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Navigation in Virtual Environments: Design and Comparison of Two Anklet Vibration Patterns for Guidance

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1 Introduction

In this study, we present a preliminary exploration about the added value of vibration information for guiding navigation in a VE. The exploration consists of two parts. Firstly, we designed two different vibration patterns. These patterns, pushing pattern and compass pattern, differ conceptually in the levels of abstraction. Secondly, we undertook an experiment to compare the two patterns in guiding navigation in a VE. The objective of the comparison is to establish a baseline for examining the suitability of using vibration patterns to guide navigation.

2 Design of Vibration Patterns

Two different patterns were designed by using vibrating devices of Vibrotact bracelets.

2.1 The bracelets

We used the Vibrotac bracelets. Each bracelet is composed of six independent motors. The numbering of each motor is in spatial sequence, starting from the one under the large rectangular shape (the control box) of the bracelet. By specifying a voltage pulse with its width in time and its amplitude between 0.0 V and 3.0V, each motor can be activated to generate a vibration with a specified duration and intensity.

In our work, we used two bracelets. Instead of placing the bracelets around the wrists, we mounted them about the left and right ankles of a user. Both bracelets had the same vibration pattern to stimulate the anklets, so that the user perceived a guidance for navigation at both ankles. This montage of the bracelets took account the following considerations: (a) Navigation in a natural environment involves much more the legs/feet than the arms/hands; (b) The bracelets need to be kept stationary for guidance to allow the user' perception of the pattern without inducing extra motion; (c) The user needs to apply his/her hands to manipulate a path of navigation in a VE, as described in Section 3.

2.2 Pushing pattern

The pushing pattern for guidance consisted of two types of vibration. On a bracelet mounted about an ankle, one first type was a vibration on the back of the ankle while the user faced the direction of his/her movement. This type of vibration was to guide the user to move forward in the VE, resembling to pushing the user forward from his/her back of the leg/ankle.

The second type was a sequence of vibration to signal the user turning left or right. This sequence of vibration was created by the consecutive activation of the three motors in front of the ankle. Each motor involved was activated for 300 ms at a full intensity (100%). The interval between 2 cycles of sequential activations was 900 ms. The activation sequence running from the right to left side of the ankle indicated the user to turn leftwards. The opposite sequence of vibration signaled to turn rightwards. This type of vibration is comparable to grabbing the user by the leg/ankle to force a turn.

2.3 Compass pattern

In contrast, the compass pattern functions like a compass. The activation of a motor always pushed the user's leg/angle towards the direction that he/she needed to follow.

This pattern assimilates a vector of pushing forces to signal the correction of the user's moving direction. The activation of a motor was in the back of the ankle while the user faced the direction to follow. To follow the direction indicated by the activated motor, the user needed to feel continuously the vibration on the back of the ankle.

3 Experiment

We conducted an experiment to compare the pushing and compass patterns in guiding navigation in a VE.

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3.1 VE and path of navigation

We created a VE, where a user could promenade to navigate a grassy plain by using a pair of Razer Hydra game pads. Representing the walking of the user, a pair of shoes were displayed on the grassy plain. Under either of the pushing and compass patterns, the user needed to follow an invisible path of navigation. Although the user could not view the formation of the path, the path was configured as a sinusoidal curve with a period of 12 meters and 6 different amplitudes of 0.0 m, 0.3 m, 0.6 m, 1.2m, 2.4 m and 4.8 m. The path ran each amplitude for two periods, corresponding 24 meter.

3.2 Setup and protocol

We had obtained an ethics clearance following the Canadian Tri-Council Ethics Guidelines prior to begin the experiment, due to the involvement of human participants.

Before the experimental block, each participant underwent a pre-test block of 2 sessions. One pre-test session checked the participant for the color Vision, handedness, and footedness.

Another pre-test session verified the sensitivity of the participant to vibration. A participant, who could not sense different vibrations, was not allowed to undergo the experimental sessions.

The experimental block consisted of 3 learning and 2 testing sessions. During the first learning session, the participant acquired the skills of how to navigate in the VE using only the game pads. Then, the second learning session began. The participant was to learn one of the two patterns for guiding navigation

After the second learning session, the participant underwent the first testing session – to navigate the VE by following the guidance given by the learned pattern from the bracelets. There was no time constraint for the navigation, and the participant was instructed at his/her own pace to promenade in the VE. The actual trajectory and completion time of navigation were logged for data analyses later.

The participant learned another pattern of guidance from the bracelets in the third learning session and, in turn, carried out the second testing session to navigate the VE under the pattern.

After each session, the participant filled out a validated Simulator Sickness questionnaire. When each testing session was completed, the participant answered also a questionnaire about his/her way of navigation. The questionnaire had three bars corresponding to the following questions: (1). How well did the anklets guide your promenades? (2). How well was your response to the guidance of the anklets? (3). How well do you like the guidance of the anklets?

Half of all participants took the pushing pattern first, then the compass pattern; another half of the participants underwent the order of the two patterns in reverse.

3.3 Results and discussion

The experiment had a total of 11 participants. Three of them went sick and did not complete the experiment. Thus, we retained 8 participants, aged from 25 to 44 years old with a mean of 30 years old. Three participants were male and 5 were female.

From the logged data of each participant, we calculated the surface between his/her actual trajectory and the intended path that he/she should follow. This surface indicates how far the actual trajectory departed from the path. Half of the participants did better under the guidance of the pushing pattern than the compass pattern; whereas another half had an inverse trend.

On average, the surface for the pushing pattern was 54 ± 49 m²; while the surface for the compass pattern was 79 ± 45 m². After validate the normal distribution and variance equivalent conditions for the surfaces, a paired t-test gave $p = 0.427$, larger than the significance level $\alpha = 0.05$. Thus, there is no significant difference of the surface impacted by both vibration patterns.

However, the completion time of navigation had a different observation. All participant took more time to complete the navigation under the pushing pattern than the compass pattern. Under the pushing pattern, the completion time of all participants was 907 ± 69 s; while this completion time under the compass pattern was 659 ± 108 s. A paired t-test on the completion time revealed $p < 0.0001$, much smaller than the significance level $\alpha = 0.05$. Hence, there is a significant difference of the completion time between both vibration patterns, with the compass pattern 27% less time than the pushing pattern.

To calculate the precision that each participant followed the intended path, we defined the width of the path as 60 cm (equivalent to the shoulder width of an average person). In counting the length of the actual trajectory within the boundaries of the path, Eq. (1) yields the percentage of precision as follows:

$$\%\text{of precision} = \frac{\text{Trajectory length within the boundaries}}{\text{Total path length}}. \quad (1)$$

Thus, the ratio between the percentage of precision and the completion time gives a performance index, P, in Eq. (2) below:

$$P = \frac{\%of\ precision}{the\ completion\ time\ of\ navigation}. \quad (2)$$

On average, the performance index was 5.8 ± 1.1 under the pushing pattern, compared to 7.3 ± 1.3 under the compass pattern. A paired t-test on the performance index yields $p = 0.022$, lower than the significant level $\alpha = 0.05$. That is, the performance under the compass pattern is significantly better than under the pushing pattern.

In examining the response in the questionnaire about the participant's way of navigation, we observed that 6 participants preferred the compass pattern to the pushing pattern. Five participants reported more reactive to the compass pattern than the pushing pattern. This subjective preference agrees with the objective results of the completion time and performance index.

The above observations indicate that the compass pattern is more efficient for guiding navigation and is preferred by most participants. This indication is confirmed by the objective outcomes of the participants and their subjective perception. Thus, the compass pattern has a better impact on guiding navigation in terms of time and precision. Compared to the pushing pattern, the compass pattern might be more intuitive for the user. Under the compass pattern, the moving direction of the user is aligned to his/her facing direction. This alignment might reduce his/her cognitive workload to compute a moving direction. In contrast, the user needs to combine both forwarding and turning directions under the pushing pattern. This combination would increase his/her cognitive workload to compute a moving direction. Hence, the levels of abstraction are different for both pushing and compass patterns. The compass pattern is less abstractive than the pushing pattern.

4 Conclusion and Future work

This work revealed that the compass pattern yields better performance of navigation than the pushing pattern. This indicates a potential of using the compass pattern to facilitate navigation in VEs. Future work includes the refinement of the compass pattern for reducing cybersickness.