea – the examinee in apnoea dives in shallow water with fins and tries to swim as far as possible. The result is measured in metres. Each examinee had two attempts.
Static apnoea – the examinee holds his breath face down in a pool as long as possible. The result is measured in seconds. Each examinee had three attempts.
Variable calculated in the simulator:
Variable weight – the result is the maximum achieved depth in metres shown on the simulator from which the examinee managed to ascend holding breath. If the examinee did not succeed in reaching surface before the disruption of apnoea, the result was recorded as drowning. Each examinee had four attempts.

2.1.3 Data processing methods

According with the goals of the research, relations between the results of examinees in real diving in a pool (dynamic and static apnoea) and the results in a simulator were established. The basic descriptive variable values were calculated, and the basic parametre values and correlations between the variables were plotted on a graph.

3 Problem Solution

The examinees were divided in two functional categories regarding their results (successful – less successful, which in reality corresponds to the categories of beginners or recreationists – sport divers or professionals) and it was observed which of the categories had the higher instance of drowning.
Figures 3, 4, 5 were made based on the results of the examinees in the three variables. Histograms were made for each variable separately and for each of the two categories of the examinees, the ones who were virtually drowned and the ones who were not.

Fig. 3. Histograms of the results in the variable weight discipline

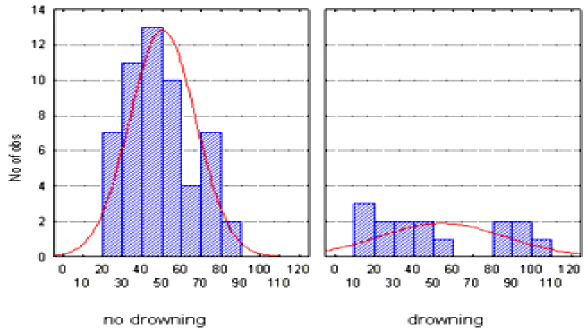


Fig. 4. Histograms of the results in the dynamic apnoea discipline in a pool

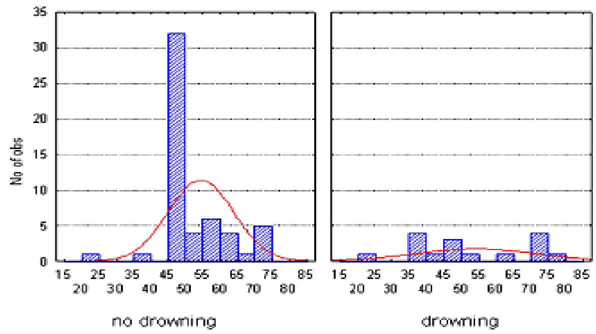
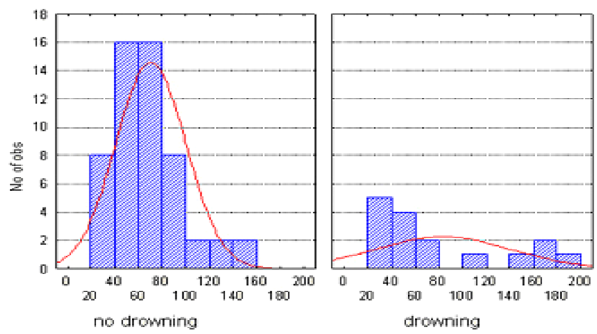


Fig. 5. Histograms of the results in the static apnoea discipline in a pool



In all three graphs, divided into two categories according to whether the examinees "drowned" or not while ascending, normal distribution of results can be observed among those who did not "drown", and

poorly indicated, but nonetheless bipolar distribution of results among those who did "drown".
Results of the "drowning" examinees in all variables, those calculated in a pool and those calculated in a simulator, indicate that there are two groups of "drowning" examinees: the ones with poor results and the ones with good results. Reasons for drowning are quite different. The examinees with poor results "drowned" because of their lack of experience and poor judgement of their own capabilities, various mental disorders, such as panic attacks and other. Examinees should have been able to assess their capability of reaching the maximum depth respecting the principle of gradually increasing depth in each new attempt. That is why one of the criteria of the research was detection of risky divers who were not able to assess their capabilities. Each diver that "drowned" two out of four times was profiled as a potential risky diver. Four such cases were recorded. The reason some examinees "drowned" repeatedly is probably not just the poor judgement of their own capabilities in achieving the maximum depth.
The examinees with good results "drowned" because they overestimated their capabilities. Inexperienced divers do not normally belong to this group. Because of the experience gained in their previous diving activities, the examinees pushed the limits and exceeded their capabilities. Although under safe laboratory conditions the examinee consciously took a risk, in a real undersea environment poor judgement can lead to fatal accidents. Breath-hold diving professionals mostly die because they manage to raise the limits of their personal mental barriers through psychophysical training and thus get very close to the ultimate limits of their capabilities. One of the advantages of research being carried out in a virtual environment is that a diver can get close to his limits without risking his life. Table 1 shows basic statistical values of the analysed variables. The highest variability can be seen in the results of the examinees in the static apnoea discipline.

Table 1. Descriptive Statistics

	N	Mean	Min	Max	St.D.
Dinamic apnoea	70	54.19	24	79	11.67
Static apnoea	70	72.97	27	183	37.56
Variable-weight	69	50.97	18	107	20.74

It is interesting that the lowest variability can be seen in the results of the examinees in the dynamic apnoea discipline. This is to be attributed not to the real psychophysical capabilities of the examinees but to the conditions under which the research was carried out. Namely, the data was acquired from the results of the exam in Swimming/Diving course at the Faculty of Kinesiology. The fact that 50 metres was the required distance to pass the exam, was enough to reduce the variability in this variable. The results of a certain number of potentially best, but not enough motivated divers were not included in the final data precisely for this reason. Measuring apnoea in virtual reality environment can help in determining psychophysiological limits of the divers under safe conditions. One has to of course include the variables that can be considered as a distorting factor in these and other similar disciplines.
The calculated coefficients of the correlation indicate that, despite all the objections to the laboratory conditions, there is between 60.84 and 67.24 per cent of common variability among the variables.

Table 2. Correlations

n = 69	Dinamic apnoea	Static apnoea	Variable weight
Dinamic apnoea	1.00	0.78	0.82
Static apnoea	0.78	1.00	0.84
Variable- weight	0.82	0.84	1.00

The data shows a considerable correlation between the results achieved in real diving conditions in a pool and the results from the simulator in the variable weight discipline.

4 Conclusion

The results of the research show a considerable correlation between the results achieved in real diving conditions in a pool (dynamic and static apnoea diving) and the results achieved in a simulated variable weight dive.
Credibility of the results achieved during virtual diving was confirmed with the occurence of accidents, similar to the ones hapenning during real diving. Both the examinees who achieved bad results, even during real diving, and those who achieved great results and are experienced divers, experienced "drowning". Only the examinees who achieved extremely good results in a pool, i.e. people who are experienced divers experienced blackouts during simulated diving. Diving accidents were the rarest among the examinees who achieved average results.
It was also noted that the simulation was experienced subjectively better and more like real diving by the

examinees with greater diving experience. The reason for that probably lies in the complex visualisation process and the combination of imagination and experiential images.

We have to however take things as they are and realise that great scepticism is expressed by apnoea diving connoisseurs who claim that it is almost impossible to simulate real conditions of deep-sea diving in a laboratory. With the depth increase, the level of specific diver stress also rises. Apart from mental strain, awareness of the unability to breathe and constant change of the amount of oxygen in the blood, a diver is also affected by a range of obscure and often unfavourable physical and biochemical phenomena. Water pressure oscillations surrounding the diver, which result in constant need of pressure levelling in cranium cavity in order to prevent sinus and ear barotrauma that can indirectly cause hypoxic conditions put the diver's body under great stress. Additional stress is due to sudden temperature changes in the environment, often very bad visibility, radical gravity decrease, entirely different movement pattern, sudden alterations of dark and light, change in colour spectrum, lack of sound orientation, etc. However, there are researchers who are well aware of the significance of such a machine (a simulator) that would enable calculation of pysiological and psycholgical parametres variations, which is almost impossible under the conditions of a real dive. Furthermore, the development of technology offers more and more possibilities to manipulate artificially generated stimuli.

In order to give credibility to the results achieved in the simulator it is necessary to provide for the conditions similar to the ones the examinee would be experiencing in a real dive. That is why the experiment of observing examinee's reactions should in the end be conducted in pressure chamber under conditions of real deep-sea diving. Of course, the number of variables also needs to be considerably increased.

References:

[1] S. Fels, Y. Kinoshita, T. Chen, Y. Takama, S. Yohanan, S. Takahashi, A. Gadd, K. Funahashi, *Swimming Across the Pacific: A VR Swimming Interface - A locomotion interface for swimming and floating in a virtual ocean is part of the interactive installation of the Swimmingacross the Pacific artwork*, IEEE Computer Graphics and Applications , Vol.25, No.1, 2005, pp 24-31.

[2] J. Hamilton, Virtual Reality: *How a Computer-Generated World Could Change the Real World*, Business Week, 1992, pp. 97-105.

[3] D. Katović, N. Viskić – Štalec, *Virtual Reality in sport and medical simulations*, Hrvatski športskomedicinski vjesnik. (Croatian Sports Medical Journal) Vol.15, No.3, 2000, pp. 101-106.

[4] J. Li, *Virtue Not to Ski*, Skiing, No.2, 1993, pp.20.

[5] Systems Technology, Inc., *Parachute Flight Training Simulation*, http://www.stiparasim.com/, 1997

[6] F.H. Tong, S.G. Marlin, and D.J. Frost, *Cognitive Map Formation in a 3D Visual Virtual World*, IRIS/PRECARN Workshop, 1995

[7] N. Viskić-Štalec, D. Katović, *Skydive virtual environment: cognitive processing*, Pass.com performance, sport science, computers, Cardiff, Centre for Performance Analysis, UWIC, 2001, pp. 49-56.

[8] N. Viskić – Štalec, D. Katović, J. Štalec, D. Dizdar, V. Filipović, I. Drviš, M. Jeričević, *Virtual Reality technology in education*, Collected papers, Teacher Training College, Croatian Pedagogical Literary Convention 2004. pp. 65-7

[9] L. Vranjković – Petri, N.M. Petri, *Psihološki aspekti selekcije sportskih autonomnih ronilaca: psihološki profil hrvatskih ronilaca – prethodno priopćenje* (Psychological aspects of selection of autonomous sport divers: psychological profile of Croatian divers – previous report), Medica Jadertina, Zadar, 2002.