Impact of Auditory Distractions on Haptic Messages Presented Under the Foot

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Abstract: When compared to vision and audition, communication capabilities of the haptic channel remain underexploited. In this paper, we investigate the impact of auditory distractions on the learning of haptic messages presented under the foot plantar. From a set of six haptic messages that have been designed in order to be easily differentiable one from another, participants have to select four. With and without the presence of auditory distractions, we evaluate the completion time and the number of iteration required to reach an identification rate greater than 95%. For both measures, we observed that having auditory distractions was detrimental to the performances of users.

1 INTRODUCTION

In human-machine interaction, to take advantage of full capabilities of human sensory-motor capacities main modalities (vision, haptics, and audition) are generally exploited. That defines a multimodal interaction. Like many researchers, we think that a modality is directly related to human senses (Fikkert et al., 2007). We define the modality as the form of exchange that can be established between a user and a digital system (Menelas, 2014). In contrast to the unimodal condition where only one form of communication is possible, in a multimodal rendering several forms of communication are available. When compared to the unimodal condition, the design of a multimodal rendering one has to take into account interactions that may exist between different channels. For Friedes, multimodality appears as an aggregate of several unimodal renderings, where each one has its own characteristics (Freides, 1974). Each channel must thus be assigned to the rendering of a particular type of information (Nesbitt et al., 2003). Bowman et al. (Bowman et al., 2004) adopt a more general view by defining multimodality as the combination of several modalities that aims to provide a richer interaction. They recognize six types of multimodal associations: complementarity, redundancy, equivalence, specialization, competition, and transfer. Recently, beyond the interactions between the different modalities, Menelas showed that the task to perform played a preponderant role in a multimodal interaction (Menelas, 2014). He proposed a taxonomy based on the tasks that the user wants to achieve. All these studies focused on situations achieved in a controlled-environment (immersive room, work station etc.). Therefore, one question arises: what happens if one has to exploit a multimodal rendering in an uncontrolled environment like on the street or in public transport? In other terms, would the association of some rendering be detrimental to performances of users? We are interested in this situation, as our project concerns the use of the haptic feedback to communicate information to a user using an enactive shoe.

This enactive shoe has been designed in order to prevent accidental falls (Fig. 1) (Otis and Menelas, 2012; Otis et al., 2016; Ayena et al., 2016). This device has a set of sensors used to characterize the dynamics of walking, the gait and physical properties of the environment (Otis et al., 2016; Ayena et al., 2016). Besides, it regroups several actuators (notably a haptuator (Yao and Hayward, 2010)) aiming to transmit haptic signals to the user (see Fig 1). These signals will be used to alert the user to dangerous situations or to correct anomalies of his gait. In this sense, these signals appear as an aid aiming to assist the user (Otis and Menelas, 2012; Otis et al., 2016; Menelas and Otis, 2012). We are interested in transmitting these messages by the mean of haptic messages because this channel may allow to communicate with the person without preventing him from being fully aware

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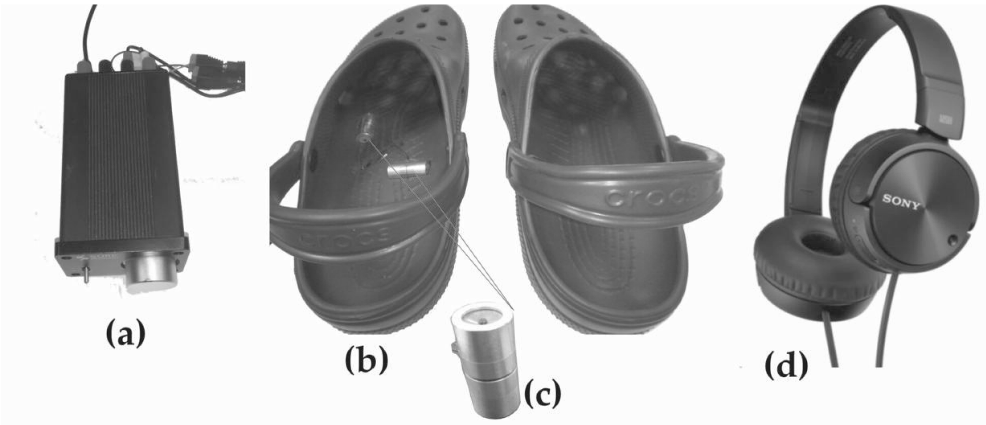

Figure 1: Enactive shoe system overview: (a) Audio amplifier to manage output signal. (b) enactive shoe: A rear strap enabling the shoe to be firmly strapped on the foot. (c) Haptuators mounted in the left foot. (d) Earphones to render auditory distractors.

of his external environment; as it could have been with visual or audible communications. Knowing that users will wear the shoe during walking (uncontrolled environment), the objective is to be able to transmit haptic messages that remain interpretable in spite of the distractions of the environment. While walking in a street, such distractions may be the walk in itself, visual or auditory stimuli. As a preliminary work, we investigate here how auditory distractions may impact the learning of haptic messages presented to the foot plantar via an enactive shoe. We have selected to study the impact of auditory distractions for two main reasons. Recently, Meier et al. (Meier et al., 2015) evaluated the suitability of vibrotactile feedbacks, in different areas of the body including sole of the foot and toe, as a mean of guidance. Their study suggests that, firstly, the foot provides the most promising results for the identification of vibration patterns while walking. Secondly, the use of vibrotactile feedbacks on the foot (side/sole/top) allows to reduce the stress and the need for visual attention. Other research has investigated the rendering of tactile stimuli via instrumented shoe.

The main contribution of this paper is to study the impact of auditory distraction on the identification of a *tacton* presented under the foot plantar.

2 RELATED WORK

The study of haptics as an information mediation channel has focused on the hand (Brewster and Brown, 2004; MacLean and Enriquez, 2003). In this study, we are interested in evaluating the perception capabilities of the foot in the presence of distractive sounds. Following sections briefly, review the identification of haptic messages presented under the foot plantar and the impact of auditory distractions on the perception of haptic messages.

2.1 Identification of Haptic Messages Presented Under the Foot

When compared to other areas of the body, the use of foot for haptic perception remains limited. One of the first works on this topic studied the usability of an instrumented tile to mimic physical properties of soils such as ice, crack and sand (Visell et al., 2009). Later, Turchet et al. (Turchet et al., 2013) observed that haptic feedbacks presented to the feet may enhance the realism of walking or simulate it. In the same way, Nordahl et al. (Nordahl et al., 2010) have studied the combination of haptic and sound feedbacks in order to simulate the sensation of walking on virtual surfaces. The haptic information was presented at the foot of the user through an instrumented shoe. The studies carried out indicated that subjects were capable to recognize most of the stimuli in the audition only condition, and some of the material properties such as hardness in the haptics only condition. Recently, Meier et al. (Meier et al., 2015) evaluated the suitability of vibrotactile feedbacks, in different areas of the body including sole of the foot and toe, as a means of guidance. Their study suggests that the foot provides the most promising results for the identification of vibration patterns while walking. Also, it indicates that the use of vibrotactile feedbacks on the foot (side/sole/top) allows to reduce the stress and the need for visual attention. Other studies have investigated the rendering of tactile stimuli via instrumented shoe. For instance, by using an array of sixteen dots of actuators, Velazquez et al. (Velãzquez et al., 2009) have shown that some geometric shapes could be discriminated in order to guide a blind person while walking.

2.2 Impact of Auditory Distractions on the Perception of Haptic Messages

There has been little work into how auditory distractions influence the haptic perception of a person on various work tasks. Chan et al. noted that the learning and identification capabilities of vibrotactile messages decreased significantly with the addition of visual and audible disturbing elements (Chan et al., 2005). Later, Tikka and Laitinien noticed that when interacting with mobile devices, auditory stimuli do biased the perceived intensity of haptic feedbacks (Tikka and Laitinen, 2006). In the same way, Qian et al. specified that the type of background sounds had a significant effect on identification accuracy, identification time, and probably on the cognitive workload as well (Qian et al., 2013). These results confirmed those presented in (Oakley and Park, 2008) where Oakley and Park showed that walking could significantly affect the ability to identify haptic messages. However, this work did not analyzed the level of external distraction that was tolerated nor the influence of age or training on the ability to identify haptic messages.

To the best of our knowledge, no research has yet investigated the impact of audible distractions on the perception of haptic messages presented via the foot. This work addresses this aspect. The next section describes the performed experiment. We ended with results and discussion. The evaluation with participants was approved by the local Ethical Committee of the University of Quebec at Chicoutimi (certificate number 602-462-01).

3 EXPLOITED SIGNALS AND APPARATUS

Two types of signals are exploited in this study: Haptic messages and auditory distractions. The haptic channel is used as a communication medium whereas audio signals are exploited as distractors.

3.1 Selected Tactons

Given that the cutaneous sense, a rich and a powerful communication medium, remains underexploited when interacting with computers (Menelas et al., 2014), we want to exploit haptic messages to communicate with the user throughout the foot. For this, we are interested in using mechanoreceptors situated under the foot plantar. They are responsible for sensing and transmitting physical deformations, caused by external forces, to the nervous system (Velãzquez et al., 2009). To ensure the ability to transmit tactile information to the user, the haptic messages used in this study are *tactons*. Brewster and Brown (Brewster and Brown, 2004) defined *tactons*, or tactile icons, as structured, abstract messages that can be used to communicate messages non-visually. Here we use a set a six *tactons* represented in Table 1. They are coming from a previous study (Menelas and Otis, 2012) and they are designed to be easily differentiable. They will be used to convey the information of a two-bit alphabet.

From this set of six *tactons* (T_1, T_2, T_3, T_4, T_5, and T_6), participants have to choose four preferred considered to be the most different. We allow participants to express their preferences among a set of six *tactons*, based on the work reported in (Garzonis et al., 2009). These authors have observed that there is a strong positive correlation between preference and successful identification of auditory notifications. The six proposed *tactons* are shown in Table 1.

Table 1: Proposed Tactons.

Name	Equation
T_1	sin(180πt)
T_2	sin(6πt)sin(122πt)
T_3	sin(12πt)sin(122πt)
T_4	sin(62πt)square(50%;71)
T_5	$(-t^2+0{:}5)$ sin(120πt)
T_6	t^2sin(120πt)
	t = [0 : 1/9600 : 1] sec.

3.2 Selected Auditory Distractions

We used two auditory distractions (see Fig. 2). They are external noise commonly heard in everyday life. The first metaphor mimics the sound of a car horn and the second is an approaching ambulance siren. The duration of each stimulus is two seconds, with an intensity of 60 dB SPL. To avoid abrupt noise onsets, noise distractions intensity increased gradually. The auditory distractions are presented continuously during the test in the associated condition.

3.3 Apparatus

To render the *tactons*, we use an enactive shoe with two Haptuators as shown in Fig. 1. Haptuators are vibrating devices directly in contact with the foot plan-

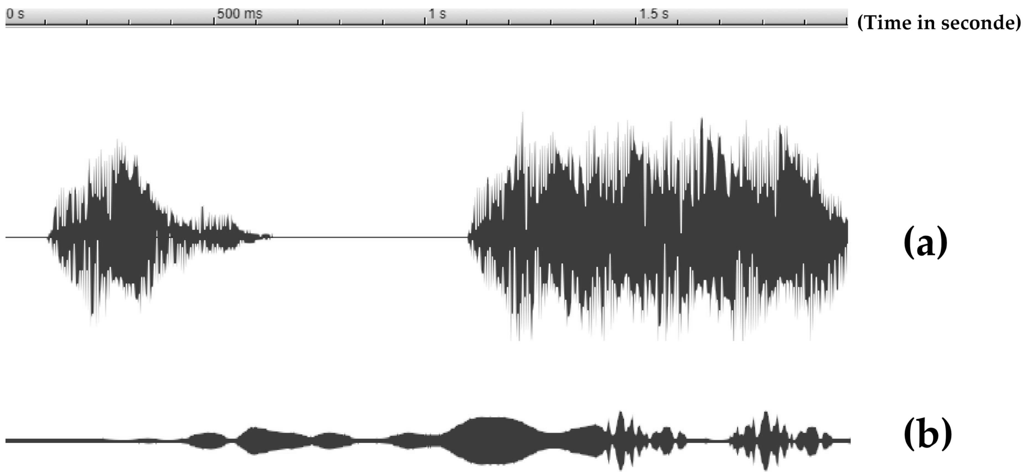

Figure 2: Auditory distractions send on participant's ear during the test. (a) Audio wave frequency of a car horn. (b) Audio wave frequency of approaching ambulance siren. Wave frequencies have been obtained using ®WavePad Sound Editor software.

tar of the participant. The Haptuator is discreet and fits well in the designed enactive shoe. The sound card of an Android smartphone is exploited to transmit the *Tactons*. These signals are then amplified (by an audio amplifier showed in Fig. 1 - a) and sent to both Haptuators in (Fig. 1 - c) embedded into a shoe (Fig. 1 - b).

We use a Sony Noise Canceling Headphone, Black - MDRZX110NC (Fig. 1 - d) in order to render a distracting auditory and canceling external noise to participants.

3.4 Positioning the Haptuator Under the Foot

We perceive and distinguish various tactile feeling on the skin by touching. We know that people can easily discriminate a very fine signal of a surface thanks to the tactile feeling. For instance, it is reported that our finger can distinguish a micron order difference of surface roughness of sandpapers (Asamura et al., 1998). This differentiation is possible thanks to the mechanoreceptors located under the skin. Indeed, Pasquero reported that mechanoreceptors are characterized by the size of their receptive field and their adaptation rate to a stimulus (Pasquero, 2006). Types I allows to discriminate small and well-defined borders while types II intervene for large and poorly-defined borders. Also, Velazquez and Pissaloux reported that mechanoreceptors of the foot plantar are usually classified based on their rate of adaptivity and receptive field (Velázquez and Pissaloux, 2008). Generally, there are four types of mechanoreceptors in the foot plantar: slow adapting type I (SAI), slow adapting type II (SAII), fast adapting type I (FAI) and fast adapting type II (FAII) (Velázquez and Pissaloux, 2008). Only two afferents, one FAI and one FAII, have the receptor terminal on the hairy skin of the calf (Kennedy and Inglis, 2002). Then, it seems that stimulation of FAI mechanoreceptors is more suitable for transmitting information to the foot (Velázquez and Pissaloux, 2008). However, Kaya has identified some interesting features: The FAIs are the Meissner corpuscles that best respond to light touch, and the FAIIs are the Pacinian corpuscles which are best for vibrations (Kaya, 2014). The position of the haptuators has been selected in order to be in contact with FAI and FAII. Hence, a better perception of the signal is expected. In order to convey the same vibration with a quick perception, the transmitted signal will be identical on both haptuators and will be located on FAIs and FAIIs.

4 EXPERIMENT

The experiment aims at measuring the impact of auditory distractions on the learning of *tactons* presented to the foot. Participants have to learn to identify four *tactons* presented on the foot plantar. To reflect a real-life situation, we assess how everyday sounds do impact performances of their task.

Two experimental conditions are specified: with audio distraction (AD) and with no distraction (ND). Namely, in the ND condition, only the *tacton* is rendered via the enactive shoe. In the AD condition, during the rendering of the *tactons* under the foot plantar, auditory distractions described previously are also rendered through the headphone. For both conditions, we evaluate the performances of participants to identify four *tactons* specifically the completion time and the number of iterations required to reach an identification rate greater than 95%.

4.1 Participants

A total of 38 participants (21 males and 17 females) aged between 20 and 40, took part in the experiment. In this set of participants, one counts four postgraduates and ten graduates. The others are undergraduates. Based on our pre-experimental questionnaire, five participants had previous experiences with haptic messages. The later reported having used haptic messages in everyday life with smartphones. More importantly, all participants reported normal levels of auditory and tactile perception. Fig. 3 shows a participant experimenting the system.

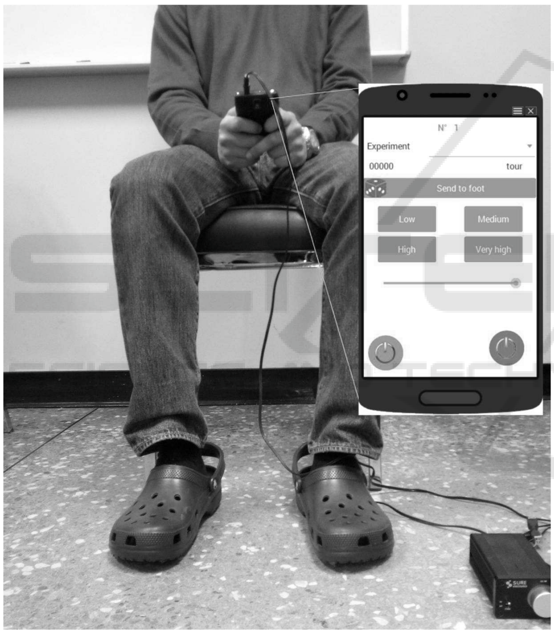

Figure 3: Experiment setup while no distraction condition. A seated participant performing the test with the device mounted on the left foot.

Participants are randomly divided into two groups (G_1 and G_2) of 19. To minimize learning effect, participants of G_1 completed the test in the ND condition (No Distraction) then in AD condition (with Audio Distraction). Participants of the second group G_2 performed the test in the opposite order.

4.2 Experimental Plan

Materials described previously are employed for this experiment. At the beginning of the test, participants are invited to sit. The details of the experiment are presented. They are also encouraged to ask questions if needed. After all, they are asked to sign the associated consent form. Subsequently, participants have to wear the described enactive shoe. At this stage, each participant is invited to choose four *tactons* among the six described at subsection 3.1. To do this, the participant uses a software running on an Android device. It allows to render *tactons* by touching buttons on the screen of the mobile device. Afterwords, the evaluation begins.

The evaluation consists of several trials where the participant seeks to correctly identify the *tactons* rendered via the enactive shoe. For each participant, the total number of trials required will be the number of rounds that this participant needs to achieve an identification score greater than 95 %. For each trial, the participant is asked to randomly identify each *tacton* three times. Hence, a total of twelve identifications have to be made. For each trial, we record the identification score, the number of iterations, and the completion time taken to complete theses twelve identifications (Duration). The percentage of correct identification is defined by the ratio between the number of correct identification and 12.

5 RESULTS AND DISCUSSION

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5.1 Results

All participants successfully completed the test with an average time of 30 minutes. Regarding the number of iterations required to achieve an identification rate greater than 95%, in ND condition the average iteration is 2.47. It rises to 3.32 when auditory distractions are presented. In the same way, the average duration to complete all identifications rise from 38 sec in ND condition to 82.36 sec in AD condition. Results are reported at Table 2.

For both factors, we observed that having auditory distractions negatively affects the identification of *tactons*. In the ND condition, five participants completed the test at their first iteration. A maximum of five iterations have been required by one participant. Among the participants, we observed that the shortest duration was 51 sec. whereas the highest was 149 sec. On the other hand, in the AD condition, three participants completed the test at their first iteration. A maximum of twelve iterations has been required by one participant. For comparison, one notes that in the AD condition, six participants completed the test in six or more iterations. No participant required so many iterations in the ND condition. In terms of duration, in the AD condition, among the participants, we ob-

Table 2: Results summarized and presented for both conditions.

ND condition			AD condition		
Participants	Iterations	Durations	Participants	Iterations	Durations
5	1	32.394	3	1	101.47
17	2	45.79	20	2	81.63
12	3	30.75	4	3	86.99
4	4	44.43	4	4	78.89
4	5	20.82	1	5	78.35
			1	6	75.22
			1	7	85.76
			1	8	64.16
			1	9	58.36
			1	12	102.88

served that the shortest duration was 54 sec whereas the highest was 271 sec.

In general, we see that participants required more iterations (12 iterations) in condition AD than in the condition ND (5 iterations). Looking at participants' performances (iteration and duration), Fig. 4 shows that the duration of the AD condition is generally the biggest. This can be confirmed by the fact that participants took more iteration to succeed (Fig. 5).

In terms of number of iterations, in the ND condition, (Fig. 4 and Fig. 5 - b), we see that five participants completed the test at their first iteration. 17 participants had to go to a second iteration. 12 participants completed the experiment after three iterations while four made it after four iterations. Only one participant succeeded with five iterations. All corresponding durations are reported in Table 3.

In terms of iteration, in the AD condition (Fig. 4 and Fig. 5 - a), we see that three participants completed the test at their first iteration. 20 participants had to go to a second iterations. But four participants had to go to the third and the fourth iteration. Finally, only one participant succeeded with five, six, seven,

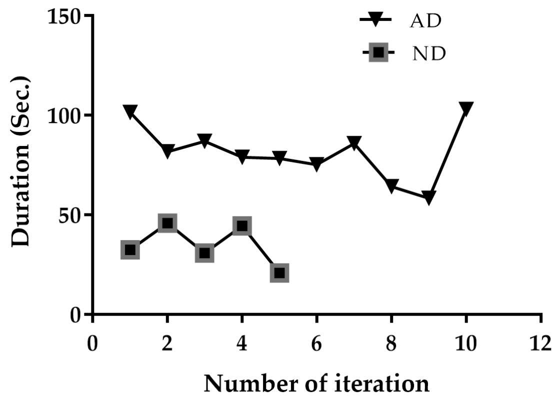

Figure 4: Summarized results of durations (AD vs ND) and iterations (AD vs ND).

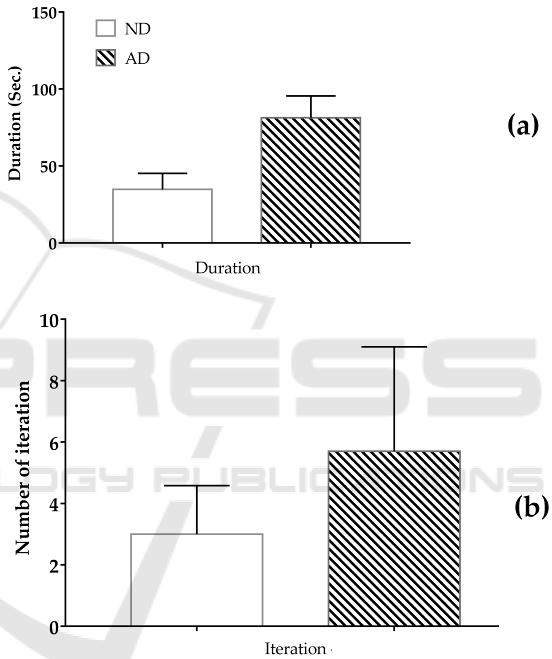

Figure 5: Performance of participant on both conditions [Auditory Distraction (AD) vs No auditory Distraction (ND)] : (a) Number of iterations by participants; (b) Duration by participants.

eight, nine and twelve iterations. All corresponding durations are reported in Table 3.

5.2 Statistical Analysis

We are looking for the effect of each independent variable in each condition of the experiment. We have one assumption: Do distractions have any effect on the identification of *tactons*?

In this analysis, we want to study the effect of auditory distractions on the identification of the *tactons*. Identification of *tactons* can be achieved in one or many iterations with different completion times.

Table 3: Two-sample T-test results for H_1 and H_2 hypothesis.

Summarized data	AD*		ND*	
	Iterations	Durations	Iterations	Durations
Sample size	38	38	38	38
Mean	3.32	82.36	2.47	38
SD	2.48	20.76	0.951	19,94
SE Mean	0.4	1.9	0.16	5.7

* AD= Auditory distraction condition; ND= No Auditory distraction condition.

Our independent variables are therefore iteration and completion time (duration). The results of the T-test presented here will validate the following hypothesis tests:

1. H_1 hypothesis for effect of the auditory distraction on the number of iterations
   (a) H_{01} The null hypothesis: The auditory distraction has no effect on the iteration.
   (b) H_{a1} The alternative hypothesis: The auditory distraction has an effect on iteration.
2. H_2 hypothesis for effect of auditory distraction on the completion time
   (a) H_{02} The null hypothesis: the auditory distractions has no effect on the completion time.
   (b) H_{a2} The alternative hypothesis: The auditory distraction has an effect on completion time (duration).

Our approach is as follows. We assumed that for the null hypotheses (H_{01} and H_{02}), all means are equal and for the alternative hypothesis (H_{a1}, and H_{a2}) at least one mean is different from another. Our significance alpha level is 0.05. The dependent variable is "distraction" and our independent variables are "iterations" and "durations" to recognize stimuli. To evaluate hypothesis H_1 and H_2 two T-test are conducted for the two conditions (with audio distraction and without distraction). The sample observation N=38.

5.2.1 T-test of the Number of Iterations on Two Conditions (ND and AD)

A paired-samples T-test was conducted to compare the number of iterations to succeed the test in two conditions (with audio distraction (AD) and no distraction (ND)). Results of this analysis are reported in Table 3. There was a significant difference in the number of iterations t(37)=2.359, p = 0.023. Indeed, the mean of the differences between factor is 0.842 located into the 95% confidence interval (0.119, 1.565). The boxplot displaying the mean of iteration's variation on both conditions is presented in Fig. 6. These results suggest that the audio distraction does have

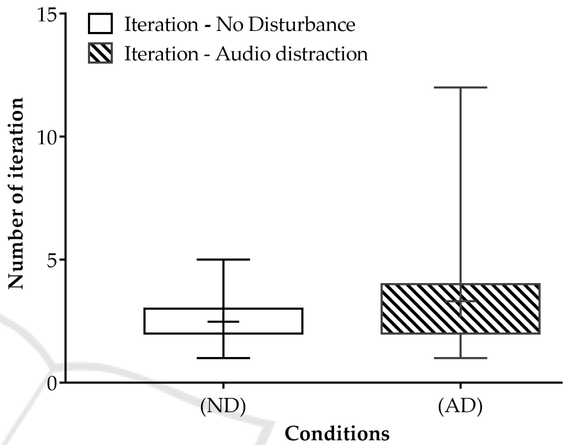

Figure 6: Boxplot of iteration (AD vs ND).

an effect on the number of iterations. Specifically, observed results suggest that when humans are exposed to auditory distractors, the number of iterations to learn stimuli increases. Since the p-value is greater than our alpha level (α=0.05), then we can say that we failed to reject the null hypothesis H01 and validate the Ha1.

5.2.2 T-test of the Duration on Two Conditions (ND and AD)

A paired-samples T-test was conducted to compare the completion time (duration) to succeed the test in two conditions (audio distraction (AD) and no distraction (ND)). Results of this analysis are reported in Table 3. There was a significant difference in the duration t(37)=11.099, p = 2.48×10^{-13}. Indeed, the mean of the differences between factor is 43.866 located into the 95% confident interval (35.857, 51.874). The boxplot displaying the full range where the duration varies is presented in Fig. 7. These results suggest that the audio distraction does have an effect on the duration taken by participants to recognize vibrotactile messages. Since the p-value is greater than our alpha level (α=0.05), then we can say that we failed to reject the null hypothesis H02 and validate the Ha2.

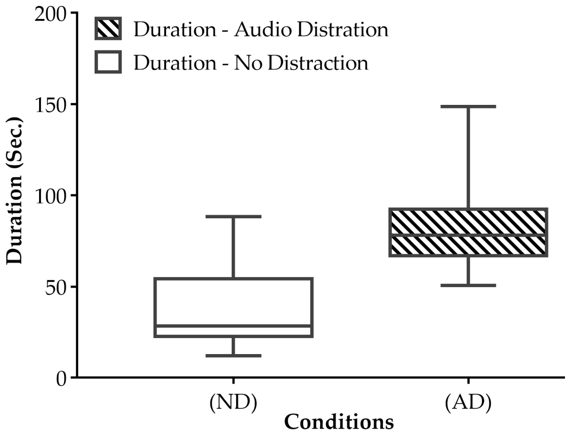

Figure 7: Boxplot of duration (AD vs ND).

The validation of this hypothesis thus becomes a major fact for the transmission of information using the haptic channel to the foot with auditory distraction. However, in our study, we simulated auditory distraction, but it would be interesting to confirm these results in a non-controlled external environment.

5.3 Discussion

In this research, we have evaluated two main hypothesis. The first one was referring to the possibility of auditory distraction to influence the number of iteration. According to results exposed in the previous subsection, it is clear that the audio distractions does have a significant effect on the number of iteration.

These results are in line with the study of Qian et al. suggesting that background sound has a significant effect on the identification time (Qian et al., 2011). Considering that the position and the types of device exploited in these studies are different this suggests that observed results may be extended to other body parts. Of courses, more studies are required to validate such observations. Mainly, considering that haptic interactions are likely to be used in wearable devices, the impact of external auditory perturbations has to study in detail.

On the basis of these results, it therefore appears that to complete this study: two aspects have to be investigated. They are: the impact of walking and the influence of aging on haptics perceptions. These aspects will be investigated in a future work.

6 CONCLUSION

This paper was aimed at measuring the impact of auditory distractions on the learning of haptic messages presented to the foot. 38 participants took part in the experiment while being at sited in a quiet position wearing the enactive shoe. They have to learn to identify four *tactons*, among a set of six, presented under the foot plantar. To reflect a real-life situation, we assess how everyday sounds do impact the performances of their identification task. For this, for two conditions: with and without auditory distractions, we evaluated how much iteration and time are required to reach a recognition rate greater than 95%? Results showed that both iteration and completion time are negatively affected by the presence of auditory distractions.

In a near future, while sending a haptic message on the foot, one extension of this study, on one hand, will be to evaluate the impact of external disturbing factors occurring in everyday life like walking task, cognitive task (counting and counting down). On another hand, we plan to identify haptic messages while walking on different types of soil in a noisy environment with youth versus elderlies participants.

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