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Do blind people move more confidently with the Tactile Radar?

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Abstract.
BACKGROUND: Individuals lacking or having impaired vision face serious difficulties during autonomous locomotion. Sensory substitution devices can contribute to alleviate such difficulties, significantly (and measurably) reducing anxiety.
OBJECTIVE: The present paper evaluates a device – the Tactile Radar (TR) – that can detect obstacles at a certain distance from the user and generate meaningful and unobtrusive tactile stimuli.
METHODS: We evaluate the impact of its use on the degree of anxiety that autonomous locomotion usually trigger on people who are blind.
RESULTS: Decreased anxiety as well as increased sense of safety and independence was observed on the tested subjects, through subjective (semi-structured interviews) and objective assessments (STAI inventories).
CONCLUSIONS: This device seems promising. More experimentation is needed to evaluate the capacity of the TR to enhance indoor localization and body placement with respect to walls and obstacles, as well as evaluation of the device in real life situations including outdoors. Last but not least, we need to consider ways of moving from a prototyping to a real production phase – of an affordable yet reliable device that can reach as soon as possible the interested population.

Keywords: Anxiety, feeling of security and independence, visual deprivation, sensory substitution device, autonomous locomotion

1. Introduction

The process of human locomotion feeds on data from spatial sensory organs as well as memory. Visuo-spatial information such as rotation, translation, direction, distance and place are key requirements for performing robust and independent autonomous locomotion. If, as stated by Sampaio et al. [1] early visual spatial experiences are key to the development of safe and independent locomotion, the anxiety and fear that accompanies the mobility of the visually impaired arise from the cognitive uncertainty generated by the lack of vision [2].

Although modal sensory reorganization and attentional shift somehow mitigate the problems stemming from the lack of vision, these are by no means extinguished. According to Clark-Carter et al. [3], 30% of the visually impaired (as recorded in the city of Nottingham, England) avoided leaving their homes to walk

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in their own neighborhoods. Although 2/3 of the surveyed were seniors, the authors of the study note that the locomotor impediment should not be attributed to old age but rather to fear and anxiety, since of the sighted elderly population, only 5% presented the same behavior. It is interesting to note however, that the feelings of fear and anxiety may not be always detrimental: when these are present in the background, they can enhance monitoring, attention and memory, only having deleterious emotional, social, cognitive and motor effects when extreme.

In the 70s, Bach-y-Rita and collaborators [4–7] created a Tactile-Vision Substitution System (TVSS) and showed how it could help a person who is blind to move safely and independently. This was achieved by channeling spatial information (normally only accessible through vision) to *proximal* sensory organs (i.e. touch). "Sensory substitution" techniques work by transforming the information captured by one sensory modality (in this case, the missing visual modality) into a form capable of being analyzed by the remaining sensory modalities (in this case, the tactile modality). Pereira and Kassab [48] point out the main advantages in the use of sensory substitution systems: 1) zero risk of infection (unlike implants); 2) application in patients with low vision and blindness from any etiology without limitations (as opposed to artificial retinas and direct stimulation of the visual cortex); 3) greater autonomy, allowing the removal for practicing sports such as swimming; and 4) lower cost and ease of use resulting in greater accessibility. Sensory substitution devices translating proximal information into audible sound waves have also been actively explored as Electronic Travel Aid (ETA) [8–10]. Understanding of relatively complex imagery is even possible using the vOICe [11,12] but its effective use seems to require hundreds of hours of training. Unfortunately, recruiting the sense of hearing interferes with an essential sensory channel for people who are blind. Moreover, images can be mapped isomorphically onto the skin surface, and therefore VTSS may require less initial training; this is of course the principle behind the Braille system and modern reconfigurable finger-displays [13,14], but the approach has been extended (following the pioneering work of Bach-y-Rita using the back and abdomen) to the forehead [15,16] and the tongue [17,18], both relatively flat surfaces apt to represent 2d images. Now, the sense of touch covers the entire body and proprioceptive information naturally fuses with it, so it is not necessary to rely on a flat surface to make sense of spatial information conveyed through tactile cues; moreover, touch can be naturally projected or "externalized" beyond the surface of the body, thanks to the phenomena of tactile distal attribution [19] as evidenced by the facility with which we manipulate physical tools (this, in essence, is why the cane for the blind is such an extremely intuitive device). Summarizing, we can say that TVSS fall into two categories: (a) those devices translating images (or 3d rangefinder point clouds) into a more or less complex 2d tactile stimuli [15–18], and (b) devices that descend directly from the distal-attribution principle of the cane, but implementing this in a subtle way using ultrasound or laser rangefinders units (hence the informal use of "radar" in their naming, to encompass non-aural echolocation systems). Integrating several of these units without necessarily forming a 2d image matrix may be a way of retaining the best of both strategies. A plethora of such devices have been studied and some commercialized [20–25], but prices remain relatively high. The aim of this study is to evaluate the impact of a new prototype of a visuo-tactile sensory-substitution, the "Tactile Radar" (TR) [20,21], on the level of anxiety experienced by people who are blind during autonomous locomotion. This device provides simultaneous spatial cues while at the same requiring very little or no training at all to interpret their meaning [20]. Last but not least, neither camera nor significant computing power is required to produce the sensorial translation, making it a good candidate for cheap production (including DIY approaches). A serious evaluation of this promising technology is in order though, and this is the aim of this preliminary study.

1.1. Vision for safe and independent locomotion

Voluntary or involuntary (i.e. automatic) motor behaviors such as those performed during autonomous locomotion are structured and guided by data captured by peripheral sensory receptors (perceptions) as well as by previous memories of those perceptions (mental representations). Independent and safe locomotion presuppose the existence of an active motor system, but also the presence of a specialized distal sensory system capable of gathering spatial information in real time; in this sense, sensory and motor systems are considered inseparable.

Gibson [26–28] showed that among distal sensory systems, vision, providing both exteroceptive and exproprioceptive information, occupies a prominent place. According to Imbiriba [29], safe and independent locomotion depends on both the capacity to localize objects in extrapersonal space (i.e., beyond limb's reach) and on the physical disposition to act in peripersonal space (i.e. the space immediately surrounding the body). While locomotion in peripersonal space is based both on information provided by distal sensorial modalities (visual, auditory and olfactory) as well as proximal sensory modalities (somatosensory, gustatory and tactile), locomotion in extrapersonal space is solely based on distal information, especially provided by the visual modality [2].

According to Moraes et al. [30,31], it is exteroceptive information (of shape and texture) that, by facilitating the location and identification of external stimuli, enables safe and independent planning and strategic spatial displacements on uneven terrain. Moreover, the works of Gobbi et al. [33] and Patla et al. [34] demonstrate that expproprioceptive information not only allows the identification and assessment of the speed and direction of different body segments with respect to the environment, but also with respect to each other. A large body of research has been conducted studying the relation between the visual modality and the possibility of safe and independent locomotor performance [35–43].

1.2. Complete visual impairment or blindness

The concept of complete visual impairment or total blindness covers two categories: *congenital or early blindness* (EB) which refers to people either born blind or who have lost vision before age 3, and *acquired or late blindness* (LB), which refers to people who lost their sight after three years of age, due to organic or accidental causes. The age of three is used as a landmark because by that time, structures and functions of the central nervous system such as the cerebral cortex and hippocampus (an important component of the limbic system implicated in spatial navigation tasks, consolidation of short-term memories, as well as symbolic and cognitive processing tasks) are stabilized [44]. Therefore, knowing when the loss of vision took place is critical to assess the configuration and cognitive arrangement that guides autonomous locomotion. While most late blinds (LB) strongly rely on remnants of visual memories over the evidence provided by their other sensory modalities, the early blind (EB), lacking those visual memories, base instead their autonomous locomotion only on the information provided by their remaining sensory modalities (tactile, auditory and olfactory). Research on the cognitive processes involved during spatial orientation is usually conducted on blindfolded *sighted* individuals [45–47]. This is a convenient solution considering the relatively small number of people who are blind, as well as the difficulties in recruiting them. However, with regard to the emotional content, autonomous locomotion in the blind is fundamentally different from that of sighted people, particularly with regard to anxiety, as evidenced by the works of Clark-Carter et al. [3] cited above. Moreover, one can assume substantial differences between early and late blind. For example, when losing all vision, late blind need a complete cognitive rearrangement to capture distal information; this is not the case of the early blind whose cognitive arrangement is determined during the early stages of motor development. Such drastic change in the late blind may generate increased anxiety during locomotion.

2. Research tools

2.1. The "Tactile Radar" sensory-substitution device

The "Tactile Radar" (TR), aims to provide greater independence and security to the visually impaired during autonomous locomotion. It takes the shape of a headband containing five identical sensor/actuator modules. Three modules cover the front, and two cover the temporal regions (see Fig. 1). Each sensor/actuator module consists on an infrared rangefinder (SHARP GP 2Y0A02) and a small encapsulated motor vibrator right beneath the sensor (Mobile Phone DC Coin Vibrator Motor C1034 from Chongqing Linglong Electronic Co.). The rangefinder's beams form an invisible "protective umbrella" around the user peri- and extrapersonal space (Fig. 2). The rangefinders are capable of measuring the distance to any object regardless of their color (however, objects that absorbs significantly in the infrared may be harder to detect at ranges $>$ 1 m). A microcontroller (ATMEGA168) continuously samples the output from these rangefinders (at about 30 Hz), and convert them into appropriate levels of vibration (details below). A small plastic box contains all the circuitry, including the microcontroller and a rechargeable battery (conferring autonomy of a couple of hours), is attached to the back of the headband (Fig. 1, right). The microcontroller checks the battery continuously and, when the battery power is critically low, shut down the motors and signals this with a continuous beep on a small piezoelectric buzzer (this helps maintaining a consistent level of vibration during the whole experiment).

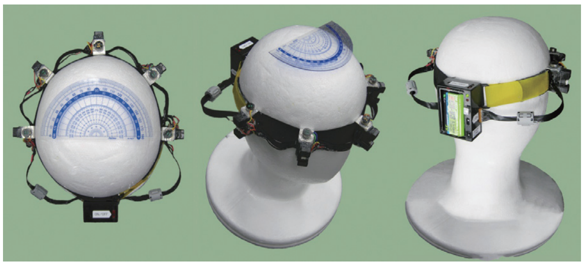

Fig. 1. View of the TR without its protective tissue, exposing the five sensor-vibrator modules covering the frontal and temporal regions, and the battery pack in the back of the head (right). (Colours are visible in the online version of the article; http://dx.doi.org/10.3233/TAD-140414)

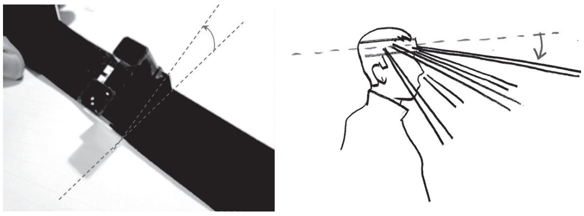

Fig. 2. A slight downward inclination (about 30 deg) avoids having the rangefinders pointing upward most of the time: the TR thus forms a sensorial protective "umbrella" around the user's peri- and extra-personal space.

The TR device can operate in four different modes set through a pair of switches: (1) long/short range, and (2) discrete vs. continuous vibration. In short range mode, the maximum detection distance is 60 cm, while in long range mode, the maximum detection range is about 1 meter, thus covering the intimate/personal space of the user (this was a design feature to render the experiment repeatable – in fact, the rangefinder used is capable of a slightly larger reach, at the expenses of a noisy signal). "Discrete mode" means only three vibration levels (for instance, in short range mode these correspond to a maximum vibration for an object at a distance < 30 cm, a medium vibration for an object in the 30–60 cm range, and no vibration at all when the obstacle is at a distance > 60 cm). "Continuous mode" is not really continuous, but instead corresponds to a total of 6 levels (in short range) or 9 levels (in long range), with a strength decreasing linearly with the distance. In our experiments the TR was set to "long range" and "discrete mode". A third switch enables/disables five LED indicators (one per module, see Fig. 3). These are useful for the experimenter (to check whether or not an obstacle is being correctly signaled.

In this sensory substitution device each module acts as an invisible "micro-cane" (or an artificial whisker or antenna). When an obstacle is in the range of the sensor, the corresponding module vibrates. This informs the visually impaired – quickly and intuitively – about the direction and proximity of an obstacle to be avoided. The width of the invisible light beam projected by the rangefinder remains very narrow all along its path; this pushes the user to *actively* scan the environment through a series of exploratory (head or body) movements.

Fig. 3. The TR with its washable protective tissue, also showing the LED indictors (one per module). (Colours are visible in the online version of the article; http://dx.doi.org/10.3233/TAD-140414)

Fig. 4. The subjects walked in a corridor (21 m long × 2.70 m wide) with hanging obstacles (all at head level) built from Japanese paper (spheres) and Styrofoam (rectangular boards).

2.2. *State/Trait Anxiety Inventory (STAI)*

Developed by Spielberger et al. [49,50] and translated and adapted for use in Brazil by Biaggio et al. [51], the State/Trait Anxiety Inventory (STAI) is a self-filling psychological inventory that quantifies both state and trait anxiety using two scales: the (STAI-T) and (STAI-S) scales. Based on the definitions of Cattell and Scheier [52], the Trait Anxiety scale STAI-T (simply TA in this study) quantifies anxiety as a permanent aspect of personality (i.e., how much the subject is constitutionally anxious), while the State Anxiety scale STAI-S (SA in the present study) is more specific and punctual, quantifying anxiety as a sporadic and transient manifestation that the individual experience in certain situations and context. Stuart and Laraia [53] distinguish four different levels of anxiety: 1) low, 2) moderate, 3) high and 4) very high. A low/mild anxiety favors cognition, increases perceptual attention and motivates learning and creativity; moderate anxiety on the other hand addresses immediate concerns, thus directing the subject's attention to the areas of greatest threat and producing selective inattention. High anxiety, by focusing attention exclusively to the areas of greatest treat, would produce a significant reduction of the perceptual field, preventing the subject to be aware of any other relevant stimulus. Finally, very high anxiety would elicit a sense of dread, terror and fear, causing the loss of self-control and incapacitating the subject for proper handling of any cognitive activity, even under external guidance. The STAI score of low anxiety corresponds to about 20–34 points; mild anxiety to 35–49 points; high anxiety to 50–64 points, and finally 65–80 points indicates very high anxiety.

We relied on both STAI scales to evaluate the potential that the TR has in generating a feeling of safety in visually impaired subjects during a locomotor test (we monitored the experience to ensure that this feeling of safety was indeed a consequence of an *effective* increase of safety – e.g. the subjects *did* avoid the obstacles). The TA scale enables us to evaluate and compare the anxiogenic profile of the subjects of the two subgroups. The SA scale on the other hand helped us understanding and comparing how the use of the sensory substitution device TR affected the reactive, transient anxiety of the same subjects at two different times: before (SA1) and after (SA2) the use of the device during the experiment.

2.3. *Sample characterization*

The sample population consisted on 42 visually impaired subjects (students, faculty, or staff of the Benjamin Constant Institute of Rio de Janeiro) divided into two subgroups: 20 early blind (EB) and 22 late blind (LB) – see Table 1.

2.4. *Interviews*

To find out how the subjects from each subgroup evaluated their own locomotor performance with and without the sensory substitution device, semi-structured interviews were conducted at the end of the test. A broad range of topics were brought up during the interviews, among which the nostalgia of the visual function; the difficulties caused by the lack of locomotor independence and the feeling (and the reality) of insecurity; the white cane stigma and the prejudices about visual impairment; expectations and suggestions to the use of the TR.

3. Procedure

All the recruited volunteers signed a Free and Informed Consent (read to them by the researchers). Then, they verbally answered a socio-demographic questionnaire (age, marital status, education level and current employment situation) and completed the scales TA and SA1 of the State-Trait Anxiety Inventory (STAI). The locomotor test took place right afterwards. After a brief explanation of the operation principles and a 3 to 6 minutes period of assisted discovery with the device (e.g. placing their own hands around the headband, moving the head near a wall, etc.), the subjects walked two consecutive corridors (21 m long $\times$ 2.70 m wide). One corridor was devoid of obstacles, while the other was furnished with 7 overhead obstacles (light and flexible) placed randomly along the walking path (three 100 $\times$ 50 cm Styrofoam rectangular placards, and four spherical paper-lanterns 60 cm in diameter). The subject's task was to walk as quickly as possible following a straight line, while avoiding collision. Orientation was maintained thanks to an audible "beacon" at the end of the corridor (similar to the audible pedestrian signals used to make street crossing safer for individuals who are blind). The TR was set to "long range" and "discrete mode" (see §II). After the locomotor test, the subjects completed the SA2 scale, and responded to the semi-structured interview. This work was approved by a Research Ethics Committee (CEP/ISECENSA), with number CAAE–3746.0000.413-10.

4. Experimental results

4.1. *Trait Anxiety (TA) and State Anxiety (SA) tests obtained before (SA1) and after (SA2) locomotion using the Tactile Radar*

Regarding Trait Anxiety (TA), both groups fell within the moderate anxiety range; the early-blind group showed a lower degree ($\bar{x} = 37.6$, $\sigma = 9.98$) of anxiety compared to the late blind group ($\bar{x} = 40.9$; $\sigma = 8.72$). However, this difference was not significant $t_{(40)} = 1.15$ ($p = 0.26$). As for the State Anx-

Table 1
Socio-demographics of the participants

		Early Blind (EB)	Late Blind (LB)
Age		33.3 years ($\sigma = 16.4$)	51.14 years ($\sigma = 13.26$)
Sex	Female	7	6
	Male	13	16
Marital status	Single	12	6
	Married	6	12
	Divorced	2	3
	Widowed	–	1
Level of education	Illiterate	3	2
	Elementary School	4	12
	High School	9	7
	Higher Education	4	1
Occupational status	Active	17	8
	Inactive	3	14

iety (SA) measured *before* the locomotor experiment (SA1), both groups were also in the moderate-anxiety range; the group of the early blind showed a lower score ($\bar{x} = 34.9$, $\sigma = 8.1$) compared to the group of late blind ($\bar{x} = 35.27$, $\sigma = 10.11$). The result is reversed when the anxiety is measured after the locomotor experiment (SA2): the early blind group showed an anxiety level ($\bar{x} = 33.5$, $\sigma = 8.8$) higher than the late blind group ($\bar{x} = 29.82$; $\sigma = 8.1$) – both falling in the mild-anxiety category. The inferential analysis (ANOVA) indicates, however, that only the lowering of the level of anxiety observed in both groups after the locomotor experiment (SA2 $= 31.40$, $\sigma = 8.5$) when compared to the level of anxiety presented before the experiment (SA1 $= 35.12$, $\sigma = 9.13$) is statistically significant: $\mathrm{F}_{(1,40)} = 8.19$, $p = 0.006$. No significant differences were observed for either the blindness factor ($\mathrm{F}_{(1,40)} = 0.38$, $p = 0.53$), nor for the interaction between blindness and SA1/SA2 ($\mathrm{F}_{(1,40)} = 2.8$, $p = 0.16$).

4.2. Qualitative analysis of the interviews conducted after the locomotion test

4.2.1. Difficulties caused by lack of locomotor independence and nostalgia of the visual function

Although all the visually impaired participants mentioned having problems with autonomous locomotion, this difficulty was greater in the case of late blinds. This involves in particular a feeling of impotence and social dependence, as well as "nostalgia" of the visual function, as evidenced by the following comments: LB-20 "*totally dependent on others, even to go to the bathroom I go with someone, because I hadn't made a mental map of my house [. . .]*" (translated transcript.[1]) LB-16: "*I walk with the help of my wife. Just stay at home. I go out only with her*". LB-29: "*Locomotion is always with my companion*". LB-33: "*Always accompanied by someone [. . .] or someone from the office would drive [. . .] I always took an employee, another problem that bothered me a lot, was that the boy would wait for me. Even knowing where I was, at a relative's house or club, I would just sit. Sometimes I wanted to go, for example, to the bathroom, or even to the diner counter, but I could not go – that fear of hitting tables, of bumping into people. I would stay there, kind of embarrassed. Because, say, my wife would not be there, went to see my daughter. [. . .] I end up being kind of alone, wanting to do something and. . . I have to wait*". As for the nostalgia of the visual function, LB-8 comments: "*too bad, because, [I] didn't want to ask for anybody's help, and I would just try to see the place where I was, but actually I wasn't seeing a thing*". LB-10 (completely blind, age of 40): "*people are very attached to what they see. They often look but see nothing. Today I am sure that I look at everything; I don't see, but I see [..] a depression on the floor, its texture, everything: I use my feet. . .* ".

In these responses we see evidence for the value of vision for locomotor performance, and the difficulty faced by late blind to substitute the visual sensorial modality with any other remaining (like touch, hearing and smell). While some strive to recover a sense of vision using other sensorial modalities, most rely and find solace in the help provided by seeing companions.

4.2.2. Prejudices about visual impairment; the white cane as a stigma of blindness

The use of the white cane and the blind condition itself were often considered in a prejudiced way, both by

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[1] All translated transcripts are in italics in the text.

the early and late blind themselves: EB-40: "*The blind is a curious breed. They want to touch, to seize everything. [. . .] After many years I lost a little of the fear, of the prejudice I had regarding the cane*"; EB-47: "*those normal fears of going out in the street and such, of assuming the cane, the shame of the cane – I felt some of that too. Embarrassment of facing a person with the cane and having to ask for information: sometimes the person would avoid me, sometimes not. . . Those [are] normal street situations*"; EB-44: "*I didn't want anybody to know that I am visually impaired, because, well, I am a very proud person, so I thought that it ruined my image: [I hear expressions] like 'the four eyes' guy*"; LB-17 "*People sometimes say: ah! There goes the poor blind guy, and such. And this brings me sadness. So, sincerely, I do everything I can to avoid using the cane, but unfortunately I am obliged to. The cane, in this case, is the stigma of the blind".*

4.2.3. Expectations in the use of RT

Recurrent topics brought up by subjects after the experiment with the TR included comments on how this device could help them moving around safely by avoiding obstacles and preventing accidents, achieving independence and having the freedom to get around in unknown places, increasing the perceptual field, and even regaining the capacity to *walk straight*[2]: LB-40: "*Apart from indicating danger that might be coming up, it always warns us to avoid some 'thing'. That's important [. . .] This thing, I didn't expect it to be so good, no. . .* "; LB-27: "*Of this device I expect not to be scared of the street; being able to cross the street, which is what I am not able to do*"; LB-50: "*A lot, it helps a lot, because the accessibility that I was telling you about; [the cane] unfortun ately wouldn't help me overcome many obstacles, such as a pay phone, a newspaper stand, and this thing will help us a lot*"; LB-16: "*Ah, judging by what I tested here, it helps me follow the path [and] avoid obstacles*"; LB-20: "*To detect obstacles that are above our waist, that the cane cannot find. I found it interesting. Cool. Ah, I felt good, with a sensation of freedom!*"; LB-29's wife: "*I thought it was great because at home [..] even to go to the bathroom he bumps his head, takes the wrong path [. . .] Comparing to how he does at home, he did very well!*"; LB-17: "*My expectation? It's that people in our situation can feel practically independent*"; LB-2: "*Perhaps my biggest problem is walking in a straight line, because I always walk in zigzag, right? But with this device, we perceive that you can't go towards specific sides*"; LB-28: "*Orienting myself to the left, right, I have no coordination –you saw that–, then, for me, it can help in orientation*"; LB-7: "*It will give us the ability of resolving things without depending on anybody [. . .]*"; LB-10 "*I think it will be one more instrument for us, blind people. . . Capable of giving us more autonomy*"; EB-19: "*It can be useful [. . .] Very good. Great*"; EB-24: "*Being able to go out whenever I like – I like going out, I have to do my things, I live alone, right? I expect that. That it helps me do that*"; EB-31: "*I think it helped me avoid many high obstacles which you wouldn't be able to perceive with the cane*"; EB-32: "*I felt like 'walking in the clouds'* (The researcher asks: *"why walking in the clouds?"*) *Because, you know, to walk like this in the middle of the corridor without. . . without hitting anything, that was magnificent.*"; EB-34: "*Damn, I felt very secure, you know? And. . . not to disdain the cane, it was a lot safer, because I could avoid things without touching anything.*"; EB-47: "*Ah, it felt cool. . . and talking about walking even better because for any obstacle, be it from the sides or in front, it warns you [. . .] it's a lot better, really, I felt good, I really felt good.*".

4.2.4. Restrictions and suggestions for the improvement of the TR sensory substitution device

The early blind (EB) offered most of the criticism and improvement suggestions concerning the TR. Among their suggestions and criticisms we find: the need for the device to offer a greater variety of vibration; the need for an extended coverage of the body, especially in regions vulnerable to locomotion accidents (e.g., the legs), in particular if this device is to be used without the cane; the need for a period of training/learning for taking full advantage of the device capabilities; the need of a switch on the device to alternate between two complementary working modes: detection of presence of obstacles, or detection of *absence* of these (thus indicating a clear path); the need to expand the device's perceptual range at will, making possible greater security – and peace of mind – while planning a body response; the need to minimize the discomfort of the vibration in the head; the need to ensure the effectiveness of the device when used outdoors, where the user is confronted simultaneously

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[2] The TR does not provides any explicit directional cue as in the *feelSpace* wearable device [55], but a heightened sense of orientation may be the byproduct of a more consistent placement in space with respect to external physical references. That being said, the TR could also integrate a magnetic compass, a GPS or even a light sensor to provide a global sense of orientation.

with many other (and varied) stimuli; and finally the need to reassure the subjects of the seriousness of this research and the future availability of this sort of device. EB-31: "*I thought it was very good but I think [...] the vibration could be subtler when the obstacle is moving away. It could have a greater variation in vibration because sometimes you can be far and think that the obstacle is near and you walk hesitantly without having to, sometimes.*"; EB-36: "*Well, if one day one could have a device like a cloth capable of detecting things around us. Even the obstacles nearer the ground. Maybe one day?*"; EB-41: "*I think it will be hard, for example to walk in the middle of a crowd, both having the cane and the radar, then the radar will be vibrating all the time*"; to which EB-40 suggest an interesting solution: "*The idea could be to have a little key – actually several buttons – that you can press, for example, to change the reach of the tactile radar, but also, when you are in the street, in the middle of a crowd, then you can invert [its function] so that it will only vibrate when there is an open space, instead of vibrating when it finds an obstacle.*"; EB-20: "*I think it's pretty useful, but I think the head shouldn't be where it is. I don't know, it could be tested, for example, here in the chest, because the head, at least with me... it's tremendously uncomfortable, it gives me a headache after a while... and I used it for 20 minutes, imagine a blind person wearing this, 24 hours a day for a year.*"; EB-43 "*I feel safe. I think at least in a familiar environment or a test environment. I don't know if I'd feel like this on the street, but I feel safe as I walk, to the point that I don't need a cane to avoid objects that come toward me, because it vibrates.*"; EB-46: "*I'd like this to be really serious research....*"; EB-35: "*I think so, because it warns me a lot... I just think it's bad in my case because I have a very long step, and since it warns me sometimes too late I don't have time to stop sometimes.*"; EB-38: "*I felt good... There was a moment when I got a little confused, but then I feel it's a question of training with the device, because I was taking a vibration for another, and maybe I got a little disturbed and I just stood there, unable to decide [...] But then that's a question of habit?*"

5. Conclusion and future works

Although the TR in its present state may not be a complete substitute but rather a complement to the cane, the subjects recognized many desired features: intuitiveness, increased perceptual field in particular at the level of the head and shoulders (the TR naturally reproduces the effect of the "self-protection technique" – i.e. raising a hand at chest height and extending it forward at arm's length – used for navigating in an environment without a cane), facilitation of straight walking, avoidance of obstacles in real time, prevention of accidents, and enhanced freedom to get around alone. A decrease in State Anxiety measured *after* the locomotor test (SA2), compared to right before the test (SA1) reflects these positive (subjective) ratings. In accordance with the results of Fioravanti et al. [53], we also observed comparable scores of Trait Anxiety (TA) and State Anxiety (SA) – both in the moderate-anxiety scale. Aiming to tackle immediate concerns, the moderate degree of TA is described by Stuart et al. [54] as focusing the subject's attention to the areas of greatest threat, causing selective inattention. In the locomotion test, the "greatest threats" correspond to random obstacles presented in the walking path. The TR helped avoiding them and guided locomotion, suggesting that the low level of anxiety obtained after the test (SA2), is directly linked to the use of TR.

In conclusion, this device seems promising. Many of the improvements suggested by the visually impaired subjects themselves during the semi-structured interviews are already implemented (e.g. the freedom to place the sensors and/or actuators in different parts of the body, for instance on the legs, leading perhaps one day to a robust substitute to the cane), or are underway, including changing the response function of the device so that the vibrators will signal an open space instead of obstacles or changing the detection range at will (the range was arbitrarily fixed to 1 meter to limit the number of independent variables in the experiment); better mechanical decoupling of the vibration motors; and rhythmic –pulsed– stimulus instead of continuous vibration to prevent fatigue and sensory adaptation.

More experimentation is needed to evaluate the capacity of the TR to enhance indoor localization and body placement with respect to walls and obstacles, as well as evaluation of the device in real life situations including outdoors (we have already conducted informal experiments around the building, but since this was a preliminary experiment we were extremely concerned with safety). Future works include hardware improvements and modifications, of which an important one is the reduction in size and possible integration with clothing (hats, shirts) to make the device as low profile as possible, further reducing psychological stigmatization. An intriguing possibility in that direction involves the use of a radically different actuation mechanism using "muscle wires" (shape memory allows) that not only could be interwoven with the cloth's fabric, but may be capable of applying pressure and shearing to the skin, better mimicking the feel of a real hair or whisker and possibility even indicating the (relative) direction of motion of the obstacle. Last but not least, we need to consider ways of moving from a prototyping to a real production phase – of an affordable yet robust and reliable device that can reach as soon as possible the interested population.

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