Assessment of Tactile Languages as Navigation Aid in 3D Environments

Victor Adriel de J. Oliveira and Anderson Maciel(✉)

Instituto de Informática (INF), Universidade Federal do Rio Grande do Sul
(UFRGS), Porto Alegre, RS PO. Box 15064, CEP 91501-970, Brazil
{vajoliveira,amaciel}@inf.ufrgs.br

Abstract. In this paper we present the design and evaluate alternative tactile vocabularies to support navigation in 3D environments. We have focused on the tactile communication expressiveness by applying a prefixation approach in the construction of the tactile icons. We conducted user experiments to analyze the effects of both prefixation and the use of tactile sequences on the user's performance in a navigation task. Results show that, even if tactile sequences are more difficult to process during the navigation task, the prefixed patterns were easier to learn in all assessed vocabularies.

Keywords: Vibrotactile communication · 3D navigation · User study

1 Introduction

Usually, the design of simple tactile vocabularies follows an approach known as "tap-on-shoulders" [6]. This approach can be exemplified by a tactile sensation printed on the side of the user's body that is facing a particular target or obstacle, for example. This approach adds an iconic factor on the tactile language because the sensation directly evokes the behavior [16]. However, other approaches work on arbitrary tactile patterns as a way to enhance the vocabulary expressiveness [4]. In order to create tactile languages with more expressivity we formalized the concept of Modifier Tactile Pattern for vibrotactile displays [12]. In vibrotactile displays it is possible to vary hardware parameters (e.g. frequency, amplitude, rhythm) to create different patterns. However, arbitrary variations may result in vocabularies that are difficult to memorize and process. The use of prefixation with modifier patterns could enhance the tactile vocabulary expressiveness keeping it easier to learn.

Prefixation is not a novel approach for tactile languages. In Braille, some signs are reserved to work as prefixes. Each prefix can be attached to a basic sign modifying its meaning. A modifier pattern however modifies the meaning of an entire tactile sequence or several sequences at once. The modifier tactile pattern on vibrotactile vocabularies should act as a flag. When activated, the user must comprehend other tactons in a different way. Such pattern can be displayed simultaneously with the basic tacton or sequence, following a compound approach, or can be attached at the beginning of the sequence as an ordinary prefix.

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In this paper, we present a user study we conducted to assess the differences between tactile vocabularies made by a prefixation and a non-prefixation approach. Fifty eight users were split in three distinct groups for a between-groups analysis. Results show how each vocabulary affects the performance of each group in a navigation task.

2 Related Works

Tactile displays are commonly made for a specific purpose. In mobility and navigation tasks, there are tactile vocabularies made to display instructions and directions for astronauts [15], militaries [9], drivers [1] and visually impaired pedestrians [3]. In all those works, only one set of tactile icons was designed and refined to a specific application. In this paper, we rather built three different set of tactons, so we could assess how the different choices affect the navigation task.

The parameters used in the construction of tactile patterns were presented earlier in the literature as haptic phonemes. According to Enriquez and Maclean [5], they represent the smallest unit of a constructed haptic signal to which a meaning can be assigned. We have explored the design of vibrotactile languages through a morphological point of view. Even without using the term “prefix”, its possible to find it in the methods for syntax development proposed by Brewster and Brown [2]. It is also used for construction of tactile messages in the Terne’s [14] research about the use and effects of rhythm. In this work, more than present a tactile vocabulary made by prefixation, we compare prefixed and non-prefixed vocabularies in order to assess the value of this approach in the user’s performance.

3 Methods

3.1 The Tactile Display

Concerning navigation, the perception we have about the location of our own body in the three-dimensional space is often referenced to the orientation and location of the relatively stable trunk of the body. Therefore, we designed a tactile display made as a belt (see Fig. 1).

Our belt was constructed with eight electromechanical tactors $ROB-08449$ (Amplitude Vibration: $0.8G$; Voltage Range: $2.5V \sim 3.8V$), each with 3.4 mm and positioned at equidistant locations. Other studies also presented vibrotactile displays made with eight motors for mobility and navigation tasks [1,11].

3.2 The Tactile Vocabularies

We designed three different vocabularies to aid in a 3D navigation task. We designed them to transmit five different kinds of information: Destination, Obstacle, Course, Warning and Itinerary. The availability of such amount of information allows us to observe to what extent they are essential for the navigation

Fig. 1. The vibrotactile belt. In the middle, a participant using the belt to navigate. In the right, a top view of a humanoid showing the vibrators positioned at equidistant locations around the waist.

task and also how each information helps a person to follow a better route. The five-step methodology of Riddle and Chapman [13] was used to design the tactile icons on three different vocabularies.

The *First Vocabulary* was designed following a conventional approach, based only on metaphors; the *Second Vocabulary* was designed following a Modifier-based approach, with patterns made by juxtaposition of tactons in sequence; the *Third Vocabulary* was also designed as a Modifier-based vocabulary, this time with patterns made by superposition in order to isolate sequence as an independent variable. Figure 2 shows a representation of tactons in each vocabulary. Only motors that can be used to compose the pattern are exhibited in each tacton.

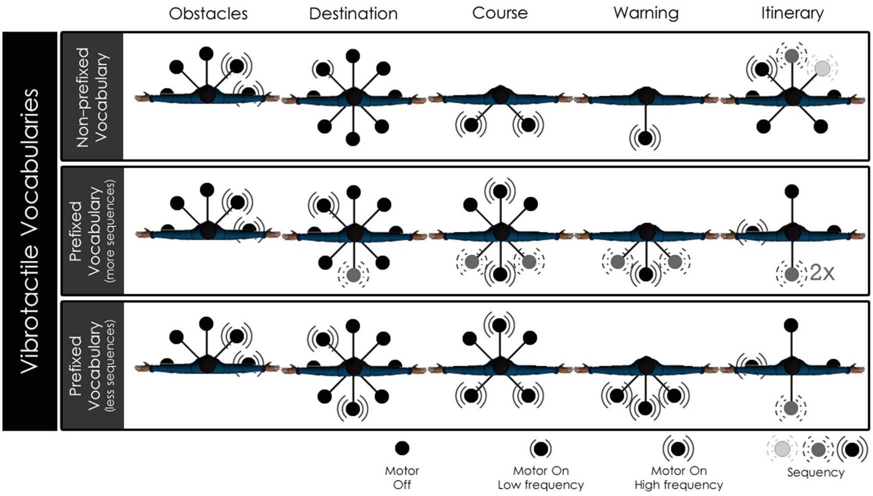

Fig. 2. Example of tactons in each vocabulary.

3.3 User Study

A population of 58 individuals have volunteered to participate in the tests; 47 are male and 11 females. The participants are students, covering an age range of 19–32 years. Testing was done in a dedicated room where just remained the volunteer and the researcher to best avoid distractions.

For a between-groups experiment, we divided our population into three distinct user groups that performed the same tasks but using a different vocabulary. The overall experiment took between 18 to 30 min for each participant.

After filling a pre-test characterization form, each participant was invited to wear the tactile belt and use a tutorial app. The tutorial is a step-by-step visual description of the vibrotactile language and the experiment. Then, each individual was exposed to tasks that evaluated their *perception* of the motors and their *interpretation* of tactons displayed by the belt. Finally, each user *navigated* through four different scenarios using the tactile belt. At the end they filled an evaluation form to give their opinions on the tactile vocabulary.

4 Results

In the preliminary *perception* test, many occurrences have been left unanswered for those patterns that were exhibited in sets of two and three motors. One-way ANOVA showed that there is a significant loss in the hits for patterns with many motors ($F(3.88) = 27.99$, $p < 0.00003$). As expected, in this task, the locations around the navel and spine provided the best correspondences. In a study about the perception of vibration across the body in mobile contexts, the stimuli delivered on the spine also was the one with the best results [10].

The results of the *interpretation* test have not presented significant difference between the vocabularies. However, the percentage of correct answers was lower for the second vocabulary (see Fig. 3).

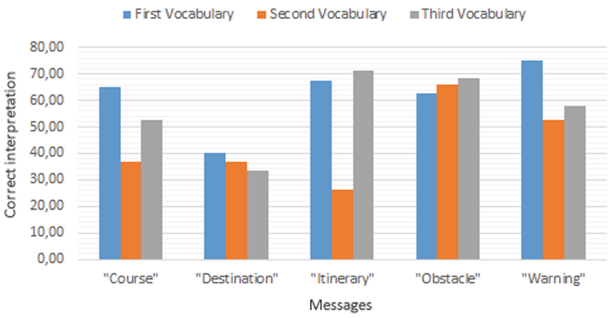

Fig. 3. Interpretation of messages by three different vocabularies.

In the *navigation* test, eleven users have shown to be outliers and were removed from the analysis. Ten of them reported to have felt significant nausea and dizziness during navigation, spending more than 2 standard deviations above the average or not being able to complete the task. The 11th outlier is one that spent more than an hour to complete the experiment.

In this test, each user navigated through four distinct scenarios that worked as levels of a game. The participants took a mean of 20 min to complete the whole task. The scenarios were displayed in a different order for each user, eliminating the effect of the scenario over the results. It is possible to observe the improvement of the three groups along the levels as their times and number of collisions decrease (see Fig. 4, left). With all vocabularies, users go faster at each subsequent level (see Fig. 4, right).

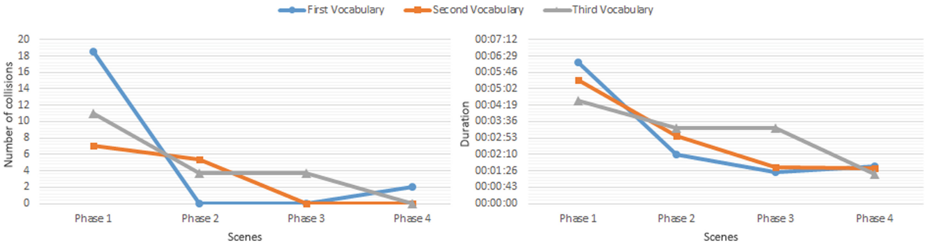

Fig. 4. User performance. Left: number of collisions in each level/scenario. Right: duration of the navigation in each level/scenario.

During this experiment, conflicts were observed between visual and tactile feedback. Most of the collisions occurred in the darkest part of the first scenario where the users could see the target very close ahead which encouraged them to anxiously ignore the tactile feedback and collide.

Figure 5 shows the mean time of each group. The group of the third vocabulary was the fastest, with a mean of 20 min (σ = 5 min : 31 s) to complete the whole task. The group of the second vocabulary took 21 min : 32 s (σ = 7 min : 35 s); the first group was the slowest with 22 min : 50 s (σ = 7 min : 03 s).

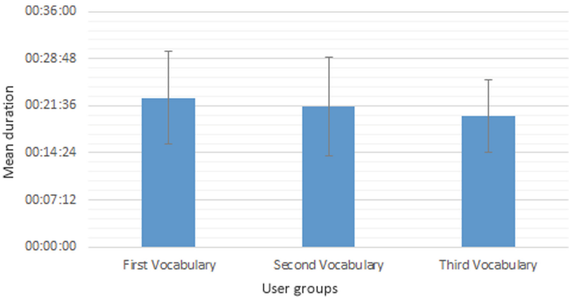

Fig. 5. Mean time to complete the task with each vocabulary.

The performance of the group with the second vocabulary in navigation was slightly better than the first group, even with more messages displayed as sequences. The users felt that the patterns in sequence were the most difficult to understand during navigation (see Fig. 6).

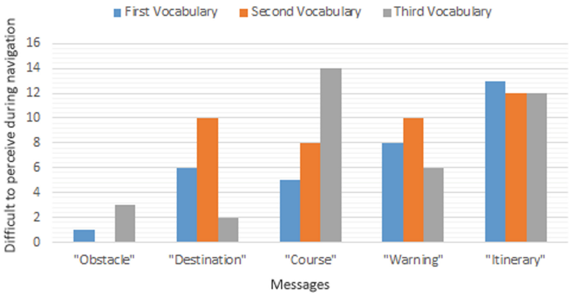

Fig. 6. Users opinion about patterns that were the most difficult to process during the navigation task.

Considering the duration and number of collisions during navigation, it can be seen that the group of the second vocabulary obtained the best results in some levels. The group that used the third vocabulary was the slowest at the third level and also the one that collided more at the third level. However, the third vocabulary had a great improvement at the last level.

5 Discussion

We proposed three different approaches to build a tactile vocabulary for navigation aid in VE. Our first vocabulary was made by varying hardware parameters as the metaphors to navigation. The other vocabularies were made with a prefixation approach. The prefixation was chosen to create tactons by the concatenation of a smallest set of tactons. The second vocabulary was made by printing one modifier pattern before the iconic representation of the information. And the third vocabulary was made by joining the sign to the prefix in order to make one single pattern for each information (except for the itinerary, that was made as a tactile sequence).

Hirsh and Sherrick [8] suggested that temporal processing can be broken down into two processes: the ability to correctly perceive that two events occurred (i.e. two strokes); and the ability to accurately judge which of two events occurred first. Thus, we know that at least two main issues are present in the tactile language processing: the processing of multiple stimuli at a time; and the processing of sequence of stimuli. Our first vocabulary is the one with more elements to recall. However, the first vocabulary is also the one with tactons made by composition of fewer motors at the same time. The second vocabulary was the one to address the sequence issue. The third vocabulary was the one with tactons made by the vibration of many motors at the same time.

In the second vocabulary four messages were displayed as sequences. The users felt that the patterns in sequence were the most difficult to understand during navigation. Sometimes the users did not even perceive the tacton during the task. The attentional blindness [7] may be the factor to explain this result. Several studies have demonstrated that attention dwells on a stimuli (visual, aural or tactile) for several hundreds of milliseconds. Therefore, it is common a person to wrongly report the existence or position of a second target of two targets displayed in sequence (Attentional Blindness). Many users understood the modifier, but could not perceive the direction during the navigation. Even with the sequence issue, the performance of the group with the second vocabulary in navigation was slightly better than the first group.

The third vocabulary achieved good results in the interpretation test and in the navigation task. The group that used the third vocabulary was especially slow at the third level. This bad result seem to be more related with the number of tactors activated simultaneously. In fact, the first task of the user experiment showed that the worst results were obtained from the perception of several motors at the same time. In the first task the users did not have to understand the meaning of the tacton; they had only to report the number and position of the active tactors. However, many users comprehended well the meaning of the tactons as seen in the second test.

6 Conclusion

We have studied three different choices in the design of a tactile language for 3D navigation. Analyzing the users performance we observed how it is influenced by tactile sequences and larger number of stimuli at same time. Even if the difference between the performances of the three groups was not statisticaly significant, the modifier-based vocabularies afforded the best results. Results show that, even if the processing of multiple stimuli at a time is more difficult, the way that the information was split into prefixation elements and iconic elements seemed to help the memorization. The results suggest a great potential for the modifier approach to be applied in the design of tactile interfaces.

The tactile language designed for navigation in virtual environments could also be used for navigation in physical environments. Therefore, our prefixal approach can be applied to render supplemental information when sight and hearing cannot be used, e.g., for orientation support in dark environments, as underground mines, or for the visually impaired, first person games for the blind and many others.

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