Audio-Visual Thumble (AVT): A low-vision rehabilitation device using multisensory feedbacks

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***Abstract*— Since the 70s sensory substitution devices have been used for blind individuals to compensate for the lack of vision and enable them to perceive environment through intact sensory modalities. In this study, we present a rehabilitation device called Audio Visual Thumble (AVT), which is a small ring-like device with LED and buzzer, that can be worn on pharynx. We focus on a unique group of low-vision individuals with a black spot or scotoma in their visual field due to a disease called Macular Degeneration. The visual localization abilities of these individuals are highly impaired due to developing scotoma. We recently showed that also their audio localization skills are impaired [9]. Rehabilitation techniques developed so far for Macular Degeneration focus on visual modality only. Since audition can also be used to improve their spatial skills, we developed the AVT device. It permits to associate the multisensory information (audio and visual feedbacks) coming from the device with the own movement (proprioceptive feedback). We propose that the AVT has the potential to help people with visual dysfunctions to improve in the identification of audio and visual targets outside or at the edge of the residual visual field. AVT could be used for a wide range of applications combined with classical rehabilitation techniques in Macular Degeneration patients.**

***Clinical relevance*— This device can be an effective addition for low-vision rehabilitation experts and can be used combined with classical rehabilitation methods.**

I. INTRODUCTION

Around four decades ago, Paul Bach-y-Rita and his team published a short article that presented an idea that people deprived of one sensory modality (vision, for example) can gain access to the missing sensory information, thanks to another intact sensory modality, by transforming the missing data in the remaining one [1]. Bach-y-Rita believed that *We see with our brain, not with our eyes,* and he proved this in his later works that if another modality provides the missing information, our brain is capable of calibrating itself to translate the transformed information. Brain is a multi-sensory organ hardwired to integrate the data coming from all sensory modalities to perceive the environment. For example, in absence of vision, several studies showed that the visual cortex is recruited by the auditory cortex to represent audio- spatial information received [2], [3], [4]. As intuited by Bach-y-Rita and colleagues [1] the concept of seeing through the brain has been taken ahead and nowadays blind people can ì use specific assistive rehabilitation devices to improve their environmental perception. For example, the ABBI" (Audio Bracelet for Blind Interaction), provides audio feedback and enable blind children to explore their body dimensions in space [5]. Another device is"The vOICe", which converts visual information from images into audio information for blind people [6]. Similarly [7] it have been presented a device for blind individuals, the "EyeMusic", that can convert visual information into tactile information. This integration of sensory information in these devices is used as rehabilitation technique for visually impaired people.

Taking the idea further in this work, we are presenting a new device called Audio-Visual Thumble (AVT), for individuals with Macular Degeneration (MD). People with MD develop a central scotoma or blind spot on their retina, causing irreversible damage to it. This blind spot creates a visual bias towards the residual healthy visual field, whereas an audio bias is present in these individuals by attracting sounds towards the blind spot [9]. To-date, the focus of rehabilitation for MD is mainly towards visual modality only. Among the typical rehabilitation techniques used for MD, there are the assessment of residual functional retina and vision [10], [11], identifying preferred retinal locus (PRL) and training for its active use as a pseudo fovea [12][13], and certain rehabilitation programs offered at specialized centers for specific skills like driving or education [14], [15]. These examples are just a few from the extensive research already in progress for this disease. However, the use of multisensory integration for rehabilitation has not been practiced yet, and to our knowledge, AVT is the first rehabilitative device for MD patients that uses multisensory feedbacks.

The AVT is a device that incorporates auditory and visual feedback, using a high integration buzzer and a high brightness red LED, respectively. The device is created to be worn on a phalanx, preferably the index, to allow people with visual dysfunctions to practice developing the ability to identify targets outside or at the edge of the visual field, associating the multisensory information coming from the device with the own movement.

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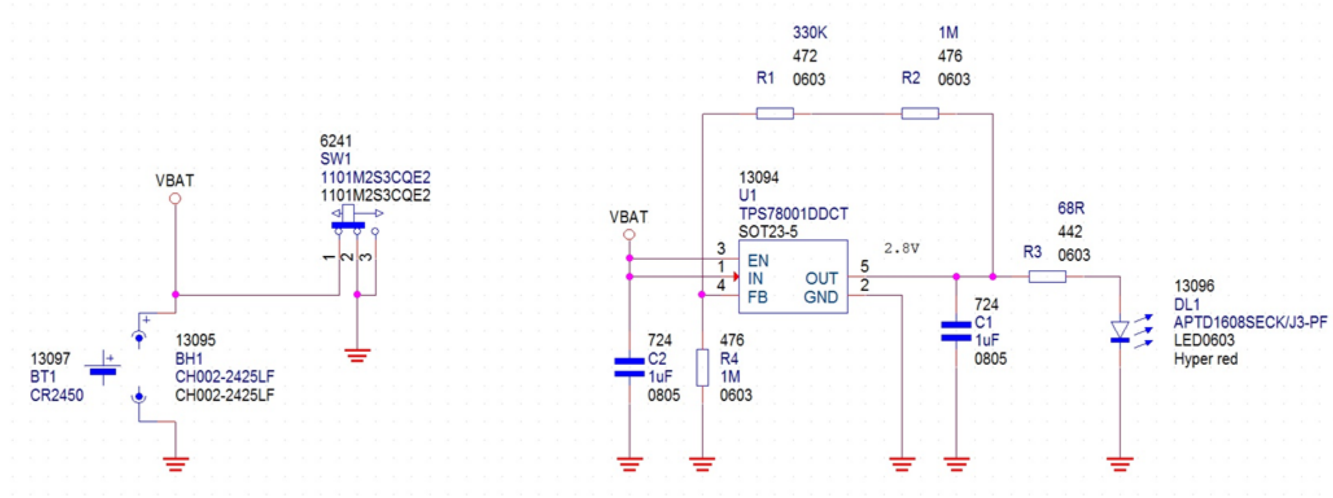

Fig. 1. Schematic diagram for AVT device

II. Design and Working

AVT integrates two disposable 3V tablet batteries, a Buzzer (SMA-13 multi-application buzzer, sound pressure = 75 dB, operating voltage = 1.5 to 24 Vdc, operating current = 1.8 mA) integrated inside a driver to generate the square wave necessary for the production of a Tone and a red LED with high brightness (SMD chip LED lamp, 1.6 x 0.8 mm, 4W, Hyper red). The schematic diagram for AVT circuit is shown in Figure 1.

The device's front and back side are encapsulated with biocompatible material. The system has two buttons, one to operate the LED and one to operate the buzzer both in continuous mode. The system can be installed on an index, middle or ring finger using a velcro strap that must be made a pass through the tabs located at the bottom of the device. The system uses two CR1220 type batteries. Once activated, the device produces a sound tone and a red light near the end of the phalanx.

A. Device Modes

Figure 2A shows a detail on the switches, in particular on the switch for the LED (L) and for the buzzer (B). At the bottom of Figure 2A, the switch activation configuration is shown. When the switch is on facing downwards (towards the rounded edge at the bottom of the LED) it is considered inactive (OFF). Vice versa, when the switch is positioned upwards it is considered active (ON). AVT allows selecting whether to activate only the LED or the LED and the buzzer together. To select the desired mode it is necessary to refer to the following table (Table I), which shows all four possible combinations of the switches, and the operating status of the device.

B. Battery replacement

AVT is equipped with a plastic case that can be opened in order to allow the exchange of the batteries. The batteries are considered exhausted when the LED light fades and the sound produced from the buzzer decreases in intensity until the battery is completely exhausted. As shown in Figure 2B, the battery can be easily replaced. On the back side of the device, the plastic housing slides to split the device into A and B parts (as shown in the Figure 2(B). Once separated, the twin batteries can be replaced by new ones by sliding the old ones under the pin as shown in the figure.

TABLE I
SWITCH MODES

L	B	Device Mode
OFF	OFF	Device turned OFF Battery disconnected LED OFF, Buzzer OFF
ON	OFF	Device turned ON Battery connected LED ON, Buzzer OFF
OFF	ON	Device turned OFF Battery disconnected LED OFF, Buzzer OFF
ON	ON	Device turned ON Battery connected LED ON, Buzzer ON

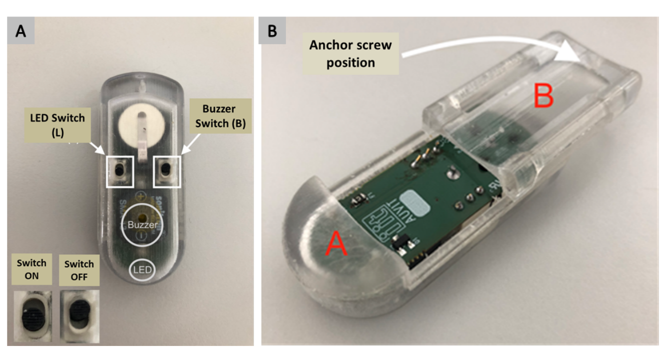

Fig. 2. A. Indication of the switches, B. Opening the device case to allow battery change

III. EXPERIMENT

AVT performance was evaluated on 5 individuals (mean age: 67.27 years, standard deviation: 17.16 years) suffering from Macular Degeneration with scotoma in their central retinal field i.e. within 40 degrees of the visual field. These participants signed the informed consent form before starting the experiment. Two kind of tests were used for the performance evaluation of AVT. (1). Audio localization test in which subjects were asked to localize sounds (white noise, 300 milliseconds) produced from one of the twenty-five speakers organized as a 2-D matrix (50 cm x 50 cm) of speakers [16]. ARENA was divided into central and peripheral regions (46 degrees and 97 degrees of visual angle) respectively, using the similar methods shown in [9] and [16]. 2). Visual localization test in which subjects had to identify the location of a flash (white dot on a black background) shown on a tactile screen. This screen was also divided into central and peripheral regions in similar fashion, as mentioned for the audio test.

Subjects performed the two tests twice before (pre) and after (post) a rehabilitation with AVT. During pre phase subjects performed audio and visual tests. During the rehabilitation phase, AVT was used to explore the squared space (70 cm x 70 cm) for 15 minutes. During the experiment, the subjects received multisensory feedbacks, by setting LED and buzzer in ON mode. Subjects were asked to follow a circular path and use their residual vision to see the LED while moving their hands (AVT on pharynx), also taking advantage of sound feedback from the buzzer and proprioceptive feedbacks with hand movements.

A. *AVT performance*

The performance of AVT was evaluated by comparing the results in pre and post training phase. For audio test, we evaluated the errors in the localization of sounds considering the central and peripheral regions. This choice was due to the fact that in one of our previous work, we observed that MD patients had an attraction of sound towards the center of their visual field. If the training would have effect we might expect a decrement of this attraction [9] and this is what we observed. The percentage of stimuli presented in center was 33.33% and in periphery was 66.67% respectively. The percentage of responses in each region was normalized using these percentage of stimuli for center and periphery respectively. Subjects performed significantly better in periphery, suggesting a reduction of the attraction toward the center (paired t-test, $t = 2.74$, $df = 4$, $p = 0.04$) after using AVT. As expected, the performance was not significant for central region for which the attraction was not evident (paired t-test, $t = 1.61$, $df = 4$, $p = 0.18$) as shown in Figure 3. Interestingly, we observed an effect of training also for visual test specific for the central field. Also in this case, AVT performance was calculated as the percentage of stimuli seen in each region as shown in Figure 4. A significant increase in seen trials in center (paired t-test; $t = 6.53$, $df = 4$, $p = 0.002$) was observed after the training. The percentage of seen responses remained unchanged in periphery for visual test (paired t-test; $t = 2.53$, $df = 4$, $p = 0.06$).

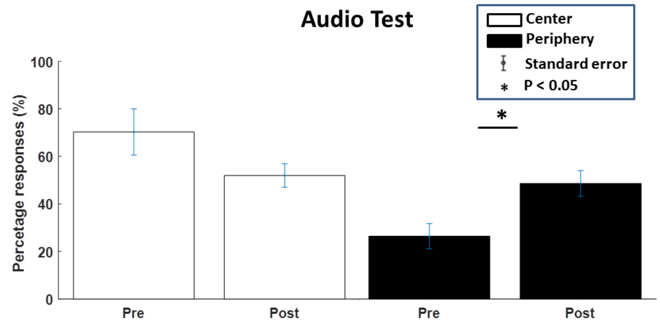

Fig. 3. AVT performance: Percentage of responses in central and peripheral regions during pre and post phase for audio test

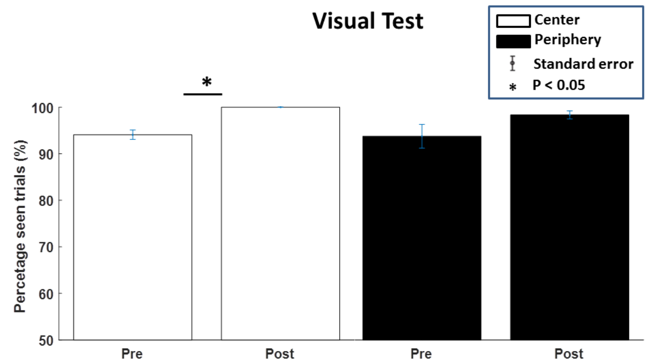

Fig. 4. AVT performance: Percentage of responses in central and peripheral regions during pre and post phase for visual test

These results for AVT performance show that AVT was effective in decreasing the central attraction in sound localization [9] (increased performance in periphery). Using AVT rehabilitation also increased performance in the visual localization of the stimuli presented in the central visual field. This result suggest that after a concise training with AVT patients improved their audio and visual localization abilities. A possible speculation is that the training activates some spatial attentional skills which makes subjects aware of their surroundings by providing multisensory feedbacks.

IV. RISKS AND PRECAUTIONS

The AVT device has an intrinsically low risk of harm to the user, because it is made using watertight switches, is low voltage, has case protection and consists solely of an LED, an oscillator circuit and a buzzer. Nevertheless, particular attention must be paid during use to avoid malfunction and actions that may also cause a failure even serious damage to the user. An instruction manual is provided with the device and the experimenter has to take special care of risk and safety instructions, for instance, participants of this study were informed about these safety instructions in the consent form. To avoid, categorically the use of AVT when:

1) The user's upper limbs are wet. The hands, upper limbs and face must be dry or at most moderately sweaty.

2) The user is in the water even with only his lower limbs immersed.
3) The ambient temperature of the place of use is above 40 degree Celsius.
4) The ambient temperature of the place of use is below -10 degree Celsius.

V. APPLICATIONS AND FUTURE

AVT is a preliminary device of its kind that is designed with an idea of providing rehabilitation training to individuals with visual impairments by integrating proprioceptive spatial sensory information With a very simple training, we found an improvement for audio and visual localization in MD patients. AVT could be incorporated with classical rehabilitation techniques for MD patients and it could prove to be a vital device in improving their spatial abilities. As the very first step, this idea could be led further to investigate the multisensory integration and rehabilitation for these patients.

There is a big room for improvements in AVT device. In terms of design, the device can be designed in a more user-friendly manner so that patients can use it at home as well. In terms of technology, though AVT is a very simple device, however, it can be incorporated with a smartphone to make it more customized, however, this idea could be a whole new research topic with further challenges like coping-up with the visual field challenges of these patients. Nevertheless, AVT is a first step forward, and we hope that it will open doors to new dimensions of rehabilitation for people suffering from visual impairments.

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Additionally, we declare that the authors have no conflict of interest in this paper.

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