Proceedings of the Institute of Acoustics & Belgium Acoustical Society
Noise in the Built Environment, Ghent, 29-30 April 2010

SOUND SIGNALS TO IMPROVE WAY-FINDING IN A TRAIN STATION

J Tardieu STMS-IRCAM-CNRS, Paris, France.
P Susini STMS-IRCAM-CNRS, Paris, France.
F Poisson SNCF, Direction de l'Innovation et de la Recherche, Paris, France
H Kawakami College of Art, Nihon University, Tokyo, Japan
S McAdams CIRMMT, Schulich School of Music, McGill University, Montreal, Québec, Canada

1 INTRODUCTION

Train stations are complex environments, and this complexity can be the source of problems encountered by travellers, such as way-finding problems. While the visual modality is largely used to address this issue[1,2], this paper aims at showing that way-finding problems can also be solved through the auditory modality (e.g. with a sound signalling system). This modality has been reported to be very effective in the case of visually impaired people, e.g., with the use of auditory beacons to specify route waypoints in a GPS based navigation system[3], or short melodic patterns to indicate different important locations (crossings, end of stairs, way out, etc.) in a train station[4]. The experiments presented in this paper involve travellers with normal vision only, but the results may also be relevant for visually impaired people.

In a previous work[5,6,7], it was shown that people are able to extract information from the soundscape of a train station. This information concerns what is happening (sound sources, human activities), and where this is happening in terms of space configuration (room effects), and type of space (e.g., hall, platform, etc.). Based on this result, we hypothesized that new auditory information such as a sound signal can be used by the travellers during their displacements within the station. This paper[8] will then question whether it is possible to improve a pathway in a train station using sound signals created in a way that is as little arbitrary as possible.

The proposed method is divided into three main phases. Phase 1 (Section 2) is the identification of problems encountered by travellers in a train station by means of an experiment performed under real conditions with recruited travellers. The second phase (Section 3) is the creation of sound signals in order to resolve the problems identified previously. This phase is composed of three steps: (1) definition of functional specifications for the sounds, (2) creation of several proposals by a sound designer on the basis of these specifications, and (3) selection of the best proposal with a panel of listeners in the laboratory. The final phase (Section 4) is an evaluation of the sound signals in the real context of the train station. A sound signalling system was installed in the station and an experiment was performed using the same procedure as in Phase 1.

2 IDENTIFICATION OF WAY-FINDING PROBLEMS IN A SPECIFIC TRAIN STATION

2.1 Method

Based on principles proposed in a previous work[9,10], an experiment is carried out under real conditions (i.e. in a Parisian train station) with travellers recruited for individual sessions. The experiment is divided into two steps:

1. The participant is given specific instructions at the beginning of the session. Then, they have to follow the instructions alone, and their walk through the train station is video recorded by the experimenter. There is no exchange between the participant and the experimenter along the way.
2. Once the participant has finished his/her walk, an individual interview is performed in order to allow the participant to explain and describe his/her actions during a replay of the video.

2.2 Description of the situation

In order to choose an appropriate situation (i.e., a train station), interviews were performed with the managerial staff of the six Parisian train stations, who were asked to report the known problems encountered by travellers. In the case of Montparnasse Station, it was reported that travellers encountered problems when they had to reach Vaugirard hall, a distant part of the station that corresponds to lines 25 to 28. We decided to apply our method in this train station, addressing the problem identified by the managers.

To reach the Vaugirard Hall, it is necessary to walk 300 m along platform 24. Three moving walkways are available to get there more quickly. According to the station managers, the cause of the problem could be that travellers don't see the first sign (at the beginning of platform 24) that indicates the location of lines 25 to 28. Therefore, the experiment described below was performed to identify clearly the problems encountered by travellers that try to reach this part of the station.

2.3 Experimental protocol

2.3.1 Instructions

At the beginning, the experimental goals were presented to the participant, in order to make him/her understand that only the faults of the train station were being evaluated, not himself or herself[9]. Then the participant was given the following instruction :

> *"You have to take the next train for Granville. You have an open ticket, so you don't know the exact schedule".*

Once the participant reports having clearly understood the instruction, he/she has to reach the goal without the help of the experimenter. The meeting point is given at the subway exit, 15 minutes before the next train for Granville, but the participant doesn't yet know that.

2.3.2 Video and interview

The participant's entire walk was recorded on video by the experimenter with a hand-held digital camera, without interfering with the course of the experiment.

Once the participant reached the goal, the video recording stopped, and the participant was taken to a meeting room for an individual interview. The goal of this interview was to have the participant explain the walk in detail during a replay of the video. This interview was conducted according to interviewing techniques[11] meant to help the interviewee describe explicitly the actions in which he/she was engaged.

2.3.3 Participants

The participants were selected according to two criteria: having a good experience in travelling by train, having no experience with this part of Montparnasse station. For example, they did not know that trains for Granville leave from the Vaugiard Hall. Ten participants, four men and six women between 26 and 49 years of age, were then recruited and paid 15 euros for the experiment.

2.4 Results

Each video was analyzed by reporting all the actions that were visible on the video. Then each interview was transcribed and analyzed in order to identify the problems encountered by the participant. A synthesis of all the participants' actions and problems is presented in the next sections.

2.4.1 Performance of the participants

Six main steps have been deduced according to the configuration of the train station and to the participants actions during the experiment. These steps are: the first sign, the 3 moving walkways, the Vaugirard hall entrance and the on-time arrival. According to the description of the situation in Section 2.2, a participant's performance was considered good when all the steps were completed without any difficulty. In other words, a good performance is when the participant sees the first sign, takes the 3 moving walkways, enters the Vaugirard Hall and arrives on time to take the train. Table 1 presents the performance of each participant for these steps. This table shows that out of 10 participants, one did not enter Vaugirard hall and arrived too late to take the train, and another one did not enter the Vaugirard hall.

	Main steps					
Participant	1rst sign	1st moving walkway	2nd moving walkway	3rd moving walkway	Vaugirard entrance	On time arrival
FM	X	X	X	X	X	X
AB	X	X	-	-	X	X
CLC	X	X	-	X	X	X
LD	X	X	X	X	X	X
KP	X	-	-	X	X	X
CI	X	X	X	X	X	X
CB	X	X	-	X	X	X
JA	X	X	X	X	X	X
MAT	X	X	-	-	-	X
MPH	X	-	-	-	-	-
Total	10	8	4	7	8	9

Table 1. Main steps of the walk, a cross means that the step was completed without any difficulty.

Column 1 of Table 1 shows that none of the participants had difficulty seeing the first sign indicating lines 25 to 28, contrary to what was presumed by the managers of Montparnasse Station (see Section 2.2).

Then, Table 1 shows that the moving walkways were not always taken. The two participants who did not take the first walkway, reported that the sign indicating lines 25 to 28 was not clearly visible. The six participants that did not take the second walkway reported an ambiguity between two signs that both indicated the direction for lines 25 to 28, but situated at two different positions. Finally, the three participants who did not take the third walkway explained that there was no sign.

Column 5 shows that two of the ten participants did not enter Vaugirard hall. In the interview, they explained that when arriving in front of the hall, there was no indication for lines 25 to 28. Indeed, the sign indicates “Gare Vaugirard – Montparnasse 3”.

2.4.2 Negative judgement

All the participants reported a lack of two types of information during the walk : a lack of confirmation that they were walking in the right direction, and a lack of information concerning the remaining distance to be covered. Consequently, their stress increased during the walk. More generally, all the participants explained that they found the walk unpleasant because the distance was too long and the environment not very friendly.

2.5 Conclusions

Three kinds of way-finding problems were identified in this section: 1) a problem of orientation towards the entrance of the moving walkways and the entrance of Vaugirard hall, 2) a lack of information confirming the direction taken, and 3) a lack of information concerning the remaining distance to be covered. None of the problems reported here were related to the hypothetical problem of the first sign that indicates the location of lines 25 to 28.

The next phase of the study sought to find a sonic solution to the three identified problems. The next section presents the specification for the design of informative non-speech signals.

3 DESIGNING SOUNDS TO IMPROVE WAY-FINDING

The sound design was based on functional specifications (section 3.1) that described the environmental characteristics of the places and the required functions of the sonic solution. These specifications were then given to a sound designer whose task was to propose appropriate sound signals to ameliorate the problems (section 3.2). Finally, a selection of the best sound signals was performed with a listening test in the laboratory (section 3.3).

3.1 Specifications for the sound design

3.1.1 Environmental descriptions

Two environmental descriptions were given to the sound designer. First, an architectural description gave the main physical characteristics of the walk between the beginning of platform 24 and the Vaugirard entrance: main distances, maps and photos were provided. Second, an acoustical description was provided: sound level measures, spectra and Ambisonic soundscape recordings. These descriptions helped the sound designer to create sounds that were appropriate to the acoustical properties of the soundscape.

3.1.2 Three sound functions

The functions of the sound signals must correspond to the problems identified in the experiment presented in Section 2. Thus, they must have three functions:

1 – Orientation: the sound signals must direct the user to the entrance of the three moving walkways and Vaugirard hall. This function is called *beacon sound* according to previous studies in which this type of sound was used to indicate exits in an emergency situation[12] or to improve navigation in a virtual environment[13,14].

2 – Confirmation: the sound signals must confirm at each step of the walk that the direction taken is the right one. This signal, called *feedback sound,* must be heard just beyond the position of the beacon sound.

3 – Timeline: the sound signals must inform the user, at each step, concerning the progression of the walk. In other words, hearing these sound signals, the travellers should understand that they are approaching the target. This function is called *timeline*.

3.2 Principle used for the sound design

The sound designer[4,15] (fourth author of this article) was given the previously described specifications, and he designed sounds according the principle of "earcons", i.e. non-speech sounds that are created to convey specific information by means of an arbitrary relationship between the sound and its meaning[16]. These sounds are generally used in human-machine interfaces (HMI) to help perform basic operations on files in a computer[17,18,19]. The type of sounds (earcons) is part of the designer's choice, which means that other types of sounds could have been proposed for the required functions, such as auditory icons[20,21] for example. The earcons proposed by the sound designer were built around two schemas, as presented below.

3.2.1 A pair of sounds for the beacon / feedback sounds

For the first two functions, the sound designer decided to create two sounds that work together, according to a call-response schema. In other words, the feedback sound is a "response" to the beacon sound. Twenty pairs of sounds were proposed according to three different types of schemas, as presented below.

- *Dynamic schema.* The pairs were built using a variation of one or two musical parameters chosen among five parameters: pitch, harmonic combination, dynamic profile, melodic profile and vibrato. For example, one pair was made of a beacon sound with a pitch increase from 800 Hz to 1600 Hz, and the feedback sound with a pitch decrease from 1600 Hz to 800 Hz.
- *Harmonic schema.* Only the harmonic combination varied, the other parameters were fixed.
- *Melodic schema*. The question-response was conceived according to classical musical principles. For example, one pair was made of a feedback sound that is a resolution of the chord heard in the beacon sound.

3.2.2 A sequence of four sounds for the timeline

For the timeline function, the sound designer proposed four different subsequences, placed at four steps between the beginning and end of platform 24. This sequence of four subsequences was supposed to indicate that the end of the walk was approaching. The sound designer created 10 different schemas to indicate the progress. The 10 schemas were based on different kinds of musical progressions in four subsequences, as presented below.

Sequence T01 was based on a harmonic progression: sub-dominant, two dominant chords and a tonic chord. In sequence T02, an arpeggio was played with internote intervals increasing from 5 to 20 semitones. In sequence T03, the number of notes in a given chord was decreased from 5 notes to 2 notes. Sequence T04 was a countdown from 4 beats to 1 beat. Sequence T05 was an arpeggio whose tempo increased progressively. Sequence T06 was based on a contour variation in a three-interval melody: 3 ascending intervals, 2 ascending and 1 descending, 1 ascending and 2 descending and then 3 descending. Sequence T07 was based on a rhythmic variation in a 4-note melody: 3 short and one long, 2 short, one long and one short, one short, one long and two short, then one long and three short. In sequence T08, the vibrato speed was increased progressively. The sequence T09 was similar to T06, but with a pentatonic scale melody. Then, the four steps of sequence T10 began with a common melody to which was added a second phrase made of a decreasing number of notes: from four to one.

3.2.3 Tonality and musical scale

The fundamental frequency of the sound proposed was tuned to the "keynote" of the soundscapes of the train station. This aesthetic notion was introduced by the Canadian composer Murray

Schafer[22] and consists of the part of the soundscape that is predominant. Using the acoustical descriptions of the soundscapes, two keynotes were found: the background noise, the spectral centroid[a] of which was close to the note C, and the spoken announcement jingle which was built on a C scale. Consequently, Kawakami decided to adjust the fundamental frequency of all the earcons to C or G and to use a pentatonic scale.

3.3 Sound selection in the laboratory

To select the sounds that would be installed in the train station, an experiment was carried out in which participants had to choose the ones that, according to them, best fulfilled the three functions. The beacon-feedback and the timeline functions were tested in two separate experiments.

3.3.1 Procedure

In both experiments, the task was the same. Using the computer interface[24], participants were asked to choose the three preferred stimuli in terms of functionality and to classify them from the most to the least preferred. The stimuli were equalized in loudness, and presented through headphones. They could listen to the stimuli as many times they wished to. They could not interrupt the sound until it ended.

Thirty participants (15 women and 15 men, between 26 and 49 years of age) were recruited and paid for this experiment. None of them reported having hearing loss. No musical background was required. The functions of the sounds were explained to the participants, and a description of the train station was given (photos and map).

3.3.2 Results

Each sound was given a weighting N that was calculated as follows: N=3*n1+2*n2+n3, where n1 is the number of times that the sound was classified in first position (i.e. the most preferred), n2 in second position and n3 in third position. For the beacon-feedback function, one pair had the highest weighting. This pair corresponds to a call-response created according to the melodic schema (see section 3.2.1) composed of an increasing melody for the beacon and two decreasing notes from the same scale for feedback. For the timeline function, the sequence T04 had the highest weighting, it is the one based on a countdown schema (see Section 3.2.2).

4 INSTALLATION AND EVALUATION OF THE SOUND SIGNALLING SYSTEM

To evaluate the sound signals, a sound signalling system was installed (Section 4.1) in the station and an experiment was performed with new recruited travellers (sections 4.2 and 4.3), using the same kind of procedure as in the first phase (see Section 2).

4.1 Installation of the sound system

The selected sounds, photos, and a 2D animation presenting the general principle of the installation are available on the following website: http://julientardieu.free.fr/sounddesign

[a] The spectral centroid of a sound signal is the center of gravity of its frequency spectrum. It indicates the frequency at which signal energy is equal above and below it in the spectrum. Perceptually, it is close to the “sharpness” of the sound[23].

The sounds were broadcast over stand-alone loudspeakers (ref: TOA EV20A) all along the walk from the beginning of the first moving walkway to the entrance of Vaugirard hall. Each loudspeaker contained a memory card onto which a sound was loaded. The sound could be triggered by an internal movement sensor (see Figure 1, left), or by an external movement sensor (see Figure 1, right). In other words, the sounds were broadcast only when a traveller walked in front of the movement sensor. In one case, the movement detection was made right next to the speaker (internal sensor), and in the second case the detection was made remotely (external sensor).

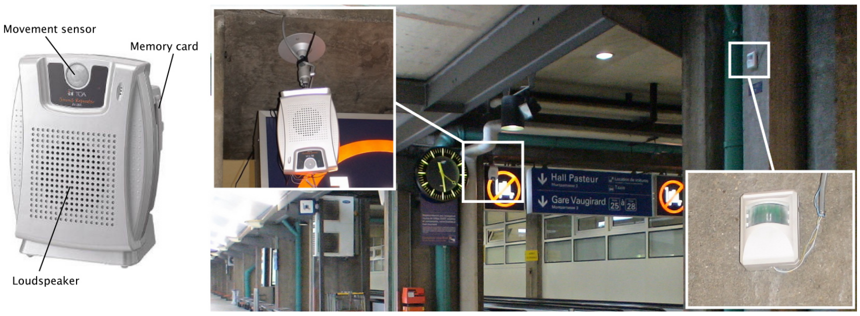

Figure 1. Left : stand-alone loudspeaker used for the sound signalling system in Montparnasse Station. Right : loudspeaker in place with an external movement sensor.

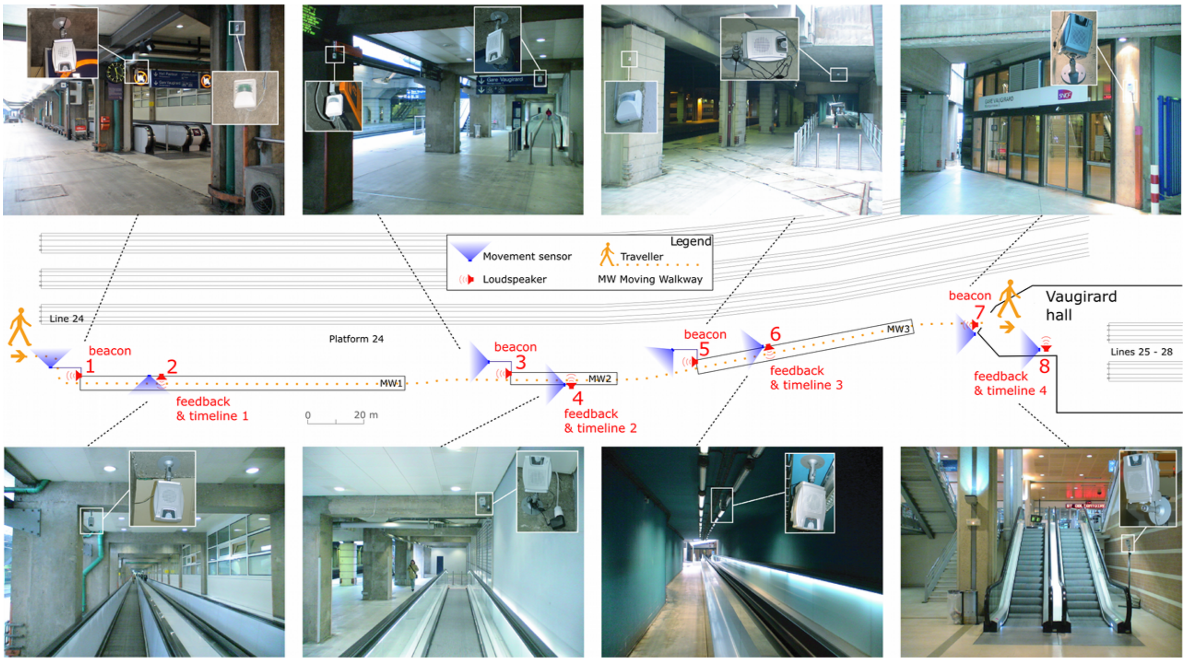

Figure 2. Sound signalling system for the Montparnasse train station.

Eight loudspeakers and three external moving sensors were installed in the train station, as shown on Figure 2. Speakers 1, 3, 5, and 7 all broadcast the beacon sound (speakers 1, 3 and 5 being triggered by external moving sensors). Speakers 2, 4, 6, and 8 broadcast the feedback sound followed by the corresponding timeline subsequence (4-, 3-, 2- and 1-beat subsequence, respectively). The system was used for three weeks without interruption.

4.2 Evaluation of the sound signalling system

The selected sounds and the signalling system were designed to solve the various problems encountered by the travellers during the analysis phase of the pathway in Section 2. This new experiment aimed to evaluate the sound signalling system on the same pathway. The method is also based on the same experiment as the one used in Section 2 for the analysis phase.

4.2.1 Procedure

The introductory part of the instructions was kept identical to that of the first experiment (see Section 2). Then, in addition to their main task (i.e. to take the next train to Granville), they were instructed to pay careful attention to the sound signals. The meeting point was the same as in the first experiment, and the video recording of the walk was performed identically as well.

As in the first experiment, each walk was followed by an individual interview during which the participant explained the walk in detail with the help of the video replay. In addition, the participant was asked to explain whether the sounds helped him/her and how they did help.

Eight new participants (5 women and 3 men, between 20 and 50 years of age) were selected according to the same criteria used in the first experiment (see section 2.3.3). The participants were paid 15 euros for this experiment.

4.2.2 Results : performance of the participants and role of the sounds

In a similar fashion as in Section 2, the performance of the participants at each of the main steps of the walk has been analysed. Except for one participant who did not enter the 3rd moving walkway, the results show that all of the participants completed the six steps without any difficulties.

In addition to the performance of the participants, the interviews have been analysed in order to find out how the participants understood the role of the sounds. The results show that all of them noticed the sounds and found them useful for their walk.

More precisely, the results show that the orientation function of the beacon sound was understood by all the participants. Then, only one participant did not understand the confirmation given by the feedback sound. This participant explained in the interview that he/she already had perceived this function in the beacon sound. This means that for this participant, the beacon sound had both orientation and confirmation functions. This was also the case for two other participants. On the other hand, the results show that none of the participants understood the function given by the sequence of timeline sounds. This could be explained in two different ways: (1) the timeline and confirmation sounds were too close in time and thus were not distinguished, or (2) the four steps of the timeline sound were not explicit enough when heard in a real context and thus would require a learning phase. More generally, all eight participants appreciated the presence of sound signals along the walk.

5 GENERAL CONCLUSION

This paper shows that way-finding problems encountered by travellers in a train station can be solved thanks to appropriate sound signals. The proposed method is made of three phases that were applied in the case of a train station in Paris (Montparnasse Station).

In the first phase, an experiment based on a principles proposed in previous works[9,10,11] was carried out in the train station with 10 recruited participants who were asked to attain a specific location in the station (i.e., the Vaugirard Hall), and to describe their walk during a subsequent individual interview. Three types of way-finding problems have been revealed : (1) orientation towards the entrance of the moving walkways and the entrance of Vaugirard hall, (2) lack of information confirming that they were headed in the right direction, and (3) a lack of information indicating the remaining distance until the end of the walk. This first experiment was particularly useful in determining precisely the difficulties encountered by travellers in the train station.

Second, sound signals were created and installed in the train station, in order to solve the three problems identified previously. They were created by a sound designer[4,15] who was given functional and environmental specifications. The specifications were the three functions of the sound signals that correspond to the identified problems: orientation, confirmation and timeline. The sound designer created several non-speech sound signals (earcons) according to principles reported in previous studies[16,19]. The sound proposed for the confirmation (feedback sound) is a "response" to the sound for the orientation (beacon sound). Therefore, the sounds to be installed were selected in the laboratory based on ratings by 30 participants who were asked to choose the sound they preferred given the function they were to fulfill. The sound signals were installed in the train station, using an experimental broadcasting system made of eight stand-alone loudspeakers triggered by internal or external movement sensors.

In the third phase, an experiment similar to the one in Phase 1 was carried out with newly recruited participants, in order to evaluate the sound signals under real conditions. The results show that most of the sound signals were understood and helped people during their walk. Only the sounds for the timeline function were not understood at all. This could be the result of an ambiguity with the preceding sound (the feedback sound), or just the difficulty to interpret this specific sound information without any pretraining session. The method deployed was therefore useful in evaluating the efficiency of new sound signals, coherently with the conclusion of a previous study on the visual signs in a train station[10].

In conclusion, the study presented in this paper shows that way-finding problems encountered by users of a public space, such as a train station, can be reduced by non-speech sound signals if users are made aware of their existence. The proposed method has been particularly useful for both the identification of the functions that the sound must fulfil and the evaluation of the sounds once installed in real conditions. In other words, it is possible to create sound signals for public spaces that not only fit the users perception, but also take into account the course of their activities. The results are successful, because most of the sounds were understood and used by the participants. In terms of sound design in public places, this paper reinforces a methodical approach by providing a new way to specify and to evaluate new sound signals created in order to help users of a public space. This approach could be integrated into the design of a fully operational sound signalling system for a train station or any large public space. Future research could also take into account users with visual impairments.

6 REFERENCES

1 Weisman J. Evaluating architectural legibility – Way-Finding in the built environment. Environment and Behaviour, Vol. 13, No. 2, pp. 189-204, March 1981.

2 O'Neill M. J. Effects of signage and floor plan configuration on way-finding accuracy. Environment and Behaviour, Vol. 23, No. 5, pp. 553-574, September 1991

3 Loomis J. M., Klatzky R., Golledge R. G. Navigating without vision: Basic and applied research. Optometry and Vision Science, Vol. 78, No. 5, May 2001.

4 Kawakami H. Sign-on: report on the study and survey of sound design, model free from the barriers from to auditory sense. Technical report, The Japan Sign Design Association (SDA), 2000.

5 Tardieu J, Susini P, Poisson F. Soundscape design in train stations: Perceptual study of soundscapes. In: Proceedings of the CFA/DAGA (Joint French/German acoustical societies meeting), Strasbourg, March 2004.

6 Tardieu J, Susini P, Poisson F, McAdams S. Soundscape design in train stations. In: Proceedings of the Journées design sonore, Paris, Octobre 2004.

7 Tardieu J, Susini P, Poisson F, Lazareff P, McAdams S. Perceptual study of soundscapes in train stations, Applied Acoustics (2007), doi:10.1016/ j.apacoust.2007.10.001.

8 Tardieu, J., Susini P., Poisson F., Kawakami, H., McAdams, S. The design and evaluation of an auditory way-finding system in a train station. Applied Acoustics, Volume 70, 2009, Pages 1183-1193.

9 Theureau J. Course-of-action analysis and course-of-action centered design. In Hollnagel E. editor, Handbook of cognitive task design, Lawrence Erlbaum Ass., pp. 55-81, 2003.

10 Theureau J. L'émergence d'un complexe d'échanges à travers les trajets des voyageurs : essai méthodologique. In Bayart D., Borzeix A., and Lacoste M., editors, Les traversées de la gare : la méthode des trajets pour analyser l'information-voyageurs, volume 118, pp. 145–190. RATP-Département du développement-Mission prospective et recherches sociales, Paris, 1997.

11 Vermersch P. L'entretien d'explicitation. ESF, 3e edition, 2000.

12 Rutherford P, Withington D. The application of virtual acoustic techniques for the development of an auditory beacon used in building emergency egress. In International Conference on Auditory Display (ICAD), Espoo, Finland, July 2001.

13 Walker B, Lindsay J. Effect of beacon sounds on navigation performance in a virtual reality environment. In: Proceedings of the International Conference on Auditory Display (ICAD), Boston, July 6-9 2003.

14 Walker B, Lindsay J. Auditory navigation performance is affected by waypoint capture radius. In: Proceedings of the International Conference on Auditory Display (ICAD), Sydney, Australia, July 6-9 2004.

15 Kawakami H, Tardieu J, Susini P, Poisson F. The sound navigation system at Montparnasse station. In: Proceedings of the World Forum for Acoustic Ecology, Hirosaki, Aomori, Japan, November 2-6 2006.

16 Blattner MM, Sumikawa DA, Greenberg RMM. Earcons and icons: their structure and common design principles. Human-Computer Interaction, 4 :11–44, 1989.

17 Brewster S. Non-speech auditory output. In The Human Computer Interaction Handbook, chapter 12, pages 220–239. Lawrence Erlbaum Associates, 2002.

18 Brewster S, Wright PC, Edwards ADN. A detailed investigation into the effectiveness of earcons. In Auditory display. Sonification, audification, and auditory interfaces. Addison-Wesley, 1994.

19 Brewster S, Wright P, Edwards A. Experimentally derived guidelines for the creation of earcons. In Human Computer Interaction, Huddersfield, UK, 1995.

20 Gaver W.W. *Everyday Listening and Auditory Icons*. PhD thesis, University of California, San Diego, 1988.

21 Gaver W.W. The sonicfinder: an interface that uses auditory icons. *Human-Computer Interaction*, 4:67–94, 1989.

22 Schafer RM. The tuning of the world, Random House Inc, 1977.

23 Zwicker E, Fastl H. Psychoacoustics, Springer, Berlin, 1999.

24 Smith B. PsiExp: an environment for psychoacoustic experimentation using the IRCAM musical workstation. In Society for Music Perception and Cognition Conference'95, University of California, Berkeley, 1995.