Evaluation of Spatial Abilities within a 2D Auditory Platform Game

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ABSTRACT
In this paper, we compare the mental maps created by sighted participants with the maps created by participants with visual impairments during the study of an auditory platform game. The game uses audio cues to convey a 2D side-scrolling view of the spatial layout of the game world. We studied three groups with 9 participants each: a control group of sighted participants playing an audio-visual version of the game, sighted participants playing the audio-only version of the game, and participants with visual impairments playing the audio-only version of the game. Immediately after playing two of the game's levels, we transferred the participants' verbal descriptions of the level's layout onto paper maps and gave each map a "mapping score" that expressed how closely a map matched the actual layout of the game level. The results suggest that in this setting, all participants were able to create maps with roughly the same accuracy no matter which version of the game they played (audio-visual or audio-only) and independent of the participant's level of visual ability (sighted persons or persons with visual impairments).

Categories and Subject Descriptors
H.5.5 [**Sound and Music Computing**]

General Terms
Measurement, Design, Experimentation, Human Factors.

Keywords
Spatial ability, visual impairments, video games, audio games.

1. INTRODUCTION
While many previous studies have investigated spatial navigation abilities of persons with visual impairments in the context of route guidance [1], there may also be benefits in investigating auditory displays for more abstract 2D spatial relationships, such as spreadsheets [2] and interactive 2D computer interfaces in general. The Audio Platform Game (APG) [3,4] (figure 1), on which the research presented here is based, conveys 2D spatial relationships via audio alone. APG is based on the same concepts as the early Super Mario Bros. platform games, in that the user navigates a character through different levels of a 2D, side-scrolling, game world by hopping on platforms. In APG's audio-only version the user perceives only audio cues about the game's content and uses these to navigate through the level and to avoid the various obstacles. For APG, we heavily borrow from the field of sonification [5] to create effective audio cues that guide a player through a relatively complex layout of a 2D game world.

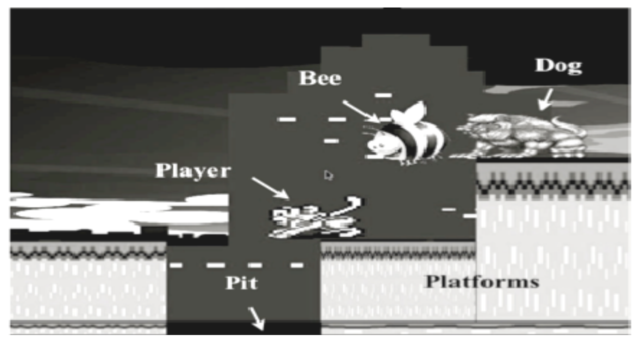

Figure 1. A screenshot showing all objects used in the game.

As part of a broader study on spatial audio games [3,4], we attempted to capture the user's mental maps of some game levels for three groups of nine participants: sighted using audio-visual (control group), sighted using audio-only, and participants with visual impairments using audio-only. Directly after playing through certain game levels, participants were asked to verbally describe the layout of their mental maps to the researcher. Paper maps were created from each participant's verbal description, which were given a score depending on the deviations from the true level layout. We used a comparison of these mapping scores to explore differences between each group in their ability to perceive spatial relationships and use those relationships to create effective mental maps.

2. METHODS
Eighteen participants (8 men and 10 women) who had normal vision (mean age = 28, SD = 6.9) were pseudo-randomly divided into an audio-only group (group 1) and audio-visual group (group 2) with equal numbers of men and women in each. Nine legally blind participants (mean age = 26,SD = 11.2; 7 men and 2 women) formed the third group, which played the audio-only version. All participants played the game with a game controller and headphones; only the group 2 could also see the game on a monitor. Participants played through a series of seven levels of increasing complexity. At the end of two levels participants were asked to describe the level verbally following a pre-defined protocol. We chose this verbal mapping technique so that participants with visual impairments would not be at a disadvantage.

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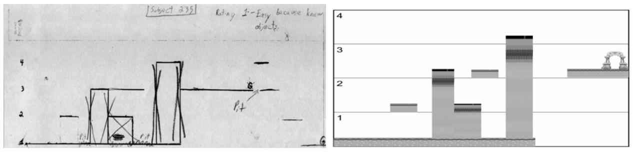

Figure 2. Example of a level diagram made from the verbal description (left) and the actual layout of this game level.

Participants were told before starting a mapping level that they would need to describe the level after finishing the game using a procedure we had introduced to them during the training process. The participant's verbal descriptions were first translated into diagrams of the level's map (figure 2, left) and then scored to provide a single numerical value for each map. The scoring technique was based on systematically comparing the diagram with the true game level (figure 2, right), this included missed objects and made up objects (i.e., objects the participant had erroneously claimed to have encountered). A score of zero meant that the player had made no mistakes when describing the level (perfect score), while deviations from the true level layout resulted in adding penalty points. One full point was added for each missed object or made up object, a half point was added for each object out of place (e.g. on a higher or lower floor) and for each object identified as the wrong type (e.g. describing an object as a solid platform when it was a floating platform). Screen and audio recordings of the participants' traversal through the level were analyzed to ensure that no penalty points were added when the participants had chosen a path that did not bring them in contact with a certain object.

3. RESULTS

There was one independent variable of interest (game version) with three levels: audio-visual played by sighted participants (n=9), audio-only played by sighted participants (n=9), and audio-only played by participants with visual impairments (n=9). The dependent measures were the mapping scores and the number of objects the participant "invented" (objects that did not exist in the actual level that the participant placed in her mental map).

We used a one-way ANOVA, with a *p*-value of 0.05 to determine significance, to compare the mental map scores of the three groups. The mean mapping scores did not vary significantly for level 3 between group 1, the control group, (M=3.11, SD=1.60), group 2 (M=4.17, SD=2.08), and group 3 (M=2.39, SD=1.50), $F(2,24) = 2.37$, $p = .12$. The mean mapping scores also did not vary significantly for level 7 between group 1 (M=3.06, SD=2.11), group 2 (M=3.11, SD=1.41), and group 3 (M=3.00, SD=1.85), $F(2,24) = .008$, $p = .99$). The lack of significant differences in these mapping score results suggest that playing the game via the audio-only interface was not a significant disadvantage for groups 2 and 3, compared to group 1 (audio/visual interface) and that their seemed to be equally able to perceive the required spatial relationships and routing information from audio alone and to use them to create an mental map of the level.

The results of a one-way ANOVA revealed that the mean number of invented objects for level 7 did not vary significantly between group 1 (M=.33, SD=.500), group 2 (M=.67, SD=.866), and group 3 (M=.44, SD=.882), $F(2,24) = .44$, $p = .65$. However, there was significant variance in the number of invented objects for level 7 between group 1 (M=.67, SD=.867), group 2 (M=2.11, SD=1.965), and group 3 (M=.11, SD=.333), $F(2,24) = 6.09$, $p = .007$, $\eta^2 p = .34$. While it is not clear why participants with normal vision using the audio-only interface invented significantly more objects for level 3 than the other participants, an analysis of their background in computer gaming suggest that prior experience with popular 2D platform games such as Super Mario Bros. and Sonic the Hedgehog may have played a role. This may have led some participants to erroneously report a certain aspect of the level layout to be true, although, in fact, this level layout did not conform to this traditional convention.

4. CONCLUSIONS

The results of this study indicate that the particular auditory interface used in this game setting, can be used to accurately convey complex 2D spatial relationships. No significant difference was found when comparing the accuracy of maps of game levels (as defined by the mapping score) that were created by participants playing the audio-only version of the game (either sighted or visually impaired) to the results of sighted participants playing the audio-visual version (control group). Also, no significant difference was found in the overall map accuracy within those playing the audio-only version, i.e., between sighted participants and participants with visual impairments.

However, due to the small sample size used, the results may not have enough power to conclude that all groups produced maps with equal levels of accuracy. An expansion of this study is needed to draw stronger conclusions and to provide stronger evidence that auditory interfaces can, in general, lead to mental maps that are as accurate as those created via visual input.

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5. REFERENCES

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