An audio game to test and train navigation skills of visually impaired people

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***Abstract*—Accessibility in games for visually impaired people is an open problem. Even though a substantial amount of experiments have been done [1], there is currently no standard effective way to create games without any visual need. Furthermore, training blind people to use audio-based navigation tools is a risky task as children can hurt themselves. Generic tools are emerging to solve the first of these problems [2], but their limitations have yet to be tested and evaluated. To find a single solution to these two problems about accessibility in games and navigation training for visually impaired people I developed *Blind Nav*: an audio game specially designed to test and train these skills playing a game. The actual goal of *Blind Nav* is to test and evaluate some kind of features that could make the difference in the design of this kind of tools. The results were fairly positive in terms of accuracy and immersion, but a larger test is required to make statistical conclusions with a relevant weight.**

I. Introduction

One of the biggest needs of visually impaired people is certainly to be able to orient and move themselves within a space. Visually impaired people need to train their navigational skills to improve their life quality. Usually professional tutors are needed to execute these training sessions and furhtermore they could be really dangerous [3]. Many researchers are working to assist visually impaired people in different ways with tools like voice based assistance, ultrasonic based assistance, camera based assistance and also with some other advanced techniques [4]. *Blind Nav* wants to evaluate some features that could be used to build a complete tool to perform this type of training sessions, while keeping the patient entertained.

Thanks to today's technologies based on sound spatialization it is possible to build real-time reactive systems that can train the visually impaired in the most realistic way [5]. 3D sound is in fact a technology that can make the user perceive the exact position of the sound through stereo headphones [6]. In the current market there are also dedicated devices with advanced features such as 7.1 surround able to simulate a complete set of seven sound emission points around the listener [7]. Although these technologies are widely used in the entertainment industry, both at home and on the market, their features make them perfect for more useful purposes such as the one presented in this article.

With a particular focus on the sounds selected for the gamificated tool, it is in fact possible to simulate the reality in an extremely realistic way. The patient would be able to perceive dangers, as well as points of interest, almost as if he were really in their proximity. One of the biggest limitations of using the sound spatialization technology alone in this kind of tool is the lack of the sense of touch. This problem can be overcome through dedicated suits [8-11] and the use of other advanced virtual reality tools.

II. Experience Design

Blind Nav was designed thinking on accessibility as the most important feature. Specifically, the game should not require any graphic component and should be playable using only the audio features. Furthermore, the blind player should be able to play the game in total autonomy without the requirement of reading any instruction previously.

A. Game Goal

The aim of the game is to reach a sequence of target positions indicated through a spatialized voice that continuously tells the player to reach it. The additional difficulty consists in the fact that there will be several components of distraction and danger within the game world. Everything that enriches the game world is inspired by the real world and designed to immerse the player.

B. Game Controls

Blind Nav was designed to be played with a gamepad. This choice was driven by the fact that it's easier for a blind person to use a gamepad instead of a keyboard, especially when there is only a voice telling you which button to press. However, support for a mouse and keyboard setup has been implemented but the game never mentions these devices.

C. Main Components

In this section I briefly outline all the main components of the game for a better understanding of the following sections.

- *Helper Voice*
  The *Helper Voice* is an AI generated humanoid voice that guide the player through the all experience. The *Helper Voice* audio source is set to play the sounds without spatialization. This means that the player can always hear it and do not need to be focused on it. Furthermore when the *Helper Voice* speaks, all other features of the game are paused. This aspect

has been carefully designed to let the player being fully focused on that voice avoiding comprehension problems during the experience. The *Helper Voice* may then override the real-time simulation to assist the player.

- *Target Voice*
  The *Target Voice* indicates the location of the target points to the player through a voice in loop. For this purpose, its sound source is clearly spatialized in the 3D space. The *Target Voice* is not limited to simply repeating a set of phrases to the player, but it's based on a dynamic system that can communicate the right sentence to the player according to the situation.

- *Obstacles*
  There are three different types of obstacle:
  - *Environmental Obstacles*
    They are the simplest obstacles and consist of any environmental object, such as a fence or a house. They do not make any sound and the player can only try to remember their position after hitting them hearing the hit feedback sound. Nothing happens to the player when he hits them.

  - *Safe Obstacles*
    These obstacles make sounds in loop and the player have to avoid them by hearing their sounds. They are used also to let the player orient himself into the game world. They are related to real world stuff that would not hurt the blind, such as a person. The player position is reset to some meters away from the obstacle when he hits them.

  - *Dangerous Obstacles*
    These obstacles are the same as the *Safe obstacles*, but the player position is reset to the last reached checkpoint when he hits them. They are related to dangerous stuff that can hurt the blind in the real world, such as a moving car or an aggressive dog.

  An important note is that *Safe* and *Dangerous obstacles* can be *moving* or *fixed* in a specific location.

D. Tutorial

The game starts with a black screen and the *Helper Voice* that requires the player to press any key to start the game in loop. Once started, the tutorial begins. Initially the *Helper Voice* explains to the player the goal of the game and its main features.

Next, the presentation of some spatialized sound examples is performed. Sequentially, a sequence of sounds are reproduced, anticipated by a description of each of them made by the *Helper Voice*. The player will be asked by the *Helper Voice* to press some buttons to indicate the correct perception of the sounds. In the case that a continuous wrong perception of the spatialized sounds is detected, the *Helper Voice* invites the player to close the game and contact the developer.

As evidenced by the description above, the game does not require any visual component from the beginning.

Fig. 1. The only screen present in *Blind Nav*. The commands displayed are also explained by the *Voice Helper*.

E. Levels

Blind Nav is made up of a total of three different levels with a growing level of challenge.

1) *Level 1*
   At the end of the tutorial the first level begins. It is a very simple level that is designed to let the player try the character controls. It consists of two targets located exactly in front of the player. Between the first and the second target there are some *Safe* and *Dangerous obstacles* that aim to help the player get used to orientation in the virtual world through sounds.

2) *Level 2*
   The second level is the first with a real level of challenge. It is set within a large park and consists of four targets. There are only *fixed obstacles*, both *Safe* and *Dangerous*.

3) *Level 3*
   The third level is the most complete and contains all the features implemented for *Blind Nav*. Specifically, *moving obstacles* have been added. It is set in a town and includes the crossing of several different areas, including a residential complex, a construction site and a park.

F. Player Support

The game offers various aids to the player through the *Target Voice* and the *Helper Voice*. If the character direction were to be wrong with respect to the target for too long, the *Target Voice* would notify the player by inviting him to turn towards the origin of the voice. If the character were to stay too long in an area away from the target, the *Target Voice* would also help him in this case. The last aid offered to the player is related to the manual reset of the character. If the player fails to reach the target for too long, the *Helper Voice* would ask him to reset the character's position manually to resume from a facilitated point.

Fig. 2. A Level 3 screenshot to see what's going on behind the scenes in *Blind Nav*. It's possible to notice all kinds of obstacles on this screenshot.

G. Game Options

To give the player some in-game options without any graphical interface, they have been integrated with the *Helper Voice*. Specifically, it is possible to change the game volume of three different audio channels, related respectively to the *Helper Voice*, the *Target Voice*, and the *Sound Effects*. Horizontal directional arrow keys are used to select a specific voice channel. The *Helper Voice* tells the player which channel is currently selected after the key has been pressed. Vertical directional keys are instead used to act on the volume level. Also in this case feedback sounds inform the player about the action just performed.

III. Technical Specifications

A. Tools and Technologies

The game was developed with the *Unity* game engine [12]. To get better results on the audio output I did not rely entirely on the *Unity* integrated audio system. I used the software toolkit for spatial audio made by *Valve Software*: *Steam Audio* [13]. *Steam Audio* delivers a full-featured audio solution that integrates environment and listener simulation. The specific features of *Steam Audio* used in *Blind Nav* are described below:

- *Realtime Sound Propagation*: *Steam Audio* automatically captures and camputes how sounds interact and travel through the environment.
- *Occlusion*: Static geometry on the scene occlude sounds.
- *3D Audio*: HRTF-based binaural rendering [14].

B. Settings and Setup

The *Unity's Audio Source* component allows to play any *Audio Clip* specifying some options. The sounds inside *Unity* are captured by the *Audio Listener* component that send them to the *Audio Mixer* to reproduce them with a specific output device connected to the computer.

In *Blind Nav* there are two different types of *Audio Source*: *spatialized* and *not spatialized*. The former are used for the obstacles and the targets. The latter are used for the *Helper Voice* and the option sound feedbacks.

Only the *spatialized* audio sources use *Steam Audio* and to enable its 3D sound features it's necessary to enable the *Spatialize* parameter and add a specific *Steam Audio* component: *Steam Audio Source*. It's mandatory to set also the *Spatial Blend* setting of the *Audio Source* component to 1. This means that the audio source is affected by spatial position and spread. The *Steam Audio Source* component allow us to specify all the settings provided by *Steam Audio*, such as *HRTF settings, attenuation settings, directivity settings* and *occlusion settings*.

HRTF setting is enabled as *Direct Binaural*. In this way HRTF-based binaural rendering will be used to spatialize the source. This requires 2-channel stereo audio output. Binaural rendering provides improved spatialization at the cost of slightly increased CPU usage [15]. The second parameter related to the *HRTF setting* controls how HRTFs are interpolated when the source moves relative to the listener. There are two different modes available:

- *Nearest*: Uses the HRTF from the direction nearest to the direction of the source for which HRTF data is available. The fastest option, but can result in audible artifacts for certain kinds of audio clips, such as white noise or engine sounds.
- *Bilinear*: Uses an HRTF generated after interpolating from four directions nearest to the direction of the source, for which HRTF data is available. This may result in smoother audio for some kinds of sources when the listener looks around, but has higher CPU usage, up to 2x.

In Blind Nav all the sound sources are set to *HRTF Nearest* except on car and other engine-like sounds.

Attenuation settings are enabled on all the spatialized audio sources so a distance attenuation of the sounds is applied. The distance attenuation is not physically based, but curve based. This choice has been taken to allow a precise adjustment of each single audio source based on the audio clip to be played. The use of a physically based attenuation would have been the best option for *Blind Nav*, but unfortunately not having a sound designer and having had to rely on free sounds, it was necessary to use a curve based attenuation in order to have each sound consistent within the scene. Using the physically based attenuation, in fact, some sounds would have totally covered the others and this is just one of the problems identified due to this technical limitation during the making of *Blind Nav*.

Directivity settings are only enabled for a limited set of obstacles where it makes sense to direct sound in a specific direction. For example, all obstacles representing human beings emitting sounds from their mouths have audio sources with a directivity.

Occlusion and *transmission settings* are enabled on all the spatialized audio sources. This means that *Steam Audio* considers the geometry of the scene to occlude and transmit sounds. To mark specific scene objects as static geometry, the *Steam Audio Geometry* component is provided. It's possible to specify a material related to the geometry. In *Blind Nav* almost all the geometry baked in the scene use the *'concrete'* material.

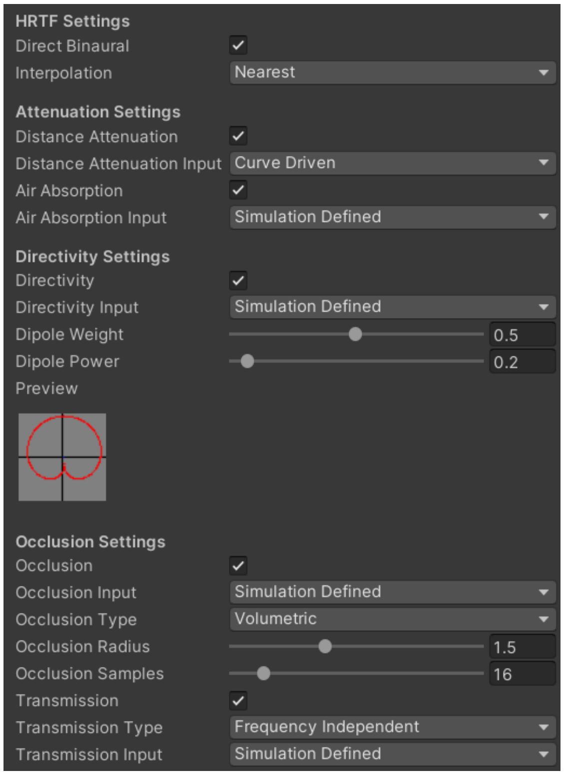

Fig. 3. The *Steam Audio Source* component on *Unity*.

IV. Experiment Results and Analysis

In this section I describe how *Blind Nav* was tested and I analyze the experiment results.

A. Experimental Setup

No ad-hoc setup was made to test *Blind Nav*. People interested in the experiment were free to test it following the advice described on the publication website [16].

All testers were invited to complete a questionnaire after the game [17]. A total of approximately 20 tests were carried out, but unfortunately only 17 completed questionnaires were received. Blind Nav automatically collects usage data during the game and at the end testers are invited to upload the file containing this data on the form containing the questionnaire. Unfortunately only 11 files with the data have been received.

According to the data collected in the questionnaire, 76.5% of the test were made using a stereo headset and the remaining ones using a set of stereo speakers.

Although the game was designed to be played with a gamepad, only 35.3% of the tests were made using one.

The questionnaire is composed by two main parts. The first part is related to the identification of the population and contains general questions about their person and their experience with video games and audio within them. The second part is related to the experience playing *Blind Nav*.

B. Population Analysis

Let's start with an analysis of the general characteristics of experiment partecipants.

When asked *"Select your gender"*, 82.4% of people selected 'Male', 11.8% selected 'Female' and the remaining 5.9% selected 'Non Binary'. This shows that our population is mostly composed of males.

Turning to the age of the population, to the question *"Select your age group"*, 58.8% answered 24-30, 29.4% answered 18-24, and 5.9% answered 30-40 and 40+ for both of these age groups. The population is therefore composed for the 88.2% of young people under 30, with however two samples with more of this age as well.

A high variance has been found in the population regarding the amount of hours spent playing video games weekly. In fact, 29.4% of the population answered 'between 3 and 7 hours' and 'between 7 and 14 hours' respectively. 35.3% answered '3 hours or less' and the remaining 5.9% aswered 'more than 14 hours'.

The next questions concern the experience of players with sounds in video games. Most of the questions require to answer with a number from 1 to 5.

To the question *"How important do you think sound is in a video game?"* 76.5% answered with a value of 5, 11.8% answered 4 and 5.9% answered 2 and 3 respectively. There is therefore a high average value of 4.56 with a fairly low variance of 0.74.

Despite the result of the previous question, to the question *"As a player, what level of attention do you put into sound effects while playing?"* the answers are distributed differently. In fact, 47.1% of the population answered with a value of 3, 23.5% with a value of 4, and 29.4% with a value of 5. We would have expected a higher average than that obtained of 3.81. The variance in this case was however rather low with a value of 0.77.

Other unexpected values were obtained with the question *"How incisive do you think sound effects can be in a player's orientation in a video game?"*. In this case the answers came back with a fairly fair distribution on the high values. 70.6% responded with a value of 5, 17.6% with a value of 4, and the last two samples with values of 2 and 3 respectively. In this case the average rose again to 4.5 and the variance remained equal to 0.75.

The last question of this section is about the experience of the population with 3D sounds in video games. When asked *"Have you ever used 3D audio functionality in a video game?"* 76.5% answered 'Yes', and the remaining 23.5% answered 'No'.

In conclusion it's highlighted how the population considers, on average, sounds as an important feature in a video game even though they admit to giving them little importance during their gaming sessions.

C. Experience Feedbacks Analysis

In this section I analyze the results obtained by the second part of the questionnaire relating to the thoughts of the testers about the experience lived playing *Blind Nav*.

The first question of the second part of the questionnaire is *"How immersive did you find the experience?"*. The results are concentrated on high values, with 41.2% of the population answering 5, 35.3% answered 4. 17.6% would score with 3 the immersion, and the remaining 5.9% with 1. The result is an average of 4.05 with a variance of 1.11.

The following questions are all focused on evaluating the difficulty encountered in the various aspects of *Blind Nav*. To the question *"How difficult did you find the experience as a whole?"*, 47.1% answered with 5, 29.4% with 4, 17.6% with 3 and 5.9% with 2. No one has assessed the difficulty with the minimum value of 1. These data clearly highlight the fact that the experience was rated, as expected, difficult, with an average of 4.17 and a low variance of 0.85.

The question *"How difficult did you find it to estimate the distance to the sounds?"* produced a lower average, with only 11.8% of the population responding 5, 41.2% answered 3, 35.3% answered 4 and 11.8% answered 2. This results in an average of 3.53. Here the variance is low as well, equals to 0.72.

We now discuss questions relating to obstacles. To the question *"How difficult was it to detect fixed obstacles through sound?"* the answers were very distributed, leading in fact to a variance equal to 1.35. 11.8% answered 5, 29.4% answered 4, 17,6% answered 3, 35.3% answered 2 and the last sample answered 1. The average is equal to 3. Given the high variance value it is difficult to draw an effective conclusion with so few samples, but it can be inferred that on average it was not excessively difficult to detect fixed position obstacles through their sound.

Regarding moving obstacles, the distribution concentrated more on the intermediate value of 3. To the question *"How difficult was it to trace moving obstacles through sound?"* 47.1% of the population answered 3. The answers relating to the other values are distributed fairly evenly, with 17.6% on answers 2 and 4 respectively, 11.8% on answer 5 and the remaining sample on answer 1. On average tracing moving obstacles through sound resulted to be 3.12 difficult with a variance of 1.

The next question is *"How difficult was it to keep track of environmental obstacles that don't make sound after hitting them?"*. The results show that the population found it more difficult to memorize the position of environmental obstacles that do not emit sounds than to identify those with an active audio source. 47.1% answered 4, 23.5% answered 3 and 5 respectively and the remaining 5.9% answered 2. The resulting average value is equal to 3.88 with a fairly low variance of 0.69.

The final question about difficulty is not about obstacles but about character control. To the question *"How difficult did you find character control and orientation?"* we got sparse responses. 35.3% answered 4, 23.5% answered 3 and 11.8% answered 5. Most of the population therefore found it relatively difficult to control the character, but 23.5% assigned a value of only 1, and one sample equivalent to 5.9% answered 2. In conclusion, an average of 3.05 was obtained, with a high variance of 1.82.

The last question about the experience is "How helpful did you find the *Helper Voice*?". 29.4% answered 5, 41.2% answered 4, 5.9% answered 3 and 23.5% answered 2. The average is 3.76 with a fairly high variance of 1.24. It is difficult to draw an actual conclusion given the responses received, but we can conclude that the *Helper Voice* was useful on average.

The last question contained in the questionnaire concerns the usefulness of *Blind Nav* in relation to its final purpose: the training of navigation skills in visually impaired people. To the question *"Do you think that an experience like this can improve the navigation skills for visually impaired people?"* 29.4% replied 3, 4 and 5 respectively, 11.8% replied 2. The answers show a fairly good trust by the population about the usefulness of *Blind Nav* as a training tool. The average value obtained is in fact equal to 3.76 with a variance equal to 1.

D. Usage Data Analysis

Blind Nav collects a series of data during the execution to evaluate different aspects of the experience. The data collected for each level are specifically the following:

- *Playing time*: the average playing time reflects expectations, having a higher average time on the third level and a minimum on the first one. In all the three levels two elements of the population are identified as outliers with times much higher than the others. The average in the first level is equal to 4m:37s but by eliminating the two outliers it is reduced to 2m:33s. The same occurs in the other two levels, passing respectively for the second and third level from 12m:18s to 5m:58s and from 14m:52s to 6m:18s. The variance is therefore very high, due to the fact that the difference in seconds between the times is often high. Also, there are very large differences between the outliers and the other members.

- *Amount of Dangerous Obstacles hit*: the count was separated between moving and fixed position obstacles. In the second level there are not moving obstacle, and for those of fixed position an average of 3.6 collisions was obtained. In this case, a single outlier with 14 collisions can be detected. By removing it from the calculation of the average, it is reduced to 2.44. The standard deviation is reduced from 4.1 to only 2.3. The data relating to the third level show no outlier and highlight how the moving obstacles have caused more difficulties than the fixed ones, with an average for the former equal to 1.89 hits and for the latter equal to 0.67. The standard deviation for fixed position obstacles is very small, equal to 0.67, while for those in motion it is higher, equal to 1.59.

- *Amount of Safe Obstacles hit*: also in this case the count was separated between moving and fixed position obstacles. The standard deviation obtained with the data relating to the second level is very high, equal to 23.3. This is due to the fact that half of the population obtained results lower than 10 with the minimum equal to 0, while the other half obtained values higher than 10 with a maximum peak of 85, showing an outlier. The average is equal to 18.30, but if the outlier is not considered, it reduces to 10.9. The standard deviation is reduced to 7.5 instead. The third level shows more regular results, with an average respectively of 1.67 and 1 for fixed and mobile obstacles. The standard deviation about fixed obstacles hits is equal to 1.83, bigger with respect to that of moving obstacles equal to 1.25.

- *Amount of Environmental Obstacle hit*: data regarding environmental obstacle hits have a similar distribution in all the three levels. High value averages are present as well as standard deviations. As expected, level 3, the richest of this kind of obstacles, is the one that has produced the most difficulties. Just to quantify, at the third level an average of 23.8 hits was made, with a standard deviation of 15.57.

- *Amount of warnings by the Helper Voice about staying in areas far from the target*: the results obtained are relatively low in all the three levels. As expected, the maximum peak of the average occurs in level 3, equal to 1.67 with a standard deviation of 1.41. This standard deviation value comes from the maximum peak relative to the single individual equal to 4 with however three individuals with a value of 0.

- *Amount of resets due to stay for too long in areas away from the target*: this data revealed to be not relevant as the values obtained are very low in all the three levels. In the third level, indeed, no individual has exceeded the value of 0.

- *Amount of warnings by the Helper Voice about the wrong direction of the character with respect to the target*: these data highlight an outlier in levels 2 and 3. The averages and standard deviations are respectively 3.6 and 4.82 for level 2; and 3.78 and 4.37 for level 3. Not considering the outlier, the values are reduced to 2.33 and 3.13 for level 2; and 2.75 and 3.46 for level 3. The standard deviation is however high because the values are divided between high and very low, with many samples equal to 0.

- *Amount of resets due to entries in areas not allowed*: in the first level there are no forbidden areas. In the second level there is a significant outlier, with 25 resets due to entry into forbidden areas. The average equals 3.9 with a standard deviation of 7.23. Eliminating the outlier results in an average of 1.56 and a standard deviation of 1.77. The results for the third level are more regular and even lower, with an average of 1.11 and a standard deviation of 1.37.

- *Amount of manual resets performed by the user*: the amount of manual resets performed by users is very low in all the three levels. This is due to the fact that the *Helper Voice* recommends doing it only after 3 minutes of not reaching a single target. The only relevant note that can be obtained is related to the fact that no member of the population has reset the character in level 3.

V. Conclusions

A. Users Suggestions and Comments

Almost all the users have highlighted the same issues:

- *Environmental Obstacles*: users have underlined the difficulty in identifying and memorizing, once hit, these obstacles. To solve this problem, the feature presented in the next point has been suggested.
- *Walking cane*: multiple users have suggested the presence of a simulated walking cane for the blind, which can allow the player to receive feedback about the presence of any type of obstacle before hitting them.
- *Perception of front and rear sounds*: the greatest difficulty highlighted in relation to the perception of sounds concerns the difference between front and rear sounds. During development this difficulty was clear, and in fact the game suggests the player to take advantage of the rotation in place to perceive the direction of the front and rear sounds. This problem related to sound rendering with HRTF model is known and several solutions have been presented in the literature [18].

B. Final Thoughts

In this paper I have proposed and analyzed *Blind Nav*, a tool to train visually impaired people in their navigation skills through play. Although the experience was difficult on average, the data regarding immersion underline that I achieved the result to reproduce a situation as close as possible to reality. The test population has in general appreciated the experience and has positive thoughts about *Blind Nav* as a tool for training navigation skills in visually impaired people.

Players have managed to orient themselves quite well with just the use of 3D sounds. Character control in the game has not been found particularly difficult, but it can certainly be improved with the use of more advanced technology such as a VR headset that perfectly fits the HRTF model for sound perception. The *Helper Voice* was able to accompany players from start to finish without anyone ever getting stuck in the game. This is the greatest success achieved by *Blind Nav*: the possibility of using an interactive gamified software in total autonomy without any graphic component. Many improvements can be made also in this aspect, such as better feedback from the *Helper Voice* regarding *Environmental Obstacles*.

The greatest difficulties were found in tracing the environmental obstacles that do not emit sounds and in estimating the distance from the sounds. In particular, many users have highlighted this last difficulty more with regard to Target Voice. This is due to the fact that the curve of his audio source is very different from that of the others, as it must always be possible to hear his voice, even at a certain distance. This fact results in less difference in volume and sound perception as you get closer to the *Target Voice* source.

More in-depth tests with an ad-hoc setup and with a more abundant population would be needed to draw more concrete and useful conclusions.

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