3D sound in the helicopter environment: localisation performance

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At IRBA, we are carrying out studies into acoustic protection and enhancement of the audio performances of combat helicopter pilots. As part of this work, we present here the results of a laboratory study concerning the localisation of spatialized sound sources using head mounted equipment (flight helmet and customized wireless ear plugs). The study involved 11 participants. Participant pointed out at the perceived position of an onboard alarm using a plastic sphere representing the proximal auditory space. Two factors were tested: silence versus helicopter type noise and individualized HRTF versus non individualized ones. Each subject fulfilled all the conditions, i.e. took part in all 4 sessions. In each session 45 positions were tested randomly 3 times each. Before recording the results, a procedural training was followed by the participants concerning the pointing task and the localisation task. Following correction of front/rear inversions, the mean centroid aiming point error for all positions taken together, was of the order of 35° (standard deviation about 20°). With customized HRTF, the subjects achieved better performances both silence and noise conditions (difference of 4°).

INTRODUCTION

3D sound aims to reproduce, in the headset, the acoustic cues used by the auditory system to locate a sound source in space. Spatializing sound data (alarms, communications) optimises their processing while relieving the cognitive load on the subject, thanks to the intuitiveness of auditory perception. 3D sound will be fully integrated into complex, high temporal pressure environments (cockpits of aircraft, air traffic control) thus facilitating the human/system interface as described by Simpson *et al.* (2005). In this way, the French "Délégation Générale pour l'Armement" (DGA), the Australian Defence Science and Technology Organisation (DSTO) have conducted since 2006 the PERTIA project on hearing protection and 3D sound generation on board Tiger combat helicopter. At IRBA, we carry out studies (e.g. Pellieux *et al.*, 1993, 1996, 1997) into acoustic protection and enhancement of the 3D audio performances of combat pilots, that lead us to take part in the PERTIA project. We present some of our participation results in PERTIA project: the localisation of spatialized sound sources in laboratory using head mounted equipment.

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MATERIALS AND METHOD

Protocol and task

The study involved 11 participants using head mounted equipment comprising wireless communication ear plugs (wCEP) and a flight helmet. The task consisted of pointing the perceived virtual sound source position of an on board alarm using a plastic sphere representing the proximal auditory space. There was no head tracking feedback, the stimulus was heard in a static posture. The stimulus was a Tiger cockpit alarm. Two factors were tested: silence versus helicopter noise, individualized HRTF versus non individualized HRTF. Each participant fulfilled all the conditions, i.e. took part in all 4 sessions. In each session 45 targets were tested randomly 3 times each. The positions of targets described a sphere. Before recording the results, trainings were followed by the participants concerning the pointing task and the localisation task.

Participants

Eleven voluntary participants, 3 women and 8 men, were 34 (mean) years old (minimum 25, maximum 47). Three of them were experienced 3D sound auditors, the others were naive. Inclusion criteria included normal otoscopy and normal hearing, i.e. for the two ears the audiograms were below 20 dB HL for frequencies up to 2 kHz and below 35 dB HL for frequencies above 2 kHz.

Materials

A transparent plastic spherical ball and an electromagnetic stylus pointer (Fastrak, Polhemus Inc., USA) are used to point out the sound source location using the Gilkey *et al.* (1995) method. Designation system accuracy (± 0.5°) and limits (- 68° elevation) have been checked carefully. The designation mean error (Table 1) is 6° and is weak enough to not distort the localisation performance measure (at least 20°).

Mean (n=704)	6.0
Standard deviation	4.4

Table 1: Pointing performance (line of sight error in degree).

The combat helicopter flight helmet (Topowl BH, Thales Company, France) was designed for a visual system (visor projected images concept) and had a customized helmet liner (Fig. 1). The helmet was fitted with wCEP–adapted design (TNO, Netherland) to increase hearing protection. The wCEP consisted of a customized silicon earplug (Protac, France) fitted with a receiver and of an emitter coil fitted in the ear shell. The advantage of this solution was to avoid acoustical leak due to cable path through ear shell. The wCEP system had a 12 kHz bandwidth.

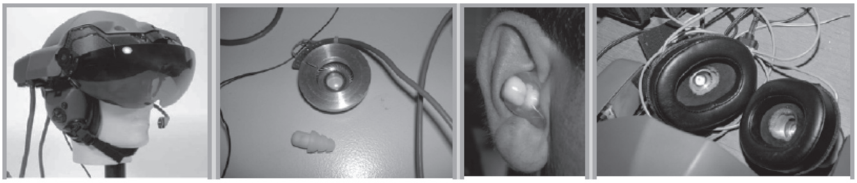

Fig. 1: Combat helicopter flight helmet (left panel), wCEP system (middle left panel), customized silicon earplug fitted with a receiver (middle right panel), emitter coil fitted in the ear shell (right panel).

The Tiger cockpit alarm was enhanced for spatialization by a method from DSTO (Carlile *et al*., 2005). The stimulus temporal length was 250 ms.

We used a reverberant room (volume: 204 m^3) for the tests. There were 9 speakers: 6 Bose type 802, 2 Bose type 302 and 1 Altec Lansing model 182A. Our acoustic energy system provided a sound field (31.5 Hz to 10 kHz) close to the spectrum of Tiger noise cockpit. This spectrum had very high level in low frequencies (below 100 Hz). We checked that the sound field was diffused at the measurement location. The noise was played at a sound level of 98 dB below the real level. A cloth sphere (radius 2 m) was used to isolate the view of the participant. This sphere was acoustically transparent and opaque inside to avoid any landmarks. All the 3D sound generation and stylus response were done in real time with TDT devices and MATLAB programs.

Two HRTF types used: individualized and non individualized

Sound spatialization requires the reproduction of location cues. These cues are captured during measurement of the head related transfer functions (HRTF). The HRTF is obtained by comparing the sound wave received by the tympanum with the sound wave produced by a sound source located in a given position. Application of the transfer function to a noise presented in a headset will result in the perception of a virtual sound source in the said position. The accuracy of location of virtual sound sources is optimum if the HRTF used are those measured on the subject (so-called individualized HRTF). For this study we used the ear canal blocked technique to fit the microphone (Sennheiser KE 4 211-2) in each ear (see Fig. 2, middle panel). HRTF measurement took place in our half anechoic room (volume: 152 m^3). One speaker described all spherical locations (radius 1.4m) with a hoop automaton (see Fig. 2, left panel). 171 measured points were recorded to be close to TNO mapping. The difference between TNO mapping and IRBA mapping was below 0.2° for azimuth and 0.8° for elevation. The lower elevation limit, due to our installation, was -56°. The method from IRBA and TNO were the same about blocked canal technique, microphone equalization and wCEP equalization (block to drum transfer function of Hammershoi and Moller (1996) and wCEP transfer function).

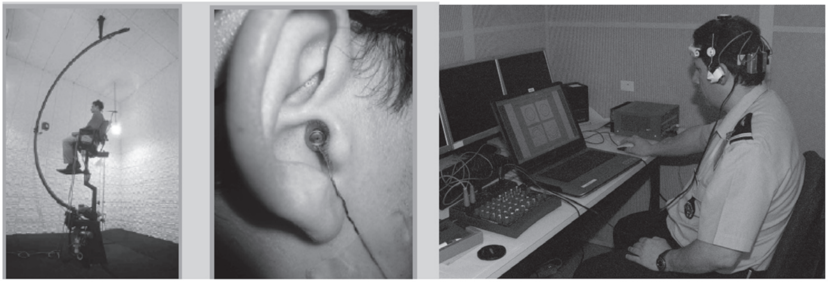

Fig. 2: Two types of HRTF measurements, individualized (left and middle panel), non individualized (right panel).

For reasons of cost in terms of availability, the skills level of the teams and of the complexity of the equipment involved, providing individualized HRTF for everyone involved is difficult. The solution to the problem of providing 3D sound to the greatest number of people is to use non individualized HRTF. Non individualized HRTF were done with the TNO program. A large database with HRTF (containing data of 79 individuals) was used. TNO assumed that for most users an HRTF can be found that sufficiently approximates the characteristics of the user's own HRTF as to yield similar performance. In fact, participant chose between several HRTF families the one which had the best localisation performances via three different psychoacoustic tests. Participants listened to 3D sound via a wCEP headset (see Fig. 2, right panel). In one of these psychoacoustic tests (see Fig. 3), the sound source was played at eight static positions around the head in a random order: four in front of the participant and four behind. The locations differed also in left/right and low/high. The participant had to indicate the location of the sound source. The participants responded by clicking on the screen to indicate the virtual loudspeaker. This test was done randomly with different HRTF. Then a percentage result was calculated for each tests and each HRTF. Table 2 shows some results gotten with the best HRTF of each participant for the whole experiment. A score of 100% indicated that the subject did not made any error of localisation with the psychoacoustic tests.

	Mean	Standard deviation	Max.	Min.
Participant score	69%	15%	96%	42%
Test duration	00:36:49	00:03:13	00:41:00	00:31:00

Table 2: TNO tests results (n=11 participants).

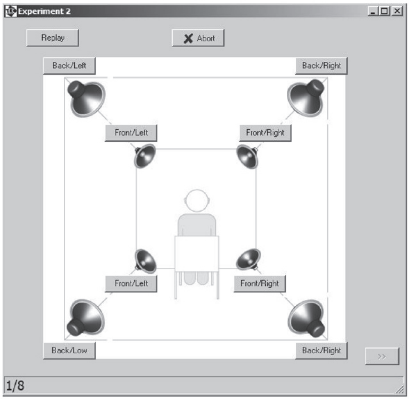

Fig. 3: TNO test (non individualized HRTF).

Procedure

Pointing training: Each participant made several pointing tests in accordance with the protocol concerning steady participant's responses. The pointing task consisted to point on the sphere the location indicated by coordinates showed on a screen (see Fig. 4).

3D audio localisation training: Before the sound localisation performance measurements, each participant made also two learning tests (280 points) in both environments to check steady participant's response. At the beginning of each test, each participant was free to adjust the master sound level as well as the right and left levels to perceive the sound as centred (az: 0°, el: 0°).

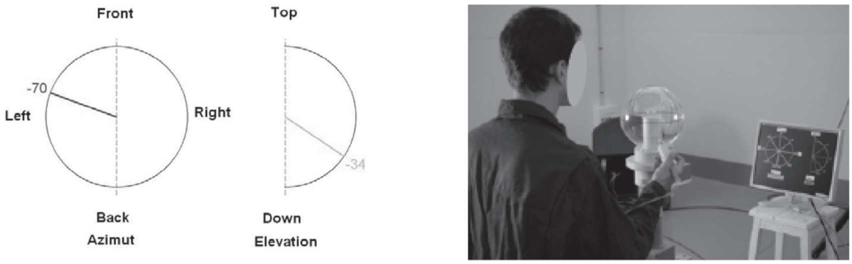

Fig. 4: Left: coordinates used for pointing training task. **Right**: participant during pointing training task.

RESULTS

After correction of front/rear confusions as the Wightman and Kistler (1999) method, the mean centroid aiming point error (Fig. 5) for all positions was of the order of 35° and the individual standard deviation was of the order of 20° (Fig. 6). The performance with individualized HRTF was weakly better than with non individualized HTRF whatever noise conditions. Considering a type of HRTF, there was no significant effect of noise condition on sound localisation performance. A participant (number 7) had strongly better localisation performances (Fig. 7). There were large individual differences in sound localisation performances. Some positions (az: ±40°, el: 40° and az: ±13°, el:-12°) induced poor performances (Fig. 8). Some positions had huge difference errors with individualized HRTF and non individualized HRTF (az: ±30°, el: -56°). The coordinated system used is shown in Fig. 9. The mean time response was about 3 s. A Mann-Whitney test showed that the effect of HRTF type was significant for both environments.

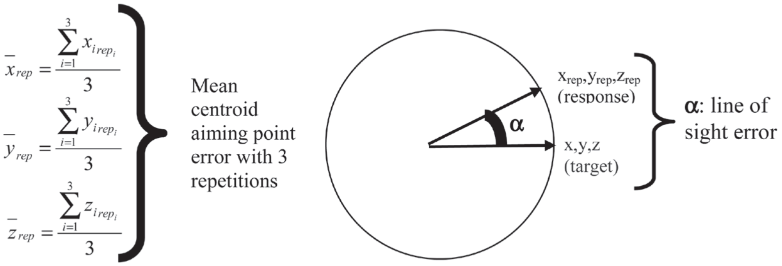

Fig. 5: Left: Mean centroid aiming point error. **Right**: line of sight error.

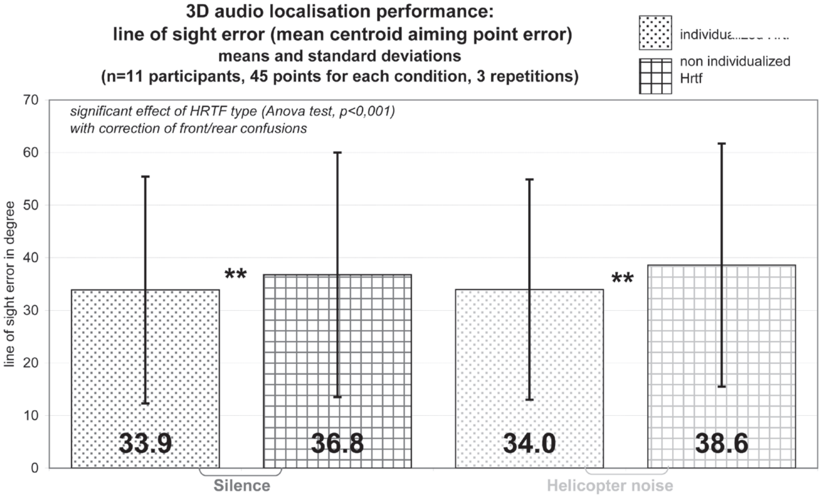

Fig. 6: 3D audio localisation performance according to four conditions.

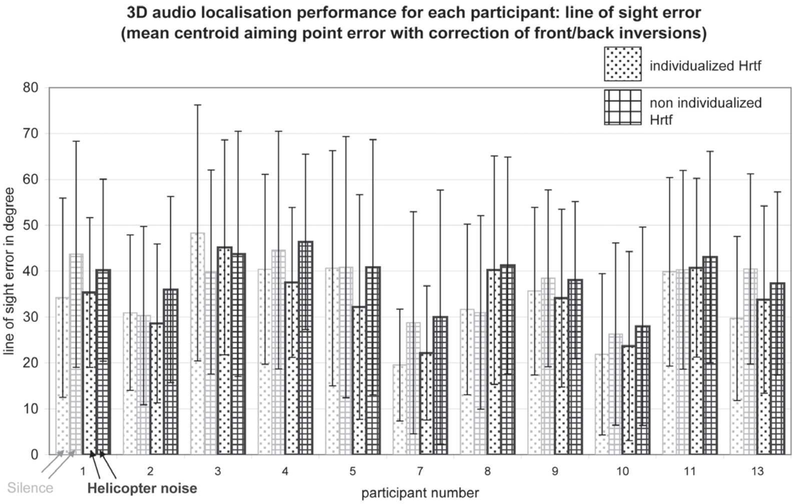

Fig. 7: 3D audio localisation performance according to participants.

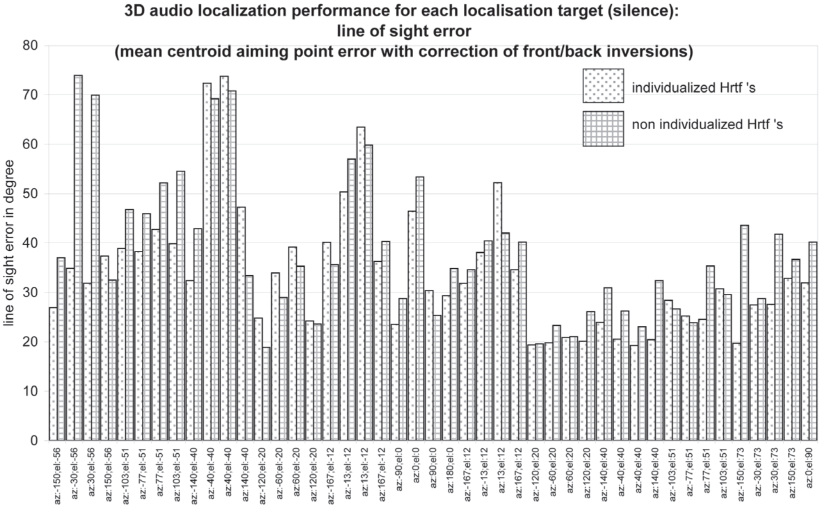

Fig. 8: 3D audio localisation performance according to targets.

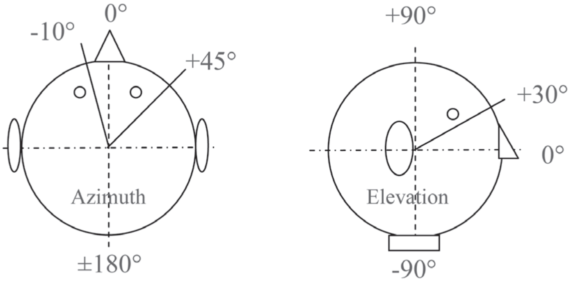

Fig. 9: Coordinates system used.

Another part of PERTIA project concerned sound localisation performance with head tracking and individualized HRTF. Three participants assessed dynamic localisation tests with continuous sound stimuli. Table 3 shows the results of 3 sessions (40 targets each) for one participant. The task consisted in pointing out from which sights the perceived sound origin. As previously reported by the literature, the performance (about 10° of azimuth error and 15° elevation error) was better than in static conditions.

EVAL 2 (n=120)	Mean Az.	Sd Az.	Mean El.	SdEl.	Mean time response
S1	9.7	9.2	16.0	13.2	8.4

Table 3: Localisation error in degree.

In practice, the wCEP sensibility was too relative to the emitter-receiver position during tests (maximal difference of 25 dB between left and right ear). So we had to check carefully the steady wCEP sensibility before and after each test to validate data. For us, wCEP technique was not mature for aeronautic environment.

DISCUSSION AND CONCLUSION

With customized HRTF, the subjects achieved better performances both silence and noise conditions (difference of 4°). Curiously, in noise, the response time with individualized HRTF (3.6 s) is longer than with non individualized HRTF (2.9 s). In other words, pointing a location listened with its own ears take much time than with other's ears. Maybe individualized HRTF lead to a “clearer” representation of the sound, thus the listener takes much care for his answer? Even if we try to optimise the 3D audio display, 3D audio display raises some issues, and some questions are determining: What is the workload on cognition resources? Is front rear reversal crippling? For example, if the pilot needs systematically to move head to remove front rear ambiguity, the pilot could be disturbed. In which situation in flight, is 3D audio contribution really efficient? Can 3D audio training be a solution to get better performances to locate? For the last step of PERTIA project, 3D sound flight test are planned on board a NH90 using Topowl head tracker at the end of 2010. The main goals of flight phase are to: evaluate 3D sound usability within a real helicopter environment and to evaluate operational benefit brought by 3D sound. For assessments, performance with objective measurements and workload with subjective evaluations will be done.

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REFERENCES

Carlile, S., Martin, R. L., and McAnally, K. I. (**2005**). “Spectral information in sound localisation,” International Review of Neurobiology **70**, 399-434.

Gilkey, R., Good, M., Ericson, M., Brinkman, J., and Stewart, J. (**1995**). “A pointing technique for rapidly collecting localization responses in auditory research,” Behavior research methods, instruments and computers **27**, 1-11.

Hammershoi, D., and Moller, H. (**1996**). “Sound transmission to and within the human ear canal,” J. Acoust. Soc. Am. **100**, 408-427.

Pellieux, L., Gulli, C., Leroyer, P., Piedecocq, B., Leger, A., and Menu, J.P. (**1993**). “Approche expérimentale du son 3D: Méthodologie et résultats préliminaires,” Agard Conference Proceedings **541**, 19_1-16_6.

Pellieux, L., Sarafian, D., and Reynaud, G. (**1996**). “Assessment of active noise reduction hearing protectors: noise attenuation and speech intelligibility,” Agard Conference Proceedings **596**, 16_1-16_19.

Pellieux, L., Sarafian, D., Villeneuve, F., and Peneau, M. (**1997**). “Localisation sonore tridimensionnelle sous écouteur par des pilotes non entraînés à l’écoute,” Rapport de recherche, IMASSA number 97-28.

Simpson, B. D., Brungart, D. S., Gilkey, R. H., and McKinley, R. L. (**2005**). “Spatial audio Display for Improving Safety and Enhancing situation awareness in general aviation environments,” Proceedings of RTO MP-HFM-123, Air Force Research Laboratory, Wright-Patterson AFB (USA), 26-1 to 26-16.

Wightman, F., and Kistler, D. (**1999**). “Resolution of front –back ambiguity in soatial hearing by listener and source movement”, J. Acoust. Soc. Am. **105**, 2841-2853.