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Vibro-Vest: Directional Information in Three Dimensions*

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***Abstract*— Directional information given in three dimensions, and sensed through vibrations via an array of vibrotactors placed around the torso, has been investigated previous to this paper. To append upon the current knowledge base, a new design iteration of the vibrovest was developed and tested for its intuitivity and efficacy. Pursuant to this endeavor, a Vibrovest with 16 vibrotactor motors, arranged in an array, was used to communicate 66 distinct angular regions, evenly spaced upon the surface of a perceptual sphere. Five participants were asked to test the device by first familiarizing themselves with it, via manipulation of a Phantom Omni spatially representative of the directions communicated through the vest, and then by being asked to determine a set preconceived spatial directions that were subsequently imparted upon them . Results showed that the design had high inuitivity and accuracy, as was intended, but could still be improved in its implementation and application. Of the 55 total trials, 81.8% of the directional guesses were within one angular region of the actual communicated direction. The ANOVA results also showed no significant difference between test subjects, but did show a significant difference between two of the 11 directions tested. Lastly, two sets of two adjacent angular regions were tested while being of different sequential separation. One set of adjacent regions was tested consecutively, while the other was tested with a sequential separation of 7 tests. Neither set was found to be mutually, or internally, significantly different from the other. This was interpreted as indicating that sequential separation played no significant role in the accurate identification of angularly adjacent regions.**

I. INTRODUCTION

In many situations involving a high dependence on visual input in order to safely and effectively operate machinery, or navigate a high stress environment in general, the decision making ability of the operator can be degraded as a result of visual overstimulation. To address this issue, other means of communicating information to the operator, through perceptions other than visual, have been, and are continuing to be, developed. Recently, a vibrotactile waist belt was tested in its ability to convey GPS navigation information to various operators via vibrational signals [1]. The test showed positive results and served as a proof of concept for future design iterations. Essential to the viability of such a system is the need for the understanding of vibrational information to not interfere with the understanding of visual information. According to a human information processing model developed by Wickens and Liu [1988], the addition of a new stream of information to a preexisting stream will not interfere with its internal processing, where the term internal is with respect to the human attempting to interpret the information, as long as it is communicated via a separate sensory channel. Under this assumption, our aim is to develop and test a vibrotactile vest which can convey directional information in three dimensions. Such a vest can be useful to operators whose visual channels are already near overload and whose tasks involve spatial awareness, as opposed to planar awareness. Serving as an extension to the vibrotactile waist belt, the Vibrovest will use an array of vibrotactors placed on both the front and back of the torso. Although encoding distance and direction into the perceptual space of an individual is a worthy endeavor, the focus of this current paper will be only to convey directional information.

II. PREVIOUS WORK

Torso displays have been used to convey directional and movement information to users. Previous works include the concept developed by Van Erp on the transmission of directions through a vibrotactile torso display. Van Erp includes in his work a concept in which stimuli on the torso can represent directions to be followed [2,4]: front is front, right is right, etc, also known as the tap-on-the-shoulder principle. The research and experiments were first performed inside of a 2D plane. Van Erp subsequently developed a vibrovest system intended primarily for helicopter pilots. This system was developed in response to, and was tested against, spatial disorientation and positional drifting encountered by pilots while using night vision goggles [3]. The vibrovest was used to convey spatial directions to the pilots when unnoticeable drift led to spatial deviations from a static waypoint at a given altitude. The results showed an increase of performance in subjects in regards to both maneuverability and dexterity. The vest did, however, contain a large number of vibrotactors, which numbered 64 in total.

III. DESIGN

A. Vest

The vest had several design requirements which needed to be taken into consideration. For instance, the vest needed elasticity so that the vibrotactors would remain in contact with the subjects skin and would not change orientation or location as the vibrotactors were actuated. The vest also needed to be able to be worn over another persons shirt, thereby reducing invasiveness during its presentation, and needed to be quickly attached and detached to the persons torso without necessitating pulling the shirt over each new subjects head. Thus, a New Balance sleeveless workout shirt was used. As can be seen in Fig. 1, the shirt was cut along one side, including the shoulder strap, so that Velcro straps could be added to secure the enclosure of the shirt. The actual shirt, with the vibrotactors and the control board connected, is visible in Fig. 2.

By combining the actuation of various vibrotactors within the array, various directions could be communicated. As can

Fig. 1. Concept vest. The blue dotted line is where the fabric was cut.

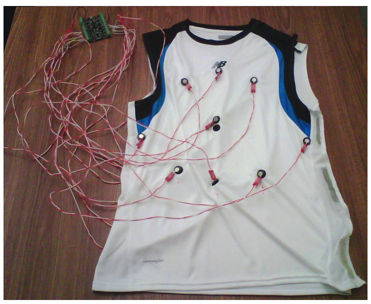

Fig. 2. The actual vest used in the experiment.

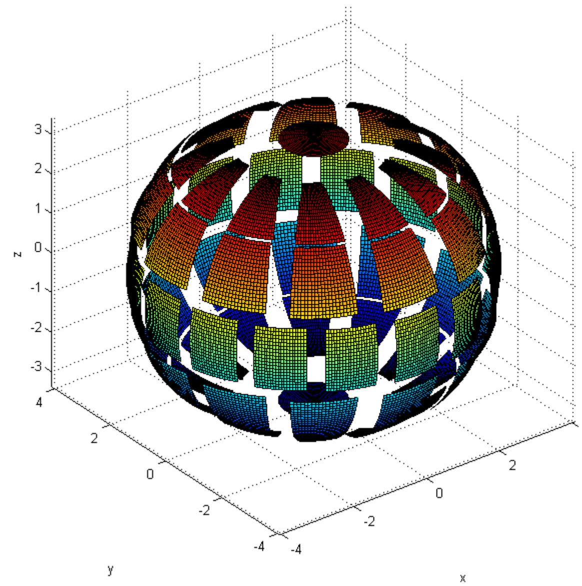

Fig. 3. The angular regions able to be communicated by this particular design.

Fig. 4. The Phantom Omni used to impart an intuitive understanding of the vibrovest angular regions.

be seen in Fig.3, a total of 66 angular regions could be encoded into the actuation routines of the vibrotactors. These regions covered the surface of a sphere and increased in resolution at the horizontal mid-plane. This increase in resolution was intentional and is justified in acknowledging that, indeed, most of our world is organized and communicated via the perceived horizontal plane. Building locations, floor maps, city maps, and even military CIC satellite operations displays place particular emphasis upon perceiving the world with respect to this horizontal plane.

B. Vibrotactors and Control Board

As can also be seen in Fig. 2, a total of 16 vibrotactors were added to the vest and were distributed as shown. Visible in Fig. 2 is the front side of the vest. The back side of the vest has exactly the same pattern. In designing the vibrotactor distribution, the tap-on-the-shoulder principle was taken into consideration. This principle states that localized vibrations on the torso can transmit spatial or directional information. It was our hypothesis that a curving of the upper and lower sets of vibrotactors would lead to higher intuitivity in the recognition of vibrationally transmitted spatial directions.

The vibrotactors were controlled via a Phidget Interfacekit control board, which was comprised of 16 input/output channels and allowed for simultaneous control of each vibrotactor. Being compatible with the C++ programming language, this control board connected, via wires and butt splices, to 16 All Electronics Mini-Pancake Vibrating Motors (CAT# DCM-707). Able to ouput 5 Volts DC, the control board was ideal for our purposes.

C. Vibrotactors and Control Board

D. Programming

As mentioned previously, the C++ programming language was used to communicate with the control board. As can be seen in Fig. 4, the SensAbles Phantom Omni was also used to communicate spatial directions to the C++ program. A series of conditional statements, concerning the spherical coordinates of the end effector tip, were then used to actuate various series of vibrotactors. By generating a virtual sphere, whose radius was 2 cm and outside of which a counterforce would be produced whose vector was always directed towards the center of the sphere and whose direction was antiparallel to the spatial direction communicated through the vibrovest, the Phantom Omni played a pivotal role in acquainting the test subjects with the design and its intentions. By simply moving the omni stylus around the sphere, participants and test subjects alike were able to train themselves in interpreting the spatial information which the vibrovest was communicating.

IV. EXPERIMENT

Five male subjects, between the ages of 23 and 28, volunteered to perform the experiment. Two of the subjects had never used the Phantom Omni before, and were not familiar with the study of haptic devices at all. The remaining three subjects had worked with the Omni device before and had received education in the theory and design of haptic devices.

Each subject was fitted with the vibrovest and then allowed to familiarize themselves with the purpose of the vest by manipulating the omni. They were each instructed to pay particular attention to certain directions, such as straight up and straight down. They were then instructed to move the omni around both vertical and horizontal directions in a circular fashion. This was done so that encountering almost all of the possible angular regions was assured and, consequently, an intuitive understanding of the design could be quickly built. Lastly, the subjects were instructed to recognize the fact that several vibrotactors being actuated simultaneously meant that the intended direction was in the centroid of the sensation.

After the familiarization routine was completed, the subjects were then given a ball which detailed and numbered each angular region. As can be seen in Fig. 5, the indication ball serves as a means for the subject to indicate to the experimenters the direction which they perceive from the vibrovest. After having been instructed in the use and purpose of the indication ball, the subjects were then given a series of spatial directions via the vibrovest. As can be seen in Fig. 6, a total of 11 spatial directions were communicated to each subject in the sequence as numerically illustrated. After receiving each spatial direction, the subjects were then instructed to use the indication ball to give their best guess as to the direction which they felt. The subjects were then given a score which represented the number of angular regions their guess differed from the actual region which was intended. This resulted in scores of 0, 1, 2 and 3. Here, zero is the best score and indicates that the subject guessed the exact region that was communicated to them. A score of one indicates that the subject guessed an angular region which was adjacent to the one communicated. A score of two indicates that the subject guessed two regions away, etc.

As can also be seen in Fig. 6, two sets of adjacent regions were tested at mutually differing sequential separation. To be explicit, Direction #3 and Direction #10 are adjacent regions and were tested seven steps apart in the sequence. On the contrary, Direction #5 and Direction #6 are adjacent regions as well, but were tested one right after the other. This was done to investigate whether or not sequential separation and spatial separation were significantly correlated, as pertains to this design in particular, but possibly to the concept of the vibrovest in general.

V. RESULTS

As can be seen in Table 1, the data collected from the five subjects contains 22 zeros, 23 ones, 9 twos and 1 three. This data was then analyzed using an ANOVA. Shown in Table 2, the ANOVA exhibits a significance threshold of = 0.05 and a confidence interval of 95%. Investigating Table 2 further, one can see that there is no significant difference between test subjects, as also shown in Fig. 7, but there is a significant difference between regional scores.

Fig. 5. The "indication ball" used to communicate the directions that the subjects felt to the experimenters.

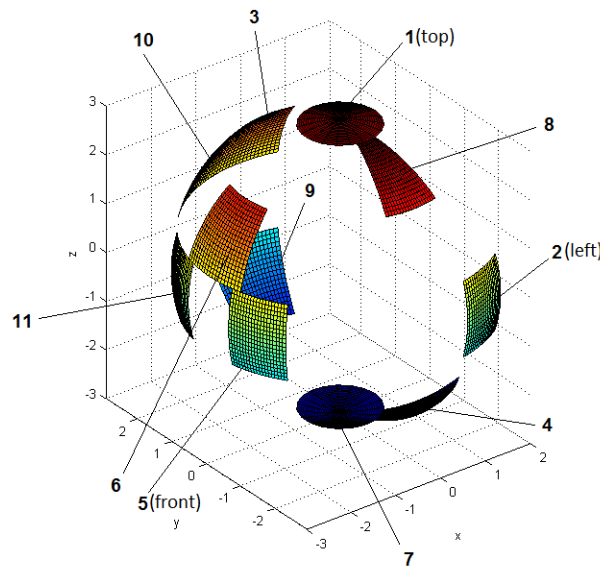

Fig. 6. The angular regions tested for each subject. The numbers correspond to the sequence in which they were tested.

As can be seen in Fig. 8, this difference occurs only between the very best scoring region (a near zero cumulative score) and the very worst scoring region (a cumulative score of 9). The rest of the regions exhibited insignificant mutual difference. The major contributing factor to this error is likely the implementation of the design instead of the design itself. In order to accommodate individuals with larger torsos than the average person, a larger sized vest was chosen. This led to areas of slack in the vest when it was applied to individuals with smaller torsos. A slackened area in the vest does not transmit the vibrations of the vibrotactor to the subjects skin as well as areas of the vest which are taut. In this way,

TABLE I

THE EXPERIMENTAL RESULTS. THE SCORES REPRESENT THE NUMBER OF ANGULAR REGIONS, AS INDICATED BY THE SUBJECTS, AWAY FROM THE COMMUNICATED REGION.

Direction	1	2	3	4	5	6	7	8	9	10	11
Subject	Regional Distance (1 = a single angular region away from that intended)										
1	1	2	1	3	0	0	0	2	1	1	1
2	0	0	1	1	1	1	0	2	0	2	1
3	0	1	1	2	1	2	1	1	1	0	2
4	0	0	1	1	0	1	0	1	0	2	0
5	0	0	0	2	0	1	1	1	0	0	0

TABLE II

THE ANOVA RESULTS COMPARING SIGNIFICANCE BETWEEN BOTH SUBJECTS AND DIRECTIONAL NUMBERS TO THE ACCURACY SCORES.

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
subject	3.8909	4	0.97273	2.25	0.0809
dir-num	11.6	10	1.16	2.68	0.013
Error	17.3091	40	0.43273		
Total	32.8	54			

certain directions are relatively doomed to failure when using an elastic, one size fits all, place over any type of shirt the subject may be wearing vest. Keeping the exact same vibrotactor array, but allowing trials in which the subject was to place the vibrovest directly over his skin would almost certainly eliminate this difference.

Also visible in Fig. 8, one can see that there is no significant difference between the accuracy of consecutively sequenced adjacent regions and sequentially distant adjacent regions. This seems to indicate that there is no correlation between angular perception and sequential separation. Also, except for one fly in the ointment, so to speak, the ANOVA results seem to indicate that there is no significant difference, in terms of accuracy, between the tested angular regions. This adds to the argument that the tested design has indeed succeeded in achieving an intuitive perception of spatial directions.

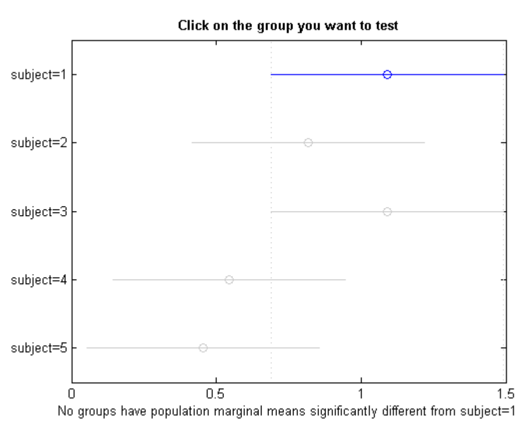

Fig. 7. The ANOVA comparisson between test subjects.

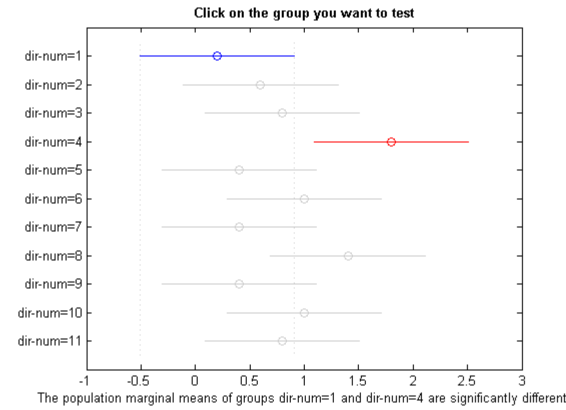

Fig. 8. The ANOVA comparisson between directional regions.

VI. CONCLUSIONS

The tested design iteration of the vibrovest shows promise. We designed an experiment that would demonstrate the inherent accuracy of the design and its intuitivity. Considering the design constraints of a wearable, noninvasive, one size fits all, over the shirt vibrovest, the actual design, and not necessarily its implementation, seems to achieve its intended objectives. Of all the scores measured from the test subjects, 55 in total, 81.8% of them were within one angular region of the intended direction and 40% were exactly the same as the intended direction.

There also seemed to be no correlation between the sequential separation of adjacent directions and their angular perception, as communicated via localized vibrations. A lack of significant difference between the test subjects, even when three of the subjects were experienced with haptics, also lends credence to the integrity of the testing procedure and the conclusion that we have indeed made a design which, if properly and skillfully implemented, shows promise.

VII. FUTURE WORK

The experimental procedure could be improved in several ways. For instance, ear phones could have been given to the subjects to block audible perception. Hearing the vibrotactors could have been a contributing factor to the error. The wires connecting the control board to the vibrotactors also transmitted vibrations themselves. If not held above and beyond the persons body, they give false directional information to the subject. This could be negated by using a wireless actuation system or smaller gauge wires and a specialized fabric with a high enough damping coefficient.

The vest also needs to be adjustable to the user, at the very least. The same vibrotactor array would probably be best employed and tested by sticking each vibrotactor to the persons skin, thereby ensuring design integrity. Again, a one size fits all approach to this design is not nearly the best way to test its abilities.

Future applications seem only as limited as the imagination. From fork lift drivers, to crane operators, to jet pilots and UAV pilots, the applications and benefits of conveying spatial directions via nonvisual input channels will continue to be investigated and optimized for operators whose visual channels are already approaching overload.

This less is more approach to the vibrotactor array design shows that an intuitive system can indeed be employed which does not require cumbersome and numerous amounts of vibrotactors to convey quite nearly the same information.

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