A Serious Game for the Learning of Vibrotactile Feedbacks Presented under the Foot: How Many and How Fast?

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Abstract. Vision and auditory channels are often used to convey information quickly. Knowing that hearing and vision are generally loaded with plenty of stimuli, the use of touch as an alternative medium of communication could unload those senses. Although many studies have been conducted on hapic icons or tactile icons, few of them have focused on the foot as a medium of communication. This paper particularly investigate the maximum number of vibrotactile messages that could be memorized when displayed under the foot. The method is based on a daily training wrapped in a serious game. In the latter, the avatar must be led to different locations through risky path. Risky events are displayed along the route through vibrotactile feedbacks, which have to be identified by the player. A preliminary experiment shows the usability of this serious game for learning a large number of vibrotactile stimuli.

1 Introduction

Several sensory channels can be used to communicate information quickly. For instance regarding the visual one, road signs allow a fast transmission of information about the roads. In the same way, auditory icons — or earcons — are commonly used in Human Computer Interaction to warn users about different events. Knowing that hearing and vision are generally loaded with plenty of stimuli, the use of touch as an alternative medium of communication could unload those senses. In [1] tactile feedbacks are used to provide better interactions with a mobile device. In a more general way, as their visual counterparts, haptic and tactile icons can be exploited for the haptic display of information [2,3].

Works on information rendering via tactile feedbacks have proved that the body part used for the presentation of the haptic stimuli plays a quite important role in the perception. Ternes et al. found that there is a noticeable difference in the perception when the stimulus is presented through the hand versus over the back [4]. As a result, several researches have analysed the perception of tactile information passed through the hand, the wrist or the back [5]. Nevertheless only few works have been focused on the perception of those stimuli when presented under the foot. Among them, they concluded in [6] that four different vibrotactile messages could be learned when presented by the inner sole of a smart shoe with minimal training. However, to the best of our knowledge, no study has yet

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investigated the maximum number of those messages that could be memorized when displayed under the foot. This paper aims at investigating this aspect throughout a serious game.

Particularly, the game wrap a daily training program that serves two main purposes. The first concerns the identification of the maximum number of *tactons* that a user could memorize when those are displayed under the foot. The second one is the improvement of the recognition speed of the vibrotactile messages. The paper is organized into the following sections. First, motivation of this paper as well as the related work are presented. Second, the proposed game is detailed. Finally, a preliminary experiment using this proposed game is described.

2 Motivation and Related Works

2.1 Motivation

Falls are a well known issue causing mobility loss of elderly. In fact, according to statistics, over one third of adults age 65 and older falls at least once a year, which cause 65% of injuries in this age group [7]. Moreover, falls may leave a psychological impact due to the fear of falling. Thus, beyond physical injuries, loss in confidence and reduction of mobility can also be consequences of a fall [8]. Despite numerous outstanding achievements of falls prevention programs, most of them do not provide a real-time monitoring of daily activities of users. Knowing that, an instrumented shoe was designed to detect potentially dangerous situations related to several risk factors, such as the gait abnormalities, the condition of the pavement and the fear of falling, to name a few.

One of the main components of an assisting system is to provide a signal harbinger of a potential danger. However, in a uncontrolled environment, vision and auditory channels are usually widely stimulated from external perturbation. Since in a potentially hazardous environment, a person's attention is usually overloaded with visual and auditory perturbations, the haptic is approached as a viable solution as a means of communicating a level of risk. Thus, to unload those channels, the designed instrumented shoes described in [9] is provided with actuator to convey vibrotactile messages to the user. As many risk factors may cause falls, many different vibrotactile messages have to be learned. In spite of several studies on vibrotactile perception, the maximum number of those messages that could be memorized when displayed under the foot is not yet assessed. This have thus motivated the conception of a serious game designed to test the ability of users to remember vibrotactile messages learned by a long-term training.

2.2 Related Works

Serious games related to healthcare are a widely studied subjects. One may note, as an example, the several games for upper limbs limb rehabilitation evaluated in [10]. In [11], they also proposed a serious game for rehabilitation of Parkinson

Disease patients. However, in spite of those numerous studies, few of them use the foot for healthcare related issues. Among them, recent papers focus on automatics balance tests. In [12], sensors incorporated in the sole of a shoe are used to assess balance on different type of soil of a maze. In the same way, in [13] a serious game for evaluating balance capability using the Berg Balance Scale is designed and evaluated. Finally, a serious game exploiting vibrotactile message applied for healthcare have been proposed in [6]. In the latter, the player navigates through a maze and must identify the soil related to the displayed haptic stimulus.

On the other hand, studies on vibrotactile feedback have lead to two particular designs: *haptic icons* and *tactons*. The first ones are complex vibrations which reproduce the impulse response resulting from the impact of physical objects, such as vibrations that occurs when a hammer is tapping on wood, iron or rock. In [2], they are defined as computer generated signals displayed through force or tactile feedback to convey information such as event notification, identity, content or state. Enriquez and MacLean propose guidelines for their design in [14]. The second ones, the tactons, are composed of a sum of sinusoids with a decay exponential envelope similar to a musical note. Introduced by Brewster et al. [3], they are described as structured abstract messages that can be used to communicate messages via vibration patterns. Guidelines for their design are presented in [15]. As an example, *tactons* can be formed by varying frequencies f_a and f_b in (1). One has to note that *tactons* will be used in the proposed game in order to limit the association between vibrotactile stimuli and real-life events (such as haptic icons).

$$Tacton = \alpha \times \sin(2\pi f_a t) \times \sin(2\pi f_b t) \quad (1)$$

3 Proposed Game

In this game, the user controls an avatar that must fulfil several displacements around the neighbourhood such as going to the bakery, walking to the bus station or going to the market. In this hazardous environment, instead of using visual icons to inform about inherent risks of the itinerary, vibrotactile feedbacks are used. In other words, during the avatar displacement, according to the risk level associated to the environment, a vibrotactile feedback is presented under the foot of the user. Will the user correctly identify the risk level associated to those vibrotactile messages?

The instrumented shoe described in [9] is used to convey the vibrotactile messages to the player. Moreover, to enhance the mobility, the game runs on a mobile device such as a smartphone or a tablet. The actuators (Haptuator, Tactile Labs Inc., Deux-Montagnes, Qc,Canada), embed in the sole of the designed shoes receive signal via the audio output of the used device as shown in Fig. 1.

Before describing the game in more details, it is important to state what challenges will the player face. To do so, there is two kinds of difficulty. Those are directly linked to the paper objectives. The first one, the difficulty level, concerns

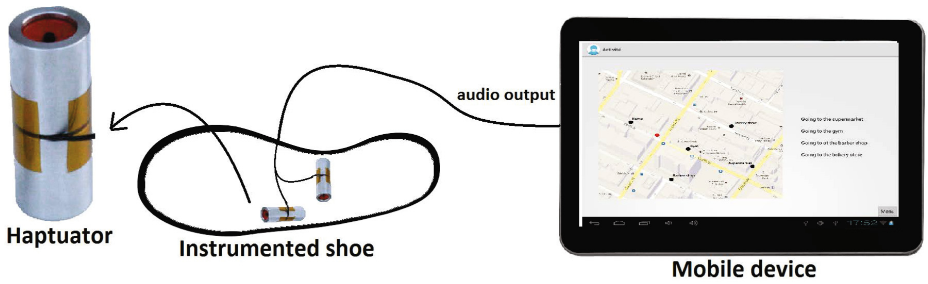

Fig. 1. Overview of the system needed to play the proposed game

the number of risk level to identify. Indeed, differencing vibrations as well as remembering their associated risk is itself difficult. Thus, increasing the number of vibrations to learn and identify will make the game more challenging. In the same way, getting the maximum number of *tacton* to learn could be acquired by monitoring the highest level reached by the player. The second difficulty, the time difficulty, is more subtle; it concerns the time allows for risk identification. In fact, identification will fail if the time taken for the risk identification is greater than the allowed time. This reaction time should decrease and be closer to the reflex response after the proposed training.

In the following sections, the main components of the game are first described. A summary of the playing sequences is then presented, followed by a discussion on how this game could reach the goal of the paper.

3.1 Main Components of the Game

To play the game, a user first have to log into the game to reaches the main menu. From there, an overview of its score is shown. Moreover, he has an access to three principal zones: the activities zone, the rewards zone and the *tactons* zone. Those three areas are where actions of the game take place. The first one is the most important: it is the memory training for the association between a risk and a tacton. The two other zones are where the players can relax and reminds risks and *tactons* association. Nevertheless, the three areas have an important role as described in the following.

Activities Zone. In the activities zone, the player is invited to select, one after the other, the four activities which his avatar should perform everyday. To do so, the player relays on the point and click paradigm; thus the player points the target destination on the screen. Upon selecting a destination, the avatar starts to walk. The movement is shown on the presented map as well as by an animation of the walking avatar. Showing such an information is important to reinforce the fact that the vibration is related to risk of falling level. In fact, it is during the path to the destination that the player is challenged. While walking by the path, risky events are displayed through vibrotactile messages under the foot. Once that happens, the player is invited to identify the correct risk level bounds to the rendered vibration. Along the path, four events are randomly selected, giving a total of sixteen vibrotactile feedbacks to identify per day. The score obtained is shown at the end of the day and saved for further monitoring of the learning curve. For each identification asked, the score is computed straightforwardly. If the risk is quickly and correctly identified, the player's score is increased by one. Neverthless, if the player fails to identify the risk or takes too much time for the identification, the score is not updated. To reinforce the learning process in case of a misidentification, the vibration is replayed and identification is asked again until a correct identification. In this case, the final recognition is not considered as a success in the score calculation. At the end of the day, once all the four activities are completed, the player receives rewards based on his daily score.

Rewards Zone. Daily rewards are what incite many smartphone game players to keep playing everyday. Since the proposed serious game features a daily training, the same idea is used to incite our players to keep assiduity in their daily training. Of course, as the fun is not the main objective of this game, the daily reward system is an additional attractive game element to increase motivation of the players. It is in fact an incentive for the daily chore the avatar has to perform. Kinds of rewards can include badges (or achievements), money or an increase of the total score. The player can exploit his reward in the rewards zone. The special reward system of the proposed game is, on his side, a bit different. It is based on a crossword puzzle where clues and words are given according to assiduity and successful identification. Indeed, upon completing all the daily activities, the player receives several information used to complete the crossword grid. It may thus take a few days to gather enough items to complete the puzzle. As an additional motivation, the puzzle is linked to the game difficulty. Thus, the number of risk to identify augments when a crossword puzzle is completed. This mean that to monitor the difficulty level, reward given after the completion of the daily activity should be carefully selected.

Tactons Zone. One has to note that there is a strong positive correlation between preference and successful identification of auditory notifications as described in [16]. Based on these results, it appears that the learning success rate could be greatly improved if the user can select the vibrotactile stimuli associated to risk levels. It is thus the main purpose of the *tactons* zone. In this area, the player can either display already assigned risk or assign a particular and unique vibration to a given new risk. This latter operation is of course a mandatory step for every new players. In fact, for every unassigned risk level, the player has to select among four vibrotactile messages the one that seems to suit best to the current risk level. The set of four *tactons* that could be associated to each risk is already sets by preliminary experimentation. Here, used *tactons* are designed according to the guidelines presented in [15].

3.2 Playing the Game

In short, upon logging into the game, a new player should first access the *tactons* zone in order to associate four initial risk to unique *tactons*. Afterwards, he can perform, on a daily basis, the evaluations associated to the activities zone. Once the activities of a day are completed, the player is rewarded. He may then access to the rewards zone in order to complete the proposed crossword with available words and cues. After a few days, the players should have enough information to complete the puzzle and so augments its difficulty level. As a consequence, two new risk levels will be added. Through the *tactons* zone, the player will have to bind the two new risks prior to continue his daily activities. The Fig. 2 shows the sequence a player should follow.

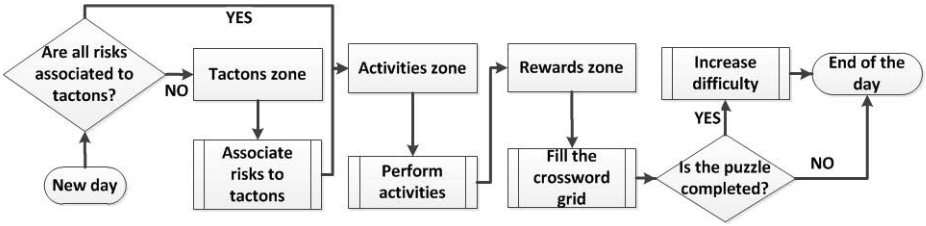

Fig. 2. Sequence of play a player should follow

While playing, time taken for identification is monitored everyday. If the player has a high success rate with a slow identification speed, the time allowed for identification will be decreased to encourage faster recognitions. On the other hand, if a low score is due to a lack of time for the evaluation, the amount of time will be slightly increased.

3.3 How Is the Contribution Reached through This Game?

In fact, difficulties of the game are set directly to achieve the game objectives, which is to identify the maximum number of *tactons* that a user could memorize and to improve the recognition speed of the vibrotactile messages. On one hand the increase difficulty level augments the number of risk level. Since this level is updated upon completing the crossword puzzle, the learning curve can be monitored by controlling the amount of clues and words given at the end of the day. The maximum number of *tacton* that could be memorized is thus equal to the maximum difficulty level reached. On the other hand, by monitoring the time allowed for risk identification, the player will have to enhance its recognition speed of vibrotactile stimuli.

One think to keep in mind is that this serious game is used for training vibrotactile messages that should inform user about inherent risk of falls. It is thus important that the perceived vibrotactile stimuli does not recall a scene in the game but a risk level. Consequently, engagement in the game should be reduced to minimum while keeping the player's motivation. This explains why the system is designed with an avatar and a crossword puzzle. On one hand, it places the user in a virtual environment where risk of falls can occur. On the other hand, it provides a context free game to enhance entertaining. In other words, it gives interesting game elements which are not necessary impregnated with particular feelings.

4 Preliminary Results

Preliminary experiments have been conducted with a prototype version of the proposed game. So far, eight days of daily training have been conducted. Participants were four graduated and undergraduated students age between nineteen and twenty-six years old. Among them, one was familiar with haptic stimuli. The game was set so that, for each difficulty level, all cues and words would be given in three days of perfect scores (16/16 score). The initial allowed time was set to 1.5 second. The tactile stimuli were played for one second. Afterwards, the player was prompt to identify the risk as fast as he could. Assiduity of all the participants were the same. In fact, none of them did performed their daily activities on weekend days, otherwise evaluation was conducted everyday.

In next sections, the scores and time for identification are first presented, followed by an evaluation of those results compared to the objectives of the proposed serious game.

4.1 Scores and Time of Identification

Three of the four participants have reached a difficulty level of 6 on the sixth day, versus the eighth day for the other. In other words, three of the participants had to identify six risks the seventh day, while the participant 3 stayed at four risks during the entire reference period. The average identification scores along the six first days are shown in Table 1. There again, participant 3 have the lowest score, which is consistent with its difficulty level reached. As too few days had been tested to obtain solid conclusion about the learning of tactons, those results still highlight the difference between haptic sensibility and perception of each person.

Table 1. Average score of each participant after six days

Participant 1	11.33/16
Participant 2	11.66/16
Participant 3	8.50/16
Participant 4	12.83/16

The results obtained from the experiment have shown that the time allowed for *tacton* identification has decreased for all the participants, has shown in Fig. 3. Moreover, we observed that this diminution did not seems to affect the success rate of any participant. For all the participant, the number of misidentification due to lack of time was null; indeed the mean time for identification was below 0.7 second. This highlights that the initial time allowed was too high and the monitoring was not thigh enough. Still it can be seem from average time a slight decrease in the identification time, which can be caused by the correct learning of *tactons* signification or/and an increased recognition speed. In fact, one of the participant states after a few day that identification was more reflective then it was at the beginning.

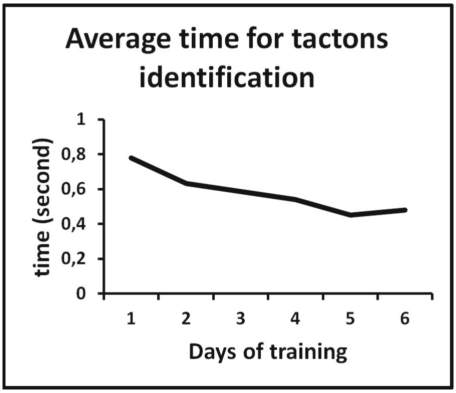

Fig. 3. Average identification time relative to days of training

4.2 Evaluation of the Serious Game

The question that now arises is to know if the use of a serious game did help the learning of the participants. While participants did not performed their activities on weekend, their assiduity was still there on week days. Moreover, no recall were done about their daily training, meaning they had other motivations to recall them about playing the game. Among them, be challenged by previously unknown stimuli was enunciated by all the participants. None of the participants seemed being annoyed by participating in this experimentation.

From observing the player during their play, it has been noted interesting reaction about their score. For example, it has been noted some disappointment sounds from failed evaluations and low score of the day. On the opposite, happy faces were often seen for nearly perfect days. Satisfaction was also noticed upon completion of the crossword puzzle.

The main difficulty stated by players was the differentiation of several *tactons* that seem similar. Knowing that participants had themselves associated risk to tactons, the risk association procedure should be improved in order to lower the confusion between two alike tactons. Methods such as clustered MDS analysis are often used for perception mapping. It had indeed been used in [2] for haptic icons design. In this serious game, it could be used to classify the initial set of tactons.

At the end, even if this serious game is not highly engaging, playing it was not annoying at all. Some lessons may still be drawn from this preliminary experiment. First, the time monitoring was too lazy to correctly incite the enhancement of the recognition speed. Second, it was found that players motivation could be increased by adding competition in the game. Thus, including leader board showing progress of the other participants could enhance interest on the game for some participants. Finally, the complete version of this game should include a robust method for the association of risk to tactons.

5 Conclusion and Future Works

In order to inform users about inherent risk of fall, the use of haptic stimuli under the foot could help to unload the visual and auditory channels habitually used for warning purpose. Nonetheless, vibrotactile stimuli have to be learned and memorized. Moreover, no studies as yet determined the maximum number of those feedback could be reminds. Thus, through this serious game, it was proposed a methods to achieves this goal in a convenient way. As a secondary objectives, enhancement of recognition speed was also promoted.

In order to overcome these issues, a serious game is described which wrap a daily training program for tactile icons (or *tactons*) learning. In the skin of an avatar, the player has to lead everyday his character to several activities through hazardous path. Risks occurred along the route is thus displayed through vibrotactile stimuli and have to be correctly identified. At the end of the day, recompenses is given based on the successful evaluations. In the form of cues and words, those rewards allow the completion, upon several days, of a crossword puzzles. Difficulty of the game depends on the numbers of risk to identify and is increased by the attainment of puzzles. The maximum number of *tactons* that could be learned is directly obtained by monitoring the difficulty level of the game. On his side, the enhancement of recognition speed is promote by tightly controlling the time allowed for risks identification.

The game has not been played long enough to state about the maximum number of *tacton* that could be memorized. However, some conclusions can still be drawn from partial results obtained from the preliminary experiment. It was pointed out the difficulty to differentiate some similar tactons, thus highlighting the importance of the association procedure of risks to tactons. Still, players have not been annoyed by the participation to the experiment. The used of a serious game to wrap a daily training was thus effective. Long-term experiments should gives credits to the usability of this serious game to the learning of a large number of vibrotactile stimuli.

This work thus proposes a preliminary step for identification of environmental risks applied to fall prevention program. By testing the final version of this game with several participants on longer time period, an ideal number of tatcon that could be learned should be extracted. Thus giving important information on how many risk levels can be differentiated. A modified version of the game could then be used as a preliminary training programs prior to the used of the designed shoes in real-life situations.

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