GUIDING DIVERS WITH SOUND

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ABSTRACT

Dive computers can be used to instruct the diver during the dive. The alarms in this study consisted of a long, repetitive Alerting sound of High or Low priority followed by a shorter Informative sound representing the functions Ascend, Descend and Change gas. An internet questionnaire was sent to 30 experienced divers, who were divided in three groups. Each group listened to the alarms in a different order and was asked to recognize the priorities and functions. They were also asked to choose the most informative, pleasant and annoying sound from three different versions of each alarm. The subjects' musical backgrounds did not affect the recognition of the sounds. The High and Low alarms were well recognized. The Ascend and Change gas alarms were quite well recognized, but the Descend alarm was perceived as very similar to the other sounds. After the validation the sound was changed to a more informative one. The A versions of all sounds received the best ratings and were chosen for further development. It may have affected the outcome that all subjects listened to these versions first in the recognition test.

1. INTRODUCTION

By definition of Richardson et al. [1], a diver needs to have specialized knowledge on techniques and procedures to dive safely. A diver can use compressed air or various gas mixtures underwater. To avoid health risks, the diver must determine the allowed dive time according to the depth of the dive. In deeper and more complex dives, the diver may need to use different gas mixtures on a single dive and make decompression stops to avoid decompression sickness.

Dive computers measure the time and depth of the dive and display the information for the diver. Many dive computers give additional information to the diver such as decompression depth and time, an ascent rate indicator, and the remaining gas pressure in the diving tank, etc. Dive computers can be used to log and plan dives and instruct the diver during the dive.

The purpose of this study was to design a set of alarms for a dive computer. In some previous dive computers, the alarms have served the purpose to alert the diver's attention. In this study, the audio sensory channel was also used to express information. An important factor to consider was also that the alarms should be heard clearly while diving. The diver is also hearing the bubbles from the dive cylinder and in cold water is wearing a hood, which blocks a lot of the sounds.

The main research questions were: Are the different alarms recognized? Can they be easily distinguished from each other? Which alarm versions are most appropriate in the given context?

2. METHODS

2.1. Designing the sounds

The dive computer alarms were divided into two parts: first there was the Alerting sound: a long, repetitive sound used to attract the user's attention. Alarms were divided in to two categories according to the priority: Low priority alarms were used mainly to attract attention, High priority alarms demanded immediate reaction. After the Alerting sound there was the Informative sound: a shorter sound used to inform the user on what he/she should do next. There were three possible informative functions: Ascend, Descend or Change gas.

In pilot testing, I started off with some rapid short sounds in 3-5 beat groups [2]. Combined with the timbre of the sound created by the dive computer processor, they resembled too much an old alarm clock in the minds of the pilot test group and did not intermit the sense of danger. The most effective alerting sound was a continuous sound with two quickly alternating frequencies resembling a fire engine.

There can be a shock effect of a loud alarm sound starting with full intensity [3]. However, with the dive computer sound processor used, the sound intensity is not very high. This reduces the shock effect significantly. The human auditory system is designed to listen for changes in sounds [3]. With the alternating two frequencies the user's attention is more easily grabbed as there is more variation to the sound. Also a warning sound that uses more frequencies is less likely to be masked by another sound than a warning sound that uses only one frequency [3]. The difference between the low and high priority alarms was made with breaks. The High priority alarm was a continuous alarm whereas the Low priority alarm consisted of a two sounds – two breaks pattern (Appendix C).

In addition to the alerting quality of the sound, the second part of the alarm used sound as an informative element. One of the goals was that if the alarms give information and instruct the diver, the diver could navigate with only the dive computer sounds even if he/she loses the mask or the mask is filled with water. The Informative part of the alarm was basically what Brewster et al. [4] call an earcon: a short, abstract sound message. In order for the listeners to recognize each earcon without reference to each other, the differences must be big. Complex intra-earcon pitch structures and putting different numbers of notes in each rhythm help differentiating effectively. A short gap should be put between serial earcons.

Walker and Kramer [5] state that in auditory display data is represented by sound attributes. Changes in pitch are more effective than changes in tempo. The direction in mapping data dimensions onto auditory display dimensions is critical. Increasing data values should not always be represented with increases in the sound. The performance of the alarms should be measured in experimental settings based on the task that requires auditory display.

In this case, the mapping of the alarm was rather to the action to be made than the data itself. The informative part of the sound was constructed so that when the diver was supposed to ascend, the sound went up. Likewise, when the diver was supposed to descend, the sound went down. The gas change was illustrated with a sound that changed by going first down and then up. (Appendix C.)

Western classical music has certain conventions of displaying emotions [6]. Minor scale, chromatic semitones and stormy rhythms are often associated with ominous premonitions [7]. I used these elements in the scales, forms and rhythms of the different variations of the informative alarms to give the diver a sense of danger.

2.2. Questionnaire

The study was made as a web questionnaire (Appendix A.), which was sent to 30 experienced divers via email. The subjects were asked to reserve 10-15 minutes to answer to the questionnaire. The subjects could listen to recorded dive computer generated sounds from Flash demos that were added to the questionnaire. They were advised to go to a quiet place and to make sure they could hear the sounds properly before answering the questions. No further advice was made whether they should listen to the sounds via headphones or from speakers. After each multiple choice question, the subject was given the opportunity to write optional comments.

The subjects were divided into three groups of ten. Each group listened to the alarms in a slightly different order (Appendix B.). The final group sizes varied a little according to the actual response rate. Subject group 1 listened to the High priority A alarm first, groups 2 and 3 started with the Low priority A alarm. All groups were asked if the alarm they heard demanded immediate reaction. Then all groups listened to both High A and Low A alarms and chose which one was the one demanding immediate reaction. After this, all subjects were given three interval versions (A, B and C) of the High priority alarm and the Low priority alarm and chose the most informative, pleasant and annoying version for both sounds (Appendix C. and D).

In the second part of the questionnaire, the subjects were given one of the three informative alarms and asked to describe it in their own words. Group 1 listened to Ascend A, group 2 to Descend A and group 3 to Change gas A. Then the subject listened to the same sound and chose the most appropriate from the four alternative descriptions: ascend, descend, change gas and depth alarm. Depth alarm acted as an extra context-related option. This way the spontaneous response was gathered first in the open question and then all subjects had to consider the same options when replying to the multiple-choice question [8]. The groups listened to the other two informative alarms and chose their descriptions from the same alternatives. Finally the subjects listened to all three different patterns (A, B and C) for each sound (Ascend, Descend and Change gas) and chose the most informative, pleasant and annoying version for each sound (Appendix C. and D.).

3. RESULTS

3.1. Subjects

The web questionnaire was sent out to 30 subjects and 22 of them responded. A dive computer from our company was raffled between all respondents.

Most of the subjects were 30-49 year-old European men, but there were also some younger and older subjects, some women and some subjects from North America, Asia and Africa. The age and sex distribution was presumed to represent quite well the target user of this dive computer: a technical diver, who has advance training beyond a recreational scuba diver and uses a mixture of different gases while diving.

The subjects had two different contexts of expertise: diving and music. All subjects were experienced divers, 19 had made 100 or more dives. Also the other 3 had at least 10 dives. All subjects were also familiar with diving computers; most had used our company's products before. In regards to the other field of expertise, I wanted to involve subjects with various musical backgrounds. I wanted to find out how easy it was for the subjects to hear the differences between the alarms and did it correlate with the amount of musical expertise. There were 2 professional musicians and 5 amateurs with some formal musical training, later referred to as Experts. The rest were non-musicians, later referred to as Novices.

3.2. Alarm recognition

The alarm recognition results were grouped together as a five-part Recognition test, where the tasks were listed as following:

1. Recognize High A or Low A priority alarm depending on the predefined group
2. Compare High A with the Low A priority alarm
3. Recognize the Ascend A alarm
4. Recognize the Descend A alarm
5. Recognize the Change gas A alarm

The Experts recognized the alarms as intended with an average of 2.9 sounds whereas the Novices recognized an average of 2.7 sounds. There was not much of a difference between them. Furthermore, the only subject who recognized all alarms as intended was a Novice.

3.3. Alerting sounds

Everyone (6 out of 6 subjects), who heard the High A alarm first in Question 1 (Appendix A.), thought that it demanded immediate reaction. 50 % (8/16) of those, who heard the Low A alarm in Question 1, thought that it demanded immediate reaction. The other 50 % recognized after comparison that the alarm did not demand immediate reaction. When comparing High A alarm to Low A alarm in Question 2, 20/22 recognized as intended that High A was the one demanding immediate reaction.

High A was considered most informative and least annoying, but High C was most pleasant while annoying quite many at the same time (Appendix D.). 3/22 would have wanted the high priority and low priority frequencies to differ as well as the rhythm. Just the rhythm change was not enough for them.

However, all of these subjects recognized the High A when compared to Low A.

3.4. Informing sounds

When listened as the first alarm in Question 5, Ascend A was not recognized very well. But with all groups combined, Ascend A was recognized quite well. Without any hints to choose from, two subjects thought of ascending. (Figure 1.) A few people thought that the two different sounds meant a question and an answer, sort of "problem recognized", "problem solved". With the Ascend A, B and C versions, Ascend A was rated clearly most informative, most pleasant and least annoying (Appendix D.).

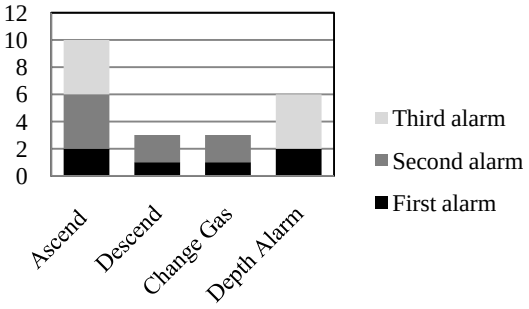

Figure 1. Recognitions of the Ascend A alarm when listened as first, second or third informative alarm.

The Descend A alarm was perceived as very similar to the other sounds. It was not well recognized, most of the subjects thought it meant ascend. (Figure 2.) One of the subjects stated that "This is quite a complicated sound that I would not want to hear while diving". With the A, B and C versions, this was perceived much the same as the Ascend sound. Descend A was considered most informative and pleasant, Descend C most annoying (Appendix D.).

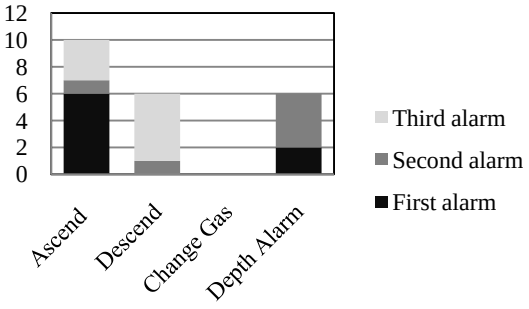

Figure 2**.** Recognitions of the Descend A alarm when listened as first, second or third informative alarm.

The Change Gas A alarm was recognized quite well (Figure 3). Without any explanation in Question 5, one subject recognized this as the Change Gas alarm. When comparing the three different versions, A was most informative and C most annoying. Quite surprisingly Change Gas C was also perceived as an even more pleasant sound than Change Gas A. But as Change Gas C was judged to be annoying by so many (Appendix D.), version A was a better choice.

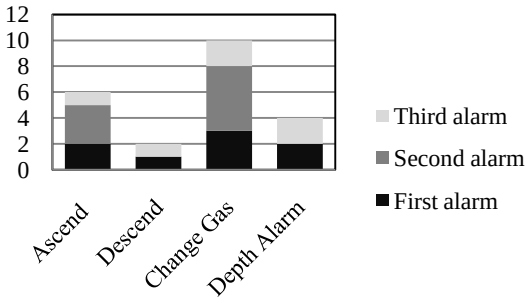

Figure 3. Recognize Change Gas A alarm when listened as first, second or third informative alarm.

In optional comments, the subjects both criticized and complimented the sounds. They were concerned that many different sounds would add confusion. One subject was very much against the whole idea on having the sound telling some information, as he/she thought it would be like learning a new language. Others liked the idea and thought that the sounds were a terrific option, not only for the diver but also for the diving instructor. One subject saw the fast repetitive sound as attention grabbing and recognized the relation between the ascending/ descending sound and the ascending/descending diver. Also he/she mentioned that the gas sound symbolized change with a sound that goes and comes back.

The quality of sounds was also discussed. Some thought the sounds were too similar and hoped for a wider scale of sounds. Others liked the idea of ascend and descend being similar even if different. Some criticized the sounds of being too boring, traditional or primitive.

4. DISCUSSION

The A versions of the sounds High and Low as well as the A versions of the sounds Ascend, Descend and Change Gas were chosen for further development. High A and Low A were very clearly recognized and differentiated from each other. Ascend A and Change Gas A were fairly well recognized, but the Descend A sound should be even more informative.

Judging from the results it seemed that musical expertise didn't matter when it came to recognizing the sounds. The Novice group did not perform essentially worse than the Experts when recognizing the sounds.

A problem related to the test arrangement was that all subjects listened to the A versions of the alarms first. These were chosen as most informative, most pleasant and least annoying in most cases, but their familiarity to the subjects might have affected the outcome. However, the results could be trusted as the subjects could compare all versions with each other. In future validations this will be taken into account.

After this validation, the Descend A sound was changed to a more informative one where the melody in the end was transposed down (G#4 – F4 – E4 – D4). Later the sounds were listened and tested underwater. Simultaneous backlight and sound caused extensive battery usage, so short breaks were added to the High alarms and the breaks in Low alarms were extended.

5. REFERENCES

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6. APPENDIX

A. The formulation of questions

Part I Alerting sounds

In the next two parts you will listen to some sounds and answer questions regarding them. You won't have to analyze the sounds thoroughly, your first impression / intuition is what we need. If you want to, you can listen to the sounds more than once but it is not required.

1. You are diving when you hear this sound from your dive computer.
   1.1. This sound demands an immediate reaction. Yes/No
   1.2. This sound most likely describes...

2. Compare the two sounds [High A, Low A] with each other.
This sound is the one that demands an immediate reaction.

3. This alarm is to alert you. It demands an immediate reaction. Listen to the three different versions [High A, High B, High C] and compare them with each other.
   This sound is the most informative. A/B/C
   This sound is the most pleasant in this context. A/B/C
   This sound is the most annoying. A/B/C

4. This alarm is mainly to notify you. It does not require an immediate reaction. Listen to the three different versions [Low A, Low B, Low C] and compare them with each other [as in question 3].

Part II Informing sounds

5. You are diving when you hear this sound from your dive computer. What does this alarm describe? What is it suggesting that you should do?

6. Now listen to the same sound again. What does this alarm describe? What is it suggesting that you should do?
   I should start ascending.
   I should start descending.
   I should change the gas that I am using.
   Depth alarm, I am notified that I am at the correct depth.

7. Second alarm [Options as in question 6.].

8. Third alarm [Options as in question 6.].

9. This sound is telling that you should start ascending. Listen to the three different versions [Ascend A, Ascend B, Ascend C] and compare them with each other [as in question 3].

10. This sound is telling that you should start descending. Listen to the three different versions [Descend A, Descend B, Descend C] and compare them with each other [as in question 3].

11. This sound is telling that you should change the gas you are using. Listen to the three different versions [Change gas A, Change gas B, Change gas C] and compare them with each other [as in question 3].

B. The order of the alarms listened by each group

Question	Subject group	Alarm listened
1.	Group 1 Group 2 Group 3	High A Low A Low A
5. and 6.	Group 1 Group 2 Group 3	Ascend A Descend A Change gas A
7.	Group 1 Group 2 Group 3	Descend A Change gas A Ascend A
8.	Group 1 Group 2 Group 3	Change gas A Ascend A Descend A

Table 1. The order of the alarms listened by each group.

C. Alarms used in this study

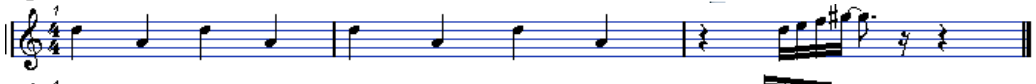
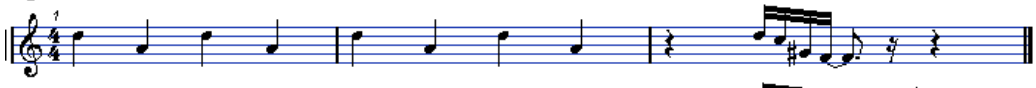
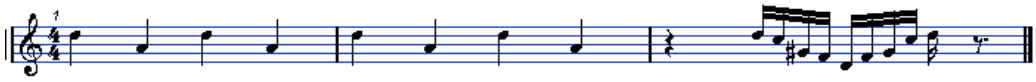
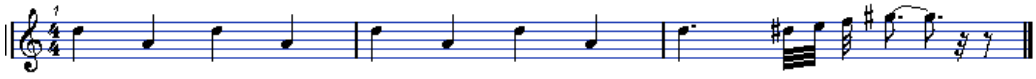
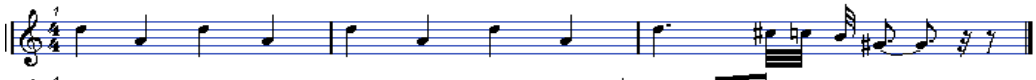
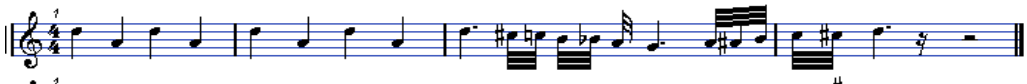
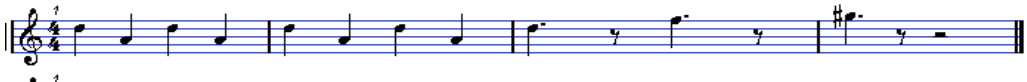
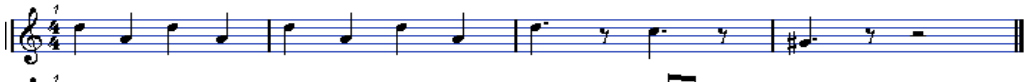
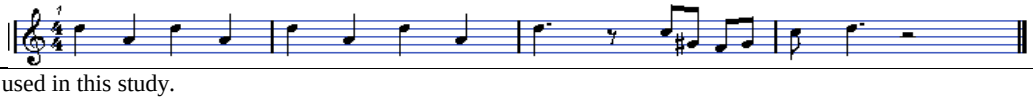
Alarm name	Notation / description (tempo = 150)
High A	
High B	
High C	
Low A	
Low B	
Low C	
Ascend A	
Descend A	
Change gas A	
Ascend B	
Descend B	
Change gas B	
Ascend C	
Descend C	
Change gas C	

Table 2. Alarms used in this study.

D. Overall ratings of the alarm versions

High priority	**A**	**B**	**C**
Informative	18	2	2
Pleasant	14	3	5
Annoying	-2	-13	-7
Low priority	**A**	**B**	**C**
Informative	12	4	6
Pleasant	8	4	10
Annoying	-2	-11	-9

Ascend	**A**	**B**	**C**
Informative	14	3	5
Pleasant	11	5	6
Annoying	-4	-4	-14
Descend	**A**	**B**	**C**
Informative	11	6	5
Pleasant	12	5	5
Annoying	-5	-5	-12
Change gas	**A**	**B**	**C**
Informative	13	4	5
Pleasant	8	5	9
Annoying	-6	-6	-10

Table 3. Ratings of the alarm versions. The amount of subjects who chose this version as the most Informative, Pleasant or Annoying. In Annoying the amount was marked negative.