

BEAT THE DOLPHIN – A MULTIMEDIA DEMONSTRATION OF DOLPHIN ECHOLOCATION

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Abstract

Multimedia applications are becoming an increasingly powerful tool that can be used to enhance educational activities and facilitate the dissemination of academic research to young audiences. Our specific area of interest is that of mammalian echolocation. We present an application we have developed that demonstrates how dolphins use sound to detect and discriminate objects underwater. The demonstration is based on an interactive multimedia Graphical User Interface (GUI) that simulates the biological sonar of dolphins and challenges the user to discriminate objects using the echoes they create, in the same way as dolphins do. A competition element is incorporated in the GUI, in which the user can gauge their ability in using echolocation. The impact of noise caused by human activities in the ocean is also demonstrated in an effort to stimulate discussion on the importance of relevant research in developing ecological and sustainable methods of using and harvesting the ocean. Further to the specific functionalities of the application, we discuss our experience from using this tool in a number of outreach events and activities in the UK.

Keywords - Scientific research dissemination, public engagement, interactive multimedia applications, cetacean echolocation.

1 INTRODUCTION

Echolocation, a sensory modality used by dolphins and other marine mammals of the *Odontoceti* (toothed whales) suborder [1], all species of the *Microchiroptera* and a few species of the *Megachiroptera* bat suborders [2], as well as some species of shrews and cave-dwelling birds, has been the object of extensive study and research for the last fifty years since its existence was first discovered and documented by Donald Griffin [3]. The study on this topic involves a wide and diverse range of scientific research fields, including those of biology, acoustics, audiology, brain neurophysiology, sonar and radar, medical imaging, materials characterisation and seismic exploration. Approaching the topic from different angles, researchers in those fields aim to decipher the evolutionary course and the ecological pressures that have led to the remarkable biological specialisations possessed by those animals and to draw bio-inspiration for the design of new and the improvement of existing technologies in their respective research fields [4, 5].

Given that humans do not possess this sensory modality (even though active research indicates that humans could indeed be trained to echolocate [6-18]), demonstrating how it works and disseminating existing scientific knowledge on this subject to the general public is a challenging task. On the other hand, this very fact adds a natural element of interest and novelty to such an activity. Another related and important aspect of such a public engagement activity has to do with the significant threats posed to many of the echolocating animal populations worldwide by the increasing level of human activity and exploitation of their natural habitats and especially the ocean. This readily provides a direct link for the discussion and dialogue with the public on the wider issues of the relation of technological research and innovation with the ecological and conservational concerns of the modern era.

We thus believe that those elements render echolocation a very suitable subject for outreach and public engagement activities. In this paper we describe the design, implementation and deployment of an interactive multimedia application that demonstrates how dolphin echolocation works and what are the related implications of human activity in the ocean. In section 2 we describe the details of the multimedia application. In section 3 we give an account of the wider public engagement project that our application is a part of and we give the details of the actual deployment of our application in the outreach and public engagement activities in which we are participating. In section 4 we conclude by

presenting the feedback we have had from the deployment of the demonstration so far and discussing possible ways for its further development.

2 DESCRIPTION OF THE MULTIMEDIA INTERACTIVE APPLICATION

2.1 General format of the application

Our application is designed to compute the echoes generated by four different objects when those are immersed in water and insonified by an impinging dolphin echolocation click-train sound wave. The computation and sound reproduction are implemented on a laptop PC and the computed sound stimuli are presented to the listener over headphones or loudspeakers. The four echo-generating objects comprise a naval mine, a sealed air-filled plastic container, a water-flooded plastic container and a school of fish. The computer simulation method for the determination of the echo generated by each of those objects and the approximations we have made to achieve that are described in section 2.3. For the outgoing echolocation sound we have used a recording of a bottlenose dolphin click-train that is publicly available on the internet [19]. This recording is time-stretched by a factor of 19.44 to a sampling rate of 11025Hz in order to fall within the range of human audibility.

The application comprises two parts. In the first (training) part the user can choose any of the four objects and listen to the outgoing echolocation train-click followed by the corresponding echo. This process can be repeated as many times as the listener wants, until he/she becomes familiar with the different sound of each one of echoes. In addition to that, the user can choose various types of noise (either natural or due to human activity) and superimpose those on the call-echo sequence at varying relative sound levels. This functionality brings to the fore the possibly adverse effect of human activity in the ocean and allows the demonstrator to initiate a discussion on this subject.

In the second (competition) part of the application, call-echo sequences corresponding to a random choice among the four objects and a random choice of superimposed noise are presented and the listener is challenged to identify the correct object on the basis of the presented echo. If the user makes the correct choice, the process is repeated with the relative level of the noise masker being incrementally increased. The process continues until the user fails to identify the correct object and a score of the number of correct choices is kept.

2.2 The Graphical User Interface

Our application is designed around an interactive Graphical User Interface (GUI) that is implemented in Matlab® and controls the presentation of the material to the user. The GUI is optimised to work on the Institute of Sound and Vibration Research (ISVR) departmental laptops that we use in our demonstration events, but it also works on any reasonably modern Windows® PC equipped with an up-to-date version of Matlab®. The GUI comprises two screens, one for each of the training and competition parts of the demonstration described above. The first of these screens is depicted in Fig. 1. The user can choose among the four objects that are listed in the lower right list box and depicted in the right part of the upper frame. Upon pressing the “PLAY SOUND” button, the outgoing echolocation click-train call is reproduced first, with a green-coloured graphic sign representing an outgoing sound wave. This is followed by the reproduction of the object-specific echo visualised by a red-coloured graphic representing an incoming sound wave (Fig. 2). During this process all other interactive elements of the GUI are disabled so that the user cannot inadvertently trigger an overlapping call-echo sequence.

As a default, the level of the incoming echo is amplified by a factor of 200 relative to the actual level of the echo computed by the method described in section 2.3 in order to render it audible. The user can adjust this relative level using the “Echo level boost” slide bar at the right part of the GUI screen. The lowest setting (far left limit) of this control corresponds to the actual level of the computed echo as described in section 2.3. At this level the echo is inaudible even in the absence of any of the masking noises. The highest level of this setting (far right limit) is set to correspond to an acceptable hearing exposure level according to ISVR’s Health and Safety regulations (see discussion in section 3.4). This functionality gives the chance to the demonstrator to explain that dolphin echolocation is an operation equipped with a very large dynamic range in terms of the signals emitted and received and to elaborate on the physiological mechanism that achieves that [20].

As was mentioned above, an additional functionality of our application is the ability to superimpose a masking noise sound on the call-echo reproduced sequence. Four types of noise are included in the

GUI, labelled “Waves (ambient noise)”, “Airgun (Oil search)”, “Ship passing by” and “Torpedo launching” and can be chosen by the user in the leftmost of the two list boxes that appear in the lower part of the screen. Sound clips that are publicly available for “non-commercial, personal, or educational purposes” on the internet [21] were used for these noises. As a default, the level of the added masking noise is set to zero (far left limit) but the user can introduce this element by increasing and adjusting its level using the “Noise level” slide bar. The highest setting (far right limit) of this control is again set to correspond to an acceptable hearing exposure level. With the exception of the natural background “Waves (ambient noise)” case, at moderately high levels (around the mid-point of the sliding bar) these maskers render the echo stimulus either completely inaudible or excessively difficult to distinguish and identify.

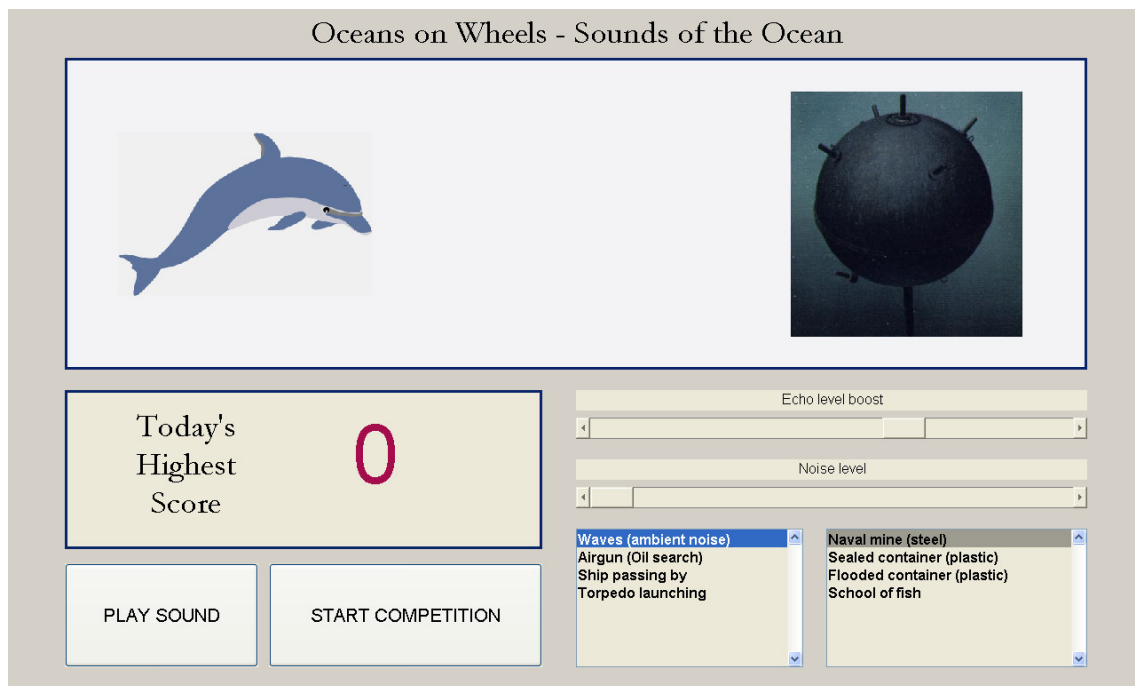


Fig. 1. First screen of the Graphical User Interface

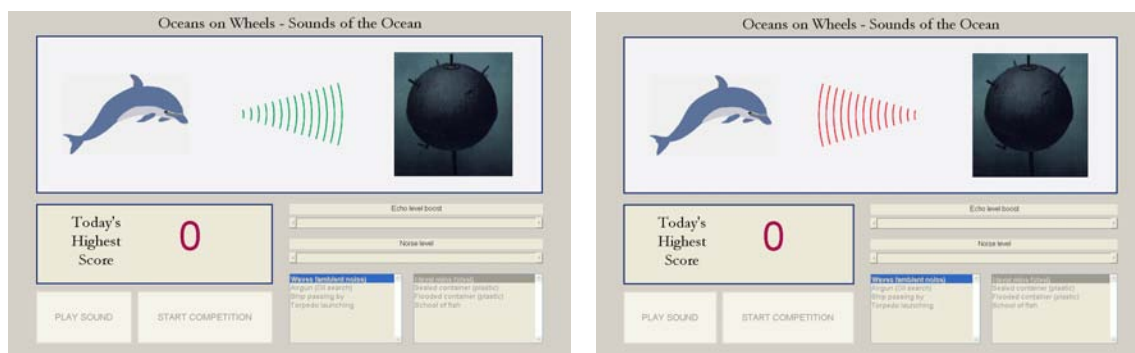


Fig. 2. Outgoing call and incoming echo representation

When the user becomes familiar with the call-echo sound reproduction options in the first screen of the GUI and has identified and memorised the individual echo signature corresponding to each of the four objects, he/she is encouraged to press the “START COMPETITION” button which initiates the second part of the demonstration. An instance of the GUI screen that presents this part is depicted in Fig. 3. When the “PLAY SOUND” in this screen is pressed, a call-echo sequence is presented comprising the echo corresponding to a random choice among the four objects. Superimposed to that is a random choice among the four noise maskers. Immediately following that, the four buttons corresponding to each of the objects in the lower right part of the screen are enabled and the user has

to identify the correct echo-generating object (or press the “PLAY SOUND” again and listen to the same stimulus). If a correct choice is made, a point is added to the “Your Score” display box and the process is repeated with a new random choice of echo-generating object and noise but with the level of the echo decreased and the level of the masker increased.

A record of the highest score from previous runs of the competition is kept (and displayed in the “Today’s Highest Score” display box of the GUI’s first screen shown in Fig. 1). If the current user exceeds this record, a sound jingle is played and a “New High Score!” label is added to his/her score counter. When the user eventually makes a wrong choice, a message box appears that displays the correct choice, the competition GUI screen closes and the GUI returns to the first screen of Fig. 1. We have pitched the progression of relative increase of masker-to-echo level so that experienced and trained users can reach a score in the order of 40 or so. In this way, at any given point in the demonstration process, the demonstrator can prove to the visitor that the task is achievable and set a compelling goal but at the same time keep the task constantly challenging.

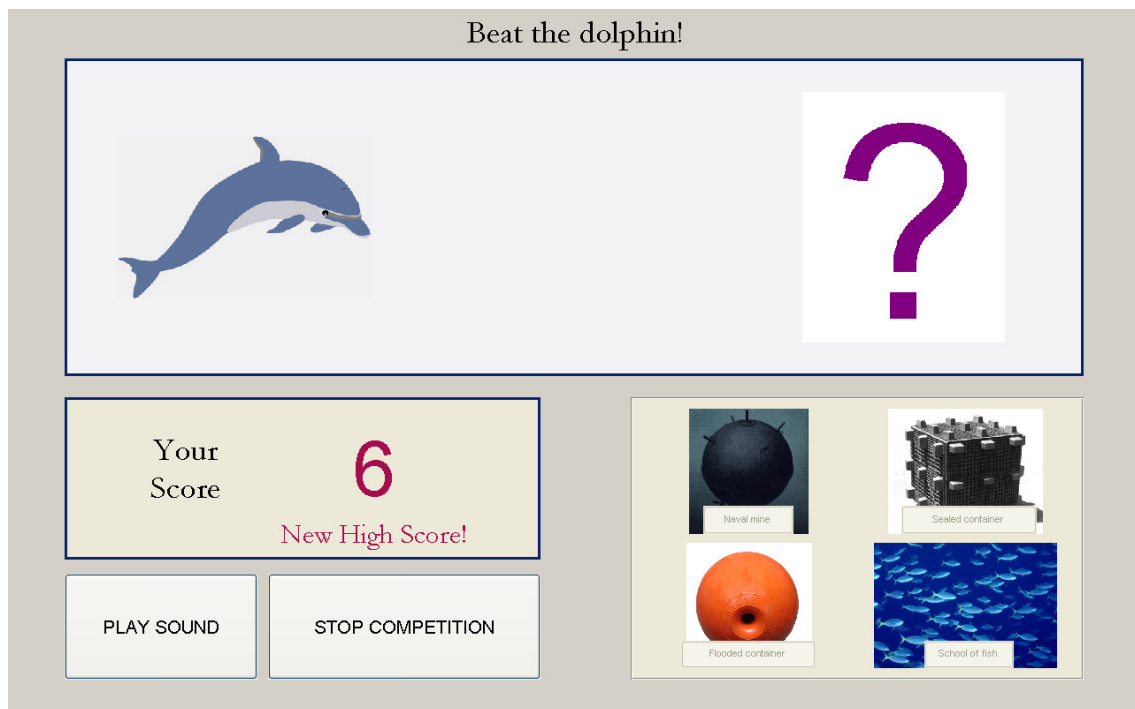


Fig. 3. Second screen of the Graphical User Interface presenting the competition element

Finally, we note that a number of safeguards are built into the design of the GUI code in order to make the interaction with the user reasonably robust against inadvertent (or indeed malicious) misuse. To that end, appropriate enabling/disabling properties have been implemented in all of the interactive controls to avoid unwanted overlapping-in-time interactions. Both screens of the GUI are designed to cover the full screen with the Windows® taskbar hidden and, furthermore, the application cannot be minimised or terminated in any way (the Windows® taskbar included) other than with the execution of a “delete(cfg)” command in the underlying Matlab® prompt. The user can, however, freely move forwards and backwards from the training to the competition part of the application by means of the “START COMPETITION” and “STOP COMPETITION” buttons.

2.3 Computation of the echoes

The echoes corresponding to each of the four objects described above were computed by modelling the echo-generating process as a linear and time-invariant system in discrete time. The determination of the impulse response $h(n)$ describing such a system, allows the output $y(n)$ (i.e. the generated echo) corresponding to any given input $x(n)$ (in our case the impinging echolocation train-click) to be predicted as the convolution of $x(n)$ with $h(n)$ [22].

The impulse responses corresponding to the four objects described above were computed in Matlab using existing analytical models for the prediction of underwater backscattering from resonantly

excited elastic bodies of simple shapes [23-25]. The “Naval mine” was modelled as 1m radius and 0.01m thickness steel spherical shell filled with air, the “Sealed container” was modelled as a 1m radius and 0.5m thickness plastic spherical shell filled with air and the “Flooded container” was modelled as a 1m radius and 0.01m thickness plastic spherical shell filled with water. For the “School of fish”, the main echo-generating mechanism was taken to be the fish swimbladder [26]. Hence the modelling in this case was that of a collection of 200 air-filled spheres of 0.1m radius and 0.001m thickness forming a randomly distributed cluster.

In all cases the computation was carried in the frequency-domain making sure that enough terms of the involved spherical Bessel/Hankel functions were included for the related polynomial expansions to adequately converge. The required impulse responses were obtained using the Inverse Fast Fourier Transform. The sampling frequency of the computed impulse responses was set to 11025Hz to match the sampling frequency of the click-train and noise sound clips.

As an example, the impulse and frequency responses corresponding to the “Naval mine” and “School of fish” objects are plotted in Fig. 4. The impulse response corresponding to the “School of fish” can be seen in the figure to be of lower level and more stretched in time. As a result, the corresponding echo can clearly be heard in the GUI to be weaker and more diffuse. On the other hand, the magnitude frequency response of “Naval mine” can be seen to have a higher frequency content in the regions around 300Hz and 1kHz. Because of that, the corresponding echo in the GUI has a whistling overtone characteristic that makes it clearly distinguishable.

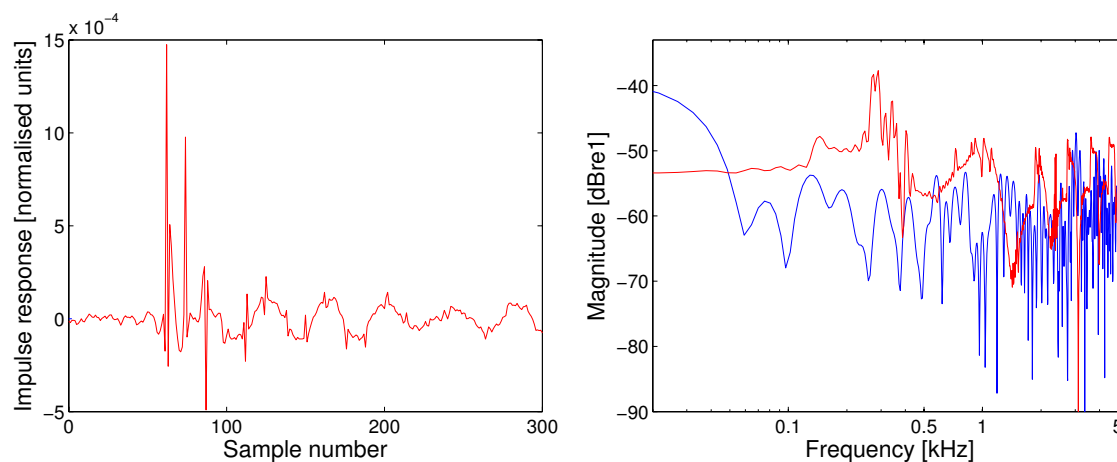


Fig. 4. Impulse responses (left) and magnitude of frequency responses (right) of the “Naval mine” (red) and “School of fish” (blue) echo-generating objects

3 DEPLOYMENT TO OUTREACH ACTIVITIES AND EVENTS

3.1 The “Oceans on Wheels Roadshow” outreach project

The initial stimulation for the development of our activity was given by the “Oceans on Wheels Roadshow” outreach and public engagement project. This is a £34k project funded by the Faculty of Engineering, Science and Mathematics (FESM) of the University of Southampton. According to its bid proposal [27], this project is “intended to build a critical mass of postgraduate and post-doc based public engagement activities within FESM, sufficient to be able to put together a FESM Roadshow at short notice. [The] intention is to develop a set of stand-alone activities with different postgraduate and post-doc teams. The Roadshow will be able to travel to regional pre-University science venues [...] in conjunction with programmes organised by the University’s Outreach & Partnership office. The Roadshow framework can build annual themes; it is likely that the first iteration of this project will have a ‘Deep Sea’ theme [...]. The main purpose of that project is to raise awareness among early career researchers and postgraduates and increase their involvement in outreach. [The] project will provide new training for significant numbers of FESM postgraduates and post-docs (estimate 40 postgraduates and 15 post-docs), [...] it will disseminate research-led outreach and public-engagement expertise across FESM, [...] it will take University of Southampton science and

engineering research to key public audiences across the region [and] significantly raise the profile of FESM research with the general public.”

Our activity, “Sounds of the Oceans – Demonstration of Dolphin Echolocation”, is one of the 6 demonstration activities selected for participation in the “Oceans on Wheels Roadshow”. The schedule and the logistics of the events we attend are managed by the organising team of the Roadshow. A team of 7 volunteers (mainly PhD students from ISVR and other departments of the University of Southampton) are rotating in groups of two or three as demonstrators in the events.

3.2 Events attended and planned

Following the planning of the overarching “Oceans on Wheels Roadshow” activity, the events and venues where our application has already been demonstrated or is planned to be demonstrated at the time that this paper is submitted are the following:

1. Demonstration at the “Ocean and Earth Day”, National Oceanography Centre, University of Southampton, UK, 14 March 2009. This day-event that attracted in excess of 2000 visitors from the general public, formed part of the University of Southampton’s activities for the UK-wide National Science and Engineering Week annual event which was awarded the “British Science Association’s Best Engineering Event 2009” [28].
2. Demonstration at Queen’s Mary College, UK, 21 April 2009. Demonstration to 150 Year 12 students.
3. Demonstration during the Family Days event at the SEARCH centre for history and natural sciences [29], Gosport, UK, 7-9 April 2009. Over 500 members of the general public visited the demonstration during that event.
4. Demonstration at the Times Cheltenham Science Festival, Cheltenham, UK, 3-7 June 2009
5. Demonstration organised by the UK public services sector organisation Aimhigher at the National Oceanography Centre, University of Southampton, UK, 19 June 2009. Approximately 100 Year 10 students are expected to attend the event.
6. Demonstration at the Thomas Hardy School, Dorchester, UK, 26 June 2009.
7. Demonstration at the Royal Society’s Summer Science Exhibition event, London, UK, 30 June – 4 July 2009. This is a highly esteemed and prestigious annual event that selects a limited number of demonstrations with a formal proposal review process and attracts considerable UK-wide publicity. It typically attracts in the order of 4000 visitors [30].

3.3 Practical issues with the deployment of the demonstration

Apart from the design of the interactive GUI, a considerable amount of our time and effort has gone into designing and planning the delivery of the demonstration in a way that suits the particular format of the events that we attend. Those events fall into two main categories. First there are the events that are open to the general public and during which visitors join our demonstration one or more at a time as they walk around other exhibits (events numbered 1, 3 and 7 in the list of section 3.2 are of this nature). In the second case, the demonstration is staged for a specific group of visitors that attend in timed slots and small groups of approximately 10-20 people (events 2, 4, 5 and 6 from the above list).

In both cases, the demonstrator has a very limited amount of time to introduce and explain the significance of what we are demonstrating and how the GUI application actually works. Further to that, on a more practical note, the demonstrator cannot go over the different types of objects in the GUI exemplifying their individual echo signatures while the visitor is wearing the headphones and listening to them. This is because our demonstration is designed to work in a noisy environment among other exhibits thus requiring the use of closed-back sound isolating headphones. Hence when the listener puts them on, he/she cannot hear the demonstrator’s introduction.

For that reason, apart from a few (typically 2-3) laptops equipped with headphones our setup also comprises one laptop equipped with loudspeakers and a projector/screen display that is used for the demonstrator’s introduction to the application. In the former type of the events described above, the demonstrator constantly demonstrates the use of the application on the projector screen or explains its use to joining visitors while previous visitors are using this workstation. In the latter case, the demonstrator spends a few minutes introducing the application on the project screen to the whole group of visitors who then take turns in using the headphone-equipped workstations. As an extra way

of introducing the application and the demonstrated material we use a collection of posters two of which are depicted in Fig. 5. Two photographs from a previous demonstration event are presented in Fig. 6

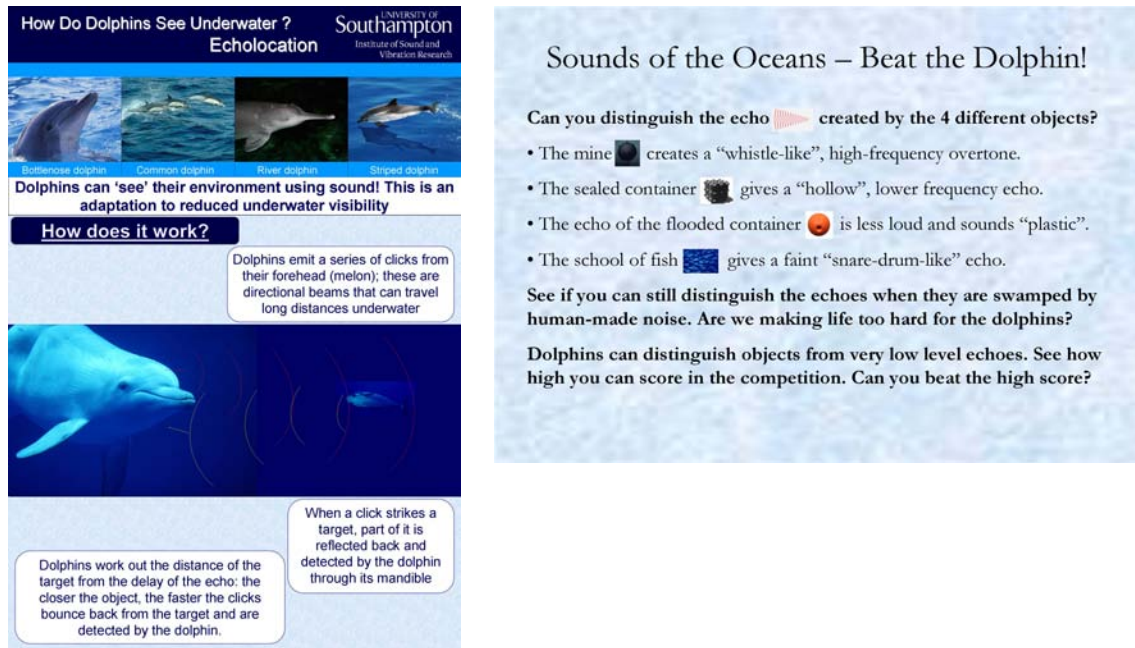


Fig. 5. Posters used in demonstration events



Fig. 6. Snapshots from demonstration events

3.4 Safety and Ethics considerations

As any application or experiment implemented within the remit of ISVR’s activity and involving the exposure of human subjects to auditory stimuli, our application had to go through the standard ISVR Safety and Ethics procedure to ensure that the level of listening exposure is within safe limits. We chose to opt out of the experimentation ethics requirement for collecting signed consent forms from all visitors to the demonstration events as this would be completely impractical given the anticipated number of visitors and the limited amount of time in each event. We are hence not allowed to collect data for experimentation purposes. Our demonstration is, however, evaluated through the feedback evaluation forms scheme of the “Oceans on Wheels” group of demonstrations. An additional health and safety requirement imposed by the University of Southampton’s Risk Assessment regulations is that we make the visitors aware of the low but existing risk of ear infection spread through the sharing of headphones and the requirement that we have disinfecting wipes available should any of the

visitors want to clean the headphones before they use them. Finally, all demonstrators participating in any of the events held in schools have to have previously obtained clearance from the UK Criminal Records Bureau.

4 DISCUSSION – CONCLUSIONS

The feedback from the members of the general public that have visited our demonstration so far has been very positive. The rating in the evaluation questionnaires we collected from the demonstration at the National Science and Engineering Week “Ocean and Earth Day” activity (event number 1 in the list of section 3.2) was 4.48 on average by kids, 4.33 by adults and 4.44 overall, out of a maximum score of 5. The rating scale in this questionnaire was “Not very good” (1), “Could be better” (2), “OK/Acceptable” (3), “(Very) good” (4) and “Excellent/Brilliant” (5). The above quoted overall rating ranks our activity as first among the other “Oceans on Wheels” exhibits that participated in that event.

Small as it may be, this rating difference between younger and older audiences seems to be indicative of a trend that was also verified in subsequent events in which we took part and for which we have not yet formally analysed the evaluation feedback results. More specifically, it seems that children up to the age of 12 or thereabouts, engage better with the interactivity element of the demonstration and spend more time in the competition part than teenagers and adults. On the other hand, rather than playing the competition part individually, teenagers seem to enjoy it more when they participate in groups on the loudspeaker/projector display workstation and play collectively. The same seems to be the case for parents that visit the demonstration with their children. This is an element that we could exploit in the future development of the activity.

The possibility of using future results of the competition part of the application for the purposes of research in the subject of human echolocation (after addressing the related Safety and Ethics requirements) is something that we also considering.

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