Reaction Time to Vibrotactile Messages on Different Types of Soil

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Abstract: This study investigates the Reaction Time (RT) to vibrotactile messages presented under the foot plantar on different types of soil. We determine whether reaction time varies while walking on different types of soil (mobile situation). A total of six young participants (n=6) aged between 21 and 28 took part firstly in this study where they had to walk on five types of soil (concrete, carpet, foam, gravel, and sand). The methodology includes 360 repeated measures. The findings have consistently revealed a decrease of reaction time to vibrotactile messages when walking on the three deformable soils (foam, gravel, and sand).

1 INTRODUCTION

With aging, many features that intervene in the postural control decline (Hay et al, 1996; Teasdale et al, 1991), it results that, the incidence of falls is over 30 percent per year for people over 65 years old (Ganz et al, 2007). In this group of the population, falls can cause physical injuries including fractures, reduce functionality, admission to a nursing home and sometimes death (Ménélas and Otis, 2014).

In this context, to prevent accidental falls we have designed a system centred on an enactive shoe (Ménélas and Otis, 2014) . Using an embedded software, this system estimates in real-time the risk level of accidental fall (low, medium, high and very high). To inform the user about the computed risk, we use a vibrotactile message presented under the foot plantar. The usefulness of these messages relies on two requirements. First, these messages have to be correctly identified. For this a previous work designed a serious game that allows users to familiarize themselves with rendered vibrotactile messages (have). Second, the messages should be perceived rapidly. The current work address this point by studying the reaction time (RT) associated with the interpretation of these stimuli. If the RT associated to such messages is too long, the user will in fact not be able to adapt her/his balance.

RT plays a very important role in our lives as its practical implications may be of great consequences. Hyman mentioned that RT is a linear function of stimulus information expressed in bits for the special case in which response and transmitted information are each equal to stimulus information (Hyman, 1953). Bricker proposes that the amount of information an organism must process or transmit is the crucial determinant of RT (Bricker, 1955). The RT is a direct consequence of the time taken to transmit the stimulus measured by the skin mechanoreceptors along the nerve to the brain and the response given to the neuromuscular system until the first action of the muscles involved in postural control. Psychologists have named three basic kinds of reaction time experiments: Simple Reaction Time (SRT), Recognition Reaction Time (RRT) and Choice Reaction Time (CRT) (Bricker, 1955; Kosinski, 2008). In a RRT situation, there are some stimuli that should be responded to, others that should get no response but there is still only one correct answer. In CRT experiment, there are multiple stimuli, and each stimulus requires a different answer. Based on reaction time's definitions provided by (Kosinski, 2008), we will situate our evaluation within the framework of a reaction time (RT) because when there are only one stimulus and one response (feeling or not) within a walking process . Our methodology is concerned with reaction time (RT) while walking in various types of soil.

Prior to our study, there is no significant traceable thread in the literature about evaluation of the RT to a vibrotactile message under the foot while walking on five different types of soil. We want to

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analyse the time needed to perceive a message sent to the sole of the foot during walking. We hypothesized that, RT, is greater when we have more difficulty to walk on a type of soil. In other words, RT depends on the types of soil. To this, we want investigate the impact of RT to vibrotactile messages presented on the foot when walking on five types of soil.

The paper is organized as follows: in the second section, we present related works, then follows the third and fourth section where we present our methodology with a full description of the experiment. The obtained results are presented in the fifth section and discussion follows in the sixth section. Finally, we present conclusion and further research in the seventh section.

2 RELATED WORK

In this section, we will analyze studies related to RT in order to convey vibrotactile messages under the foot plantar on different types of soil.

2.1 Reaction Time in Medical Applications

RT has been extensively investigated for many years in medical applications for instance to influence the balance ability (Kosinski, 2008). Also, Reaction time (RT) is one of the most important parameters used in psychology to evaluate human tasks (Kosinski, 2008). Various studies have measured the fastest response time to the human touch at about 155 milliseconds (Edward S. Robinson, 1934; Edward S Robinson, 1934; Welford, 1980). Braverman et al. showed that a RT test is an accurate predictor of early attention complaints and memory impairments (Braverman et al, 2010). Moreover, Gorus et al. showed that participants with cognitive deterioration demonstrated more slowing RT than healthy elderly (Gorus et al, 2008). Recently, Jain et al. studied a comparison of visual RT (VRTs) and auditory RT (ARTs) on the basis of gender and physical activity levels of participants (Jain et al, 2015). Participants were asked to concentrate on the fixation cross and press the “space bar” key, as soon as possible once target stimulus appears on the screen. They found a significant difference between RT of male and female students. In addition, significant results were found for the ARTs, which were faster than the VRTs. It is known that the RT has a direct impact on the risk of falling (Barr et al, 2014). For instance, Lajoie et al. investigated with two groups (fallers and non-fallers) the possibility to get a basic variable to predict the risk of falling (Lajoie et al, 2002). Results showed that RT is an interesting predictor of falling in the elderly, due to the sensory and motor components associated. Given that in everyday life, many falls occur on different types of soil (Ayena et al, 2015; Otis et al, 2016) or when walking on a stairway (Jackson and Cohen, 1995), the communication of a vibrotactile signal could be influenced by the RT of the person as well as the types of soil on which they are walking. The literature highlights usability of SRT on medical applications (balance impairment, auditory, and visual task) but not the evaluation of a simple RT to vibrotactile messages on the foot. As far as the RT from different stimuli is concerned, the literature is mature but, the above studies did not consider the specific case that we are investigating here.

2.2 Foot Reaction Time

The need for tools to communicate information under the foot on different types of soil has resulted in some interesting initiatives for investigating foot RT experiment and methodologies. Montés-Micó et al. investigated the difference between the eye-hand and eye-foot visual RT among young soccer players versus non-soccer players (Jackson and Cohen, 1995). Eye-hand and eye-foot visual RTs were determined by means of a computer-controlled stimuli device. Results showed firstly that there are statistically significant differences between eye-hand and eye-foot RTs between players and non-players of soccer. Secondly, the results demonstrated a fast SRT time with soccer players. Recently, Mali et al. conducted a study to compare Visual Reaction Time (VRT) and Auditory Reaction Time (ART) of hand and foot in young adults before and after physical training (Mali et al, 2013). VRT and ART were determined with the help of an electronic instrument “Response Analyzer”. Results show that both VRT and ART were significantly decreased in all four limbs after physical training of six months. Pfister et al. compared Reaction Response Time (RRT) between hand and foot with a controlled devices for medical application (Pfister et al, 2014). To evaluate RT they assumed that, for physiological, anatomical and ergonomic reasons, the time required to release a switch with the hand is shorter than the time required to release a switch with the foot. They tested both the dominant and non-dominant hands and feet by performing the “Kick-Test” for each participant. Results demonstrate a significant faster RT with the dominant extremity and Simple

Reaction Time (SRT) test demonstrates significant faster RT of the hands compared to the feet. All these studies focused on foot RT, but not on the case, which interests us here, namely, conveying a risk level of falling under the foot plantar while walking on different types of soil.

2.3 Reaction Time in Communication of Information

It is known that many factors do affect RT (Kosinski, 2008). RT has been widely used to convey information, to test how rapidly stimuli information can be processed and a response to it can be activated (Luce, 1986). Some studies have used SRT when work requires performance in a dual task to assess the risk of falling. This paradigm is called a probe RT. This is the case of Ming et al., they studied physical and cognitive factors associated with falls by the elderly by evaluating the probe reaction time (P-RT) (Hu et al, 2009). They used a wearable trial tool, easy to use and useful for the evaluation of the risk of falling and they discuss the relationship when walking between simple RT, probe RT and participant's risk of falling. Results showed that probe RT is useful for the evaluation of the risk of falling and when the attention demands while walking increase. Niemi and Näätänen stated that a typical SRT includes many factors that can be varied on several parameters: the warning signal (WS), the foreperiod (FP), the reaction stimulus (RS), the response (R), and the intertrial interval (ITI) (Niemi and Näätänen, 1981). For instance, Drazin evaluated the relationship between RT and foreperiod (Drazin, 1961). Also, Peon and Prattichizzo (Peon and Prattichizzo, 2013) studied RT during conveying information by comparing different sensory modalities (vibratory, auditory and visual). Results showed that the haptic canal (strong modality) can provide faster RT than the auditory one.

These studies investigated the risk of falling by evaluating SRT with various tools for communicating information by the visual, audio and haptic canals. However, these studies have focused attention on RT in various conditions, with factors like hand, finger, and foot. Obviously, they did not assess the impact of the type of soil, nor the evaluation of RT while walking (for mobile application). The haptic canal can be used for RT experiment, but in this study, we will use an RT experiment to convey vibrotactile messages under the foot aimed at alerting the user (De sa and Carrico, 2011). Our approach differs in the sense that we are planning to exploit the haptic modality to convey information under the foot plantar on different types of soil. This paper is intended to evaluate the RT when transmitting a vibrotactile message under the sole of the foot on different types of soil.

To sum up, they are various applications of RT. Several researchers have investigated the RT but about the impact of RT vibrotactile messages on various type of soil the literature still young. The vibrotactile message in everyday life could be used to inform the participant of important information about a physical situation (in balance or not) or an external environment (an alert). Moreover, in an uncontrolled environment, people walk on different types of soil without paying attention to the impact of that type of soil on their balance. Their attention is often occupied by a secondary task after walking. Then, it is therefore important to investigate the impact of types of soil affecting RT when conveying vibrotactile messages while walking.

3 EVALUATION OF THE RT TO VIBROTACTILE MESSAGE

The aim of this experiment is to evaluate the RT to a vibrotactile message presented under the foot plantar while walking on different types of soil.

3.1 Participants

Six young students from the University of Quebec at Chicoutimi participated in the study. They were recruited by means of a general invitation to participate in a study related to the reduction of the risk of fall. All the youths attended the session voluntarily. The participants were aged from 21 to 28 (two female and four male). All were novices to haptic technologies. For health issues, all participants were instructed to wear socks and we cleaned all components after each session. Before the experiment, they were totally naive about all aspects of the test and were given general instructions concerning the task. All participants follow up an interview including a questionnaire and none of them reported any problem with foot sensitivity. All volunteers involved in this study were informed about the experimental protocol and gave written consent before participating. The experience and consent form had been previously approved by the local ethics committee (certificate number 602.434.01).

3.2 Apparatus

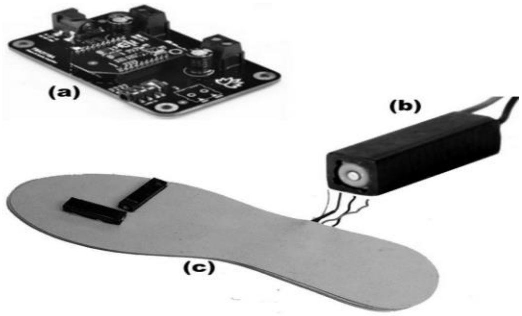

Figure 1: Enactive insole: (a) signal amplifier; (b) Mark II haptuator; (c) insole.

For this experiment, we use an enactive insole developed in the laboratory (Fig.1.c). It consists of an insole device equipped with two Mark II Haptuators. The haptuator is a high-bandwidth, iron-less, recoil-based electromagnetic vibrotactile actuator (Ellis et al, 2011). It be driven as a common loudspeaker. (Fig.1). The smartphone is fixed at the ankle (Fig. 2). Measurements are performed between 60 to 362 Hz since the optimal response of the vibration receptors (Pacinian corpusles) is reported to be at frequencies between 10 – 500 Hz (De sa and Carrico, 2011).

Figure 2: Positioning of the enactive insole on the foot: (a) signal amplifier is fixed on the ankle; (b) Enactive insole is wear into the shoe.

For the experiment, users have to walk on several types of sole representing the natural flooring surface materials that we commonly find in the daily life: concrete, foam, carpet, sand, and gravel (Fig. 3). We have designed a longitudinal and wooden partitioning device to accommodate selected sole types (Length =5m, Width =1m Height =0.05m). We filled each partition with real materials.

A set of four vibrotactile messages is proposed in the experiment. They are based on the same rhythm signal and duration of one second. They are designed according to various studies of psychophysical perception reported in (Visell et al, 2009) and (Menelas and Otis, 2012). The waveform of each vibrotactile message is described by equation (Table 1). W_1 defines a pure sinusoidal wave (121 Hz). W_2 is an amplitude modulation of W_1 by 60 Hz of pulsing vibration. W_3 is a modulation of W_1 by a 3 Hz sinusoid of rapid impulse vibration. W_4 is a 53 Hz sinusoid modulated by a 31 Hz of rough vibration sensation. W_5 is a Gaussian function where a, is the amplitude of the signal, e is the Euler number, b is the position of the center of the peak, and c adjust the bandwidth of the function. W_6 is a sinusoid modulated by a quadratic function providing an increasing or decreasing tactile sensation.

Table 1: List of equation of tactons.

Equation	Number
$W_1 = a \sin(2\pi 121t)$	(1)
$W_2 = a \sin(2\pi 60t) \sin(2\pi 121t)$	(2)
$W_3 = a \sin(2\pi 3t) \sin(2\pi 121t)$	(3)
$W_4 = a \sin(2\pi 31t) \sin(2\pi 53t)$	(4)
$W_5 = ae^{-\frac{(x-b)^2}{2c^2}}$	(5)
$W_6 = (-t^2 + 0{:}5) \sin(2\pi 60t)$	(6)
with t = (0: 1=9600: 1) sec.	

3.3 Exploited Vibrotactile Messages

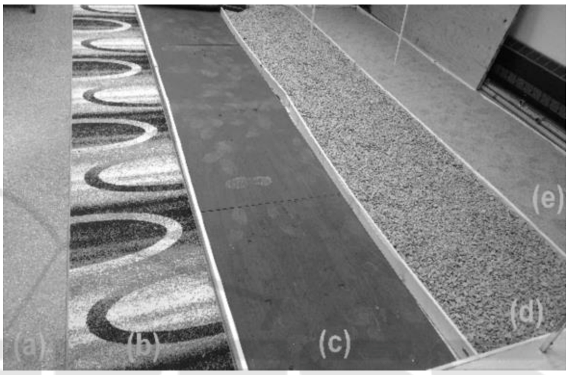

Figure 3: Types of soil. Left to right: (a) Concrete, (b) Carpet, (c) Foam, (d) Gravel, (e) Sand.

4 EVALUATION OF THE RT TO VIBROTACTILE MESSAGES

At the beginning of the experiment participants are seated, wearing an ear protection and the enactive insole on the left foot. They are then invited to select four among the six vibrotactile messages. Thereafter the evaluation starts.

Participants have to walk on the 5 types of soil (Fig.3). Three trials are needed on each soil. For each trial selected messages are randomly conveyed under the foot plantar. Doing so, 360 repeated measures (6 participants x 5 types of soil x 3 trials x 4 messages) are performed.

Whenever the participant perceives a message he/she is instructed to lift the foot as quickly as possible. The RT is computed by calculating the acceleration of the foot movement. The accelerometer attached to the foot is used to determine the real time of the stimulus perception through the speed of movement of the foot. The acceleration (m/s2) was recovered on the three axis x, y, z and was compared with an acceleration threshold value. If the value of the acceleration on one axis were equal to the threshold, the identification time (t_2) would be saved and we would compute the RT with the initial time of the stimulus conveyed (t_1): $RT_i = t_{i2} - t_{i1}$ where i represents one vibrotactile message on a type of soil. If the vibrotactile message is not perceived after the maximum time of 5 seconds, then the signal is sent back.

The overall time is 45 minutes with a break of 5 minutes between the two steps.

A semi-directed interview with Likert-based question was conducted. In our post-experimental interview, we asked participants the following question: What do you think might be the level of risk for each soil according to your RT to this soil? This question was intended for user's experience about the comprehension, and explanation of RT data analysis on different types of soil.

5 RESULTS AND DISCUSSION

All participants went through the experiment successfully.

Table 2: Mean RT in milliseconds by participants in each type of soil.

Participants	Concrete	Carpet	Foam	Gravel	Sand
A	312.5	330	330	365	347.5
B	252.5	320	397.5	527.5	587.5
C	492.5	472.5	492.5	365	907.5
D	420	445	530	777.5	710
E	490	487.5	460	545	665
F	372.5	405	460	470	450
$\bar{x}$	390	410	445	508.33	611.2
SD	96.56	71.64	71.29	152.79	198.2

5.1 Vibrotactile Messages Preference

Observed results provide a general indication on the preference of participants on the set of haptic messages proposed to convey a risk level under the foot. Among the six vibrotactile messages presented, participants had to select four and then. The results (Table. 2) show that the participants had a similar preference in the choice of vibrotactile messages. We observed, for the four risk levels of falling low, medium, high, and very high, participants have generally associated vibrotactile messages W_6, W_2, W_1, and W_3 respectively.

5.2 Observed Reaction Times

Individual results showed that the smallest RT was 252.5 msec. observed for the participant B on the Concrete soil. The highest RT was 907.5 msec. observed in participant C on the Sand soil. Mean RT results are found in (Table 2). On average, the fastest RT can be observed on the Concrete soil (390 msec.) and the slowest RT is observed on the Sand soil (611.25 msec.). All these results revealed that the RT varies according to the types of soil.

We also analyzed conditions for which participants did not perceived the vibrotactile messages. In general, five (5/6) participants did not perceive the vibrotactile messages on three types of soil (Foam, Gravel, and Sand). The breakdown is as follows: (3/6) concerning the Foam, (4/6) concerning the Gravel and (4/6) concerning the Sand. On the other hand all participants were able to identify vibrotactile messages on the Concrete and Carpet types of soil. The results also showed the mean RT were different according to the type of soil.

Table 3: Additional statistic test.

Group	Soil pair	Type of test	P-value
1	Concrete - Sand	Tukey	0,04
1	Concrete - Sand	Bonferroni and Holm	0,02
1	Concrete - Sand	Fisher	0,034
2	Sand - Concrete	Fisher	0,006
3	Sand - Carpet	Fisher	0,012

5.3 Statistical Analysis

We performed an ANOVA with repeated measure on the mean RT (Table 3). Factors are the types of soil and its associated levels are Concrete, Carpet, Foam, Gravel, and Sand. Our assumption for the ANOVA was the homogeneity of variance, we supposed that variance in different levels of each independent variable was equal. The significance level (α) is 0.05. The p-value corresponding to the F-statistic of ANOVA ($F(4, 25) = 2.92$, $p < 0.05$) was lower than 0.05, suggesting that the one or more mean RTs across types of soil were significantly different. To identify which of the pairs of soil are significantly different from the others, the Tukey HSD test, Bonferroni and Fisher's least significant difference (LSD) were performed. Results of these additional tests are reported in Table 3. We can observe that the pairs 1, 2, 3 are significant from each other. Thus, we can reject the null hypothesis and confirm the alternative hypothesis. No other statistically significant difference was found, but from data collected in our post-experimental interview, a simple contrasts indicated that vibrotactile RTs were much longer for soft or irregular surfaces according to the rank ordering of the surfaces causing concerns in Table 4.

Table 4: Types of soil causing perception difficulties.

Level of difficulty	Type of soil
Low	Concrete Carpet
Medium	Concrete Sand
High	Foam Sand
Very high	Gravel Sand

Additional question on the survey about the device revealed that 66.66% of the population feel uncomfortable with the device while walking.

5.4 Discussion and Limitations

Overall results suggest a significant effect of type of soil on RT to vibrotactile message. The factors that most influence the RT to a vibrotactile message is when participants walk on the Sand and on the Gravel.

Vibrotactile RTs were longer on deformable surfaces. A possible explanation for that is that when walking the pressure exerted on the surface induces deformations that introduce perceptual conflicts in the understanding of proposed haptic messages. As result, vibrotactile messages are thus better perceived on non-deformable soils (Concrete, Carpet) when compared to deformable ones (Foam, Gravel, and Sand). Moreover, based on, our post-experimental interview, we observed that most participants (83.33%) had experienced some difficulties to walk on these soils. They categorized them as types of soil with very high-risk difficulty (Table 4).

The main limitation of this study concerns the participants; it focuses on two aspects that will be investigated in future work. The first is related to the limited number of participants in the study. Although we had significant results, the sample being very small, it will be important to repeat the experiment with more subjects. The second limitation concerns the representativeness of the sampling. The purpose of this study was to validate the possibility of using vibrotactile feedbacks to transmit messages under the foot plantar during walking. This step now taken, we will need to validate this possibility with the population targeted by the designed instrumented footwear (Menelas and Otis, 2012). More particularly, we will have to experiment with the possibility of use and perception of these messages with elderly people.

6 CONCLUSION

This paper aimed at evaluating the RT to vibrotactile messages when walking on five types of soil. We analysed the time needed to react to a vibrotactile message sent to the foot plantar, using an enactive sole, while walking. Two main results have been noted. First, we observed that the RT was significantly longer on deformable surfaces compared to non-deformable surfaces. Second, results and answers to the post-experiment interview showed that the information (the risk of falling) conveyed through vibrotactile messages is better perceived on non-deformable surfaces. It thus appears that types of soil can influence the perception when walking. But, to increase the significance of our results, an extension of this work will be to use an apparatus adapted to improve the user experience when walking, increases the number of participants (fallers and non-fallers / youth and elderlies), and finally study the positioning of the Haptuator on the body.

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