Following the Cuckoo Sound: A Responsive Floor to Train Blind Children to Avoid Veering

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Abstract. *Following the Cuckoo Sound* is a responsive floor application designed to train blind children to walk along a straight path through the use of interactive audio. The system, based on computer vision algorithms, is able to estimate the cartesian coordinates of a user as soon as s/he enters the active area. To provide children with an efficient and playful tool which can help them in the task of walking straight, we designed an interactive audio environment based on a cuckoo sound which is altered if the child veers from a central hallway. To obtain preliminary information about the potential of the application, we organized a pilot study involving 6 blind children. Results show an improvement in the stability of the direction in 5 subjects out of 6. Moreover, the great interest among the children for interactive audio suggests that this is a promising investigation field to help wayfinding and orientation.

Keywords: Veering reduction · Gamification · Responsive floor Interactive audio

1 Introduction

Audio and visual cues provide important information for human walking and wayfinding. But, when the data coming from the visual channel are missing due to visual impairment or total blindness, spatial navigation and wayfinding become a difficult and potentially dangerous task. With the development of computer technologies, many systems have been designed to help blind people to move more independently and without assistance. Basically their structure is formed by a module for the detection of the user's position in space – such as Global Positioning System (GPS), optical motion tracking systems, or others (see e.g. [14,15]) – , a database with environmental data (detailed obstacles map

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B. Guidi et al. (Eds.): GOODTECHS 2017, LNICST 233, pp. 11–20, 2018.
https://doi.org/10.1007/978-3-319-76111-4_2

and data for route planning), and user interface, usually auditory display with spatialized sounds or synthetic speech [1].

1.1 Veering

Despite their efficiency in providing useful data for blind people's navigation, these systems assume the walker's ability to maintain a straight path from one route point to another without changing the orientation in the meanwhile. Which in many cases does not take place, as veering may occur at any time, with severe consequences for instance for blind pedestrians. Veering is a well-known phenomenon that prevents even just blindfolded sighted persons to proceed straight in the absence of some acoustic or physical features such as hallways or sidewalks. Though the reasons of veering are not yet very clear, Kallie et al. [2] postulate that the undetected motor error that produces veering may basically depend on errors in the single step orientation. Particularly, the natural clockwise and counterclockwise rotation of the body during walking would be altered by an excessive lateral placement of the foot that can change the walker's orientation. Assuming that rotation is the primary reason of veering, Guth [3] employed the Anti-Veering Training Device (AVTD) to control the walker's rotation angle. Blind walkers had to follow a simulated crosswalk 2 mt wide and 20 mt long, delimited by ankle-level infrared beams. The system notified the walkers if their rotation angle exceeded the maximum, allowing them to correct their orientation. The results of this training was a reduction of the veering due to the learning of a new pattern of motor output, which persisted for some time after the end of the training.

1.2 An Anti-veering Training Tool for Blind Children

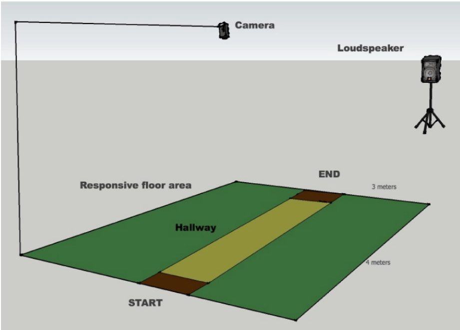
Also if newer systems can take advantage of smartphones built-in sensors to provide blind walkers with useful anti-veering information, exploiting thus the possibilities of an easier and handy technology [4], the existing anti-veering systems are usually intended for adults, and many of them require the user to carry more or less intrusive devices. Moreover, the sounds employed to drive the blind walkers are based only on functional criteria and are not intended to be attractive for the users. In recent years many applications for people with disabilities have been developed considering the potential of a higher involvement of the users through the use of game elements [5]. Motivation, engagement and application effectiveness have proved to produce better results for users in health and wellbeing applications built upon gamification principles with respect to traditional persuasive technology and health games [6]. Gamification can also be successfully employed to foster social interaction for aged people [7], for cognitive rehabilitation, therapy, disease prevention, and assessment [8]. Moreover, it can help in achieving goals due to repetitive and boring exercises, as pinpointed by Rego et al. [9]. Based on these findings, we conceived *Following the Cuckoo Sound*, a responsive floor application based upon a virtual soundscape inspired by a natural environment. The aim of *Following the Cuckoo Sound* is to build a gameful\playful environment devoted not so much to measure the veering of the user but rather to train the children in maintaining a straight route, in a comfortable and funny way. To obtain this result we introduced some game elements in the sound design of *Following the Cuckoo Sound*, with the dual goal of fulfilling for functional purposes and enriching the application's audio output, as described in Sect. 2.1. Beyond this, thanks to the possibilities offered by the *Following the Cuckoo Sound* responsive floor described in Sect. 2.2, the blind child can experience a hands-free and natural interaction, which enhances a sense of freedom and which encourages the environment exploration.

2 Following the Cuckoo Sound

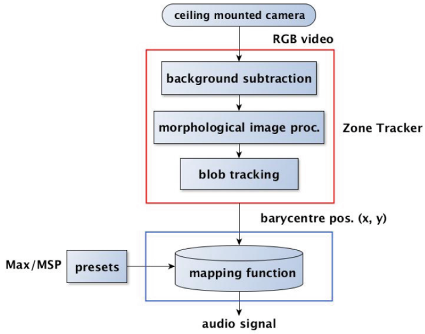
Following the Cuckoo Sound is a responsive floor system designed to train blind children to avoid veering through the use of interactive audio cues. The term *responsive floor* indicates an area where it is possible to track the presence and movement of one or more users, typically employing sensorized tiles or computer vision systems. Our responsive floor is a rectangular surface of 3 $\times$ 4 mt placed under the range of a camera hanging from the ceiling of the room. Through the camera the computer can track the movements of a person moving on the floor, allowing thus to link the blind walker's position to the audio output.

2.1 Sound Design and Game Elements

To define the sound characteristics of our environment we relied on the findings of Lewis et al. [10] who have investigated what are the best audio conditions to assist blind walkers. The authors found that a regular intermittent beep was preferred over a continuous signal and that blind walkers preferred to be notified if they were off track, with a different notification if they were off on the right or on the left of the hallway. Moreover they declared to prefer to avoid headphones. Keeping these principles in mind we conceived an ecological soundscape reproducing the sounds of a wood. The choice of a virtual soundscape inspired by a natural environment is the first game element of our application. It provides a sense of immersion which has the function to warm up the blind child's attention and curiosity in navigating the interactive space. In our pilot study we wanted to drive children along a 4 $\times$ 0.6 mt hallway put in the middle of the responsive floor, as depicted in Fig. 1a. As soon as the child occupies the *START* area the sounds of the wood are heard together with a cuckoo sound, which is intermittent by nature. The loudspeaker source, put just in front of the hallway, permits a strong and clear guidance on the path. If the child walks inside the hallway the cuckoo sound continues unaltered. If the child gets off track on the right side the cuckoo sound becomes higher in frequency, and if s/he goes on the left side the sound becomes lower. Thus the differences in the sound of the cuckoo are used to mark that s/he is going in the wrong direction and are intended as an invitation to correct it. They could as well be used to assign a score to the child's performance, based on the number of changes reported and on the time



(a) The responsive floor setup



(b) The system architecture

Fig. 1. In Fig. 1a is depicted the *Following the Cuckoo Sound* responsive floor setup. The 3 × 4 mt active area (green) has in the middle a hallway (light green) with start and end points (brown). These colors are used only to mark the interactive areas in the present Figure, while in the reality only the green carpet is visible. A hanging camera for motion tracking and a single loudspeaker put in front of the path complete the application's technological setup. In Fig. 1b is depicted the system architecture with its two software modules: the *Zone Tracker* application and the *Max/MSP* patch. (Color figure online)

the child employs to correct her/his route. Finally, as in the video games, when the child reaches the *END* position a final jingle notifies that the target has been successfully reached[1].

2.2 System Architecture

Following the Cuckoo Sound's system is based upon computer vision algorithms. Its technological equipment is composed by a video camera, a long powered USB cable for camera connection, a computer, a green carpet, and a loudspeaker. The carpet's color has been chosen has an optimal background to enhance the camera vision and to avoid excessive light reflection that could altere the visual data and that could be visible even to blind children. The system relies upon two software modules: the *Zone Tracker* application for camera data processing [11,16] and a *Max/MSP* [12] patch for the audio production, as depicted in Fig. 1b. The RGB video data coming from the ceiling mounted camera are processed by the *Zone Tracker* application. After background and morphological image processing, the algorithm defines a blob image, calculates its barycentre and outputs a couple

[1] A video showing *Following the Cuckoo Sound* while being tested at the Robert Hollman Institute (Padova, Italy) can be found at https://youtu.be/yUkPcD1M-OQ. The white tags visible on the carpet in the video were used only to notify the hallway limits and the *START* and *END* positions for clarity of the video viewers. They were removed in the experimental sessions, to avoid that their presence was felt to the touch by the children.

of cartesian coordinates of its position. These data are transmitted via Open Sound Control (OSC) [13] to the *Max/MSP* patch where the mapping functions and audio files are stored.

3 Assessment

To collect some preliminary information about the blind children's behaviour in the *Following the Cuckoo Sound* environment, we organized a pilot study at the Robert Hollman Foundation in Padova (Italy) in October 2016[2]. The study aimed at verifying if, after having walked along the hallway and having followed the cuckoo sound, the children are able to reduce veering in the absence of the audio. Moreover we wanted to check the behavior of the children and to assess their liking to gather suggestions useful to subsequent changes in the system or in the training procedure.

3.1 Subjects

For our pilot study we selected 6 completely blind children of both sexes, aged between 5 and 8 years. As reported in their studies on deviation from a set path, Lewis et al. [10] found a big difference in the response between the test subjects totally blind and partially blind ones. Accordingly, in Table 1 we reported the particular condition of subjects A and E, assuming that this can affect somehow their performance. Subject A was already experienced in the use of the long cane and thus probably had already developed motor cues useful to avoid veering. Subject E was not congenitally blind, which could potentially influence her/his behaviour.

3.2 Procedure

We arranged the responsive floor in the middle of a quiet room approximately of 8×10 mt. Children were introduced in the room one at a time accompanied by their educator. In the room a test assistant and a technical assistant were admitted. Only the test assistant spoke to the children, while all the other people were as silent as possible. Each test was preceded by a short explanatory introduction about the task to accomplish and by an exploratory phase consisting of a walk on the active area to test the reactions of the environment. The organization of each test comprehended the usual three phases of pretest, training and posttest. In the pretest children were accompanied by the test assistant to the starting point of the hallway with their face and shoulders oriented toward the end of the straight path. They had to try to reach the end point for three times without any form of assistance, that is, without any sound produced by the system or voice guidance from the educator. In the second phase the children had to undergo the same procedure but this time they heard the audio output produced by the system which could help them in maintaining the straight path. The posttest was performed exactly in the same way as in the pretest.

[2] http://www.fondazionerroberthollman.it/home-english.html.

3.3 Method

To verify our experimental hypothesis we recorded the data of each subject's walk, obtaining an overall of 9 records for each subject (3 for each phase). As soon as a subject occupies the *START* area the system begins to record the couple of cartesian coordinates of her/his position, tracked as explained in Sect. 2.2, with a frequency of 20 couples per second and stops when the subject reaches the *END* point or when s/he exits the active area. We used these data to plot the path, to measure the veering and to calculate the time employed by the children to travel along the hallway.

Table 1. Overall results of the *Following the Cuckoo Sound* pilot study. For each subject are reported the averages obtained in the three trials of the pre- and posttest with respect to the external area covered by the subject's veering (m^2) and to the time employed (s).

Subject	External area (m^2)			Time (s)		
	Pre	Post	Difference	Pre	Post	Difference
A*	0.00	0.31	−0.31	6.17	6.43	−0.27
B	0.79	0.11	0.69	13.38	7.80	5.58
C	1.19	1.09	0.10	8.93	5.00	3.93
D	1.70	0.74	0.96	9.00	12.80	−3.80
E**	0.14	0.11	0.02	12.33	11.58	0.75
F	0.87	0.45	0.42	12.07	6.27	5.80

*subject alredy trained in the use of the long cane
**subject non congenital blind

3.4 Results

The results of our pilot study are reported in Table 1. As the veering produces a curved area comprised between the straight line of one side of the hallway and the curved line produced by the subject's trajectory, we calculated the external area in m^2 and employed this finding to express the quantity of veering, as can be seen in the example reported in Fig. 2. For each subject we calculated the average of the external area measurements recored in the 3 trials of the pretest and in the 3 trials of the posttest and the difference between the two means. The differences show the effects of the sound walk on the responsive floor. A negative difference means that there is an increase of the external area (corresponding to the veering) in the posttest, while a positive difference shows the amount of the decrease obtained in the posttest trials. We report also the averages of the time (in seconds) employed by the subjects to complete the task in the pretest and in the posttest. Five subjects out of six obtained a decrease of the veering in the posttest with respect to the pretest. Subject A was already well trained in the use of the long cane, which completely prevented her from veering already in the

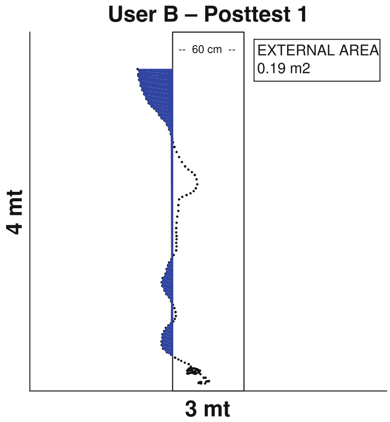
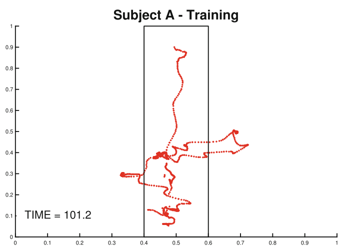
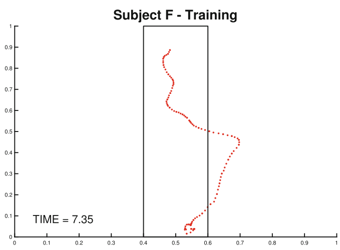


Fig. 2. An example of veering curve plotted employing the subject's coordinates recorded by the system. The rectangular section represents the hallway and the colored area is the surface external to the hallway that expresses the subject's veering (0.19 m^2 in this example). (Color figure online)

3 pretest trials, as reported in Table 1. This led her to consider the training like a game where the veering was done on the purpose of hearing the sound effect, as showed in Fig. 3a. Also the time of this test trial (101.2 s) is much longer if compared to the averages times of the same subject in the pre- and posttest trials (6.17 and 6.43 s respectively). In Fig. 3b is depicted an example of path correction by Subject F as it should happen in consequence of the changes in the audio output. As noticed by Guth [3] and as can be seen in Fig. 4a and b, the training on the responsive floor does not completely eliminate veering, but in the case of subject B noticeably decreases its amount. Subject D obtained the best improvement with respect to the trajectory correction but not with respect to the time employed. In general also a time decrease in the posttest may be

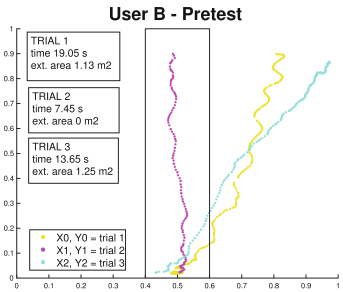


(a) Subject A - training

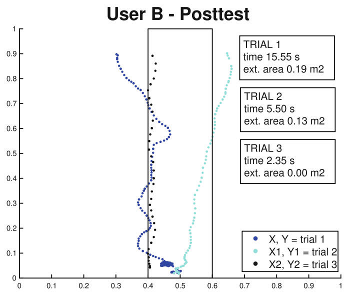


(b) Subject F - training

Fig. 3. Two training performances from different subjects. In Fig. 3a veering is done on purpose to listen to the sound effect. In Fig. 3b the path correction is made as a consequence of the changes in the audio output. (Color figure online)



(a) Subject B - pretest



(b) Subject B - posttest

Fig. 4. The 3 pre- and posttest performances of subject B with noticeable path correction.

interpreted as an improvement of the subject's confidence in walking straight, and thus be considered as a benefit obtained from the training. Subject E, the only non congenitally blind of our sample, performed nearly in the same way as in the pretest, obtaining exactly the same amount of veering and a very small decrease in the time.

3.5 Qualitative Evaluation

Children enjoyed much the experience in the *Following the Cuckoo Sound* environment. Some of them were fascinated by the soundscape produced as soon as they entered the active area and were much more interested in exploring the reaction of the responsive floor than in following the hallway where the cuckoo sound was unaltered (see Fig. 3a). Nine months after the test we found that all the six participants remember the experience and that they are eager to repeat the training. For rating the subjects' liking we used a five items Likert scale survey ranging from 1 (very few) to 5 (very much), obtaining an average score of 4.83.

4 Conclusion

In this paper we presented *Following the Cuckoo Sound*, a training system for the reduction of veering in blind children. Also if the small number of participants prevented us to obtain statistically significant results, our pilot study show that the training with the application seems to reduce the amount of veering and that the observed improvements can be considered as an indication of the potential of this approach. However, some limitations in our experimental setup need to be discussed. The training took place in a single session of 3 trials for an average overall duration of about 1.8 min, a time too short to induce lasting changes. The posttest followed immediately the training and consequently we need to be cautious that the reported decrease in the veering area are due to a

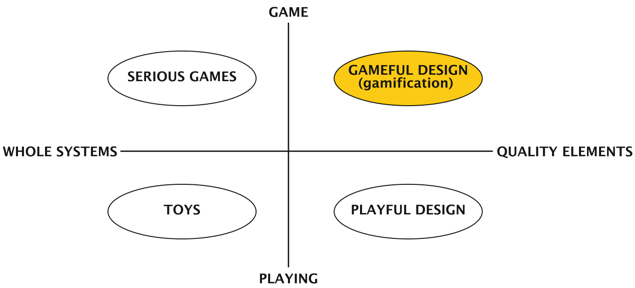


Fig. 5. Conceptual map of gamification applications adapted from Deterding et al. [5]

real improvement in orientation capacity rather than to a memory effect. Thus, further experiments including also a follow-up session are required. Moreover, despite the apparent interest shown by children in exploring the responsive floor area, the short duration of the training did not allow us to verify whether any fatigue or falling interest phenomena occur. Moreover, further research could be done including also longer as well as non-straight paths. Anyway, during the training we had some problem in controlling the behaviour of the children, as the interactive acoustic feedback has a great motivational effect in stimulating the children in the environment discovery. Following the conceptual map depicted in Fig. 5, which cathegorizes games in a bi-dimensional space defined by a *whole-systems* versus *quality-elements* horizontal axis and a *game* versus *playing* (free exploration) vertical axis, we place *Following the Cuckoo Sound* in the *Gameful design* quadrant, that is in the game area. It seems instead that the children interpreted the task of avoiding veering more as a free exploration, placing the application in the *Playful design* area. Perhaps a longer exploratory phase would help in controlling the curiosity of the children and in allowing a tidier training, more similar to a ruled game. Nonetheless this observation leads us to consider the great potential of interactive audio for the design of playful environments which, exploiting the fun and the joy of discovery, can help blind children in achieving a more confident and safe relationship with the space around them.

Acknowledgements. The authors would like to thank *Dr. Vittorina Schoch*, Clinical Director and *Dr. Maria Eleonora Reffo* Administrative Director of the Padua Center of the Robert Hollman Foundation for their cooperation in the organization of the pilot study of the *Following the Cuckoo Sound* application.

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