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A vibrotactile bracelet to improve the navigation of older adults in large and crowded environments

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Abstract – **The decline of the cognitive abilities related to age usually determines a gradual withdrawal of older adults within the domestic walls. Part of the problem is the difficulty in navigating in large and crowded environments that may be perceived as intimidating. To alleviate this problem, we propose a vibrotactile device which can be used along with a walking assistant endowed with autonomous sensing and active brakes able to guide the user. In this paper, we address the problem of guiding the user with a minimal impact on his/her freedom of motion. We propose a solution based on the use of vibrotactile feedback to display directional cues. Psychophysical tests performed on a group of older adults show the effectiveness of the proposed vibrotactile strategy for the navigation of elderly people.**

I. INTRODUCTION

Very frequently people in late ages have to live with a decline in the main sensory modalities (i.e., vision, hearing, taste, and smell). A direct consequence is a reduced mobility, which increases disability in a self-reinforcing loop. In this context, the final goal of this research is to develop a walking assistant, referred to as the c-Walker, that allows older adults to maintain confidence and mobility in such environments as would be otherwise intimidating for the emotional stress that they generate. An important aspect of the guidance system should be its limited intrusiveness. A possible solution consists in the use of *wearable haptic devices* to “suggest” to the older adult the optimal path decided by the c-Walker. Noninvasive human-robot interaction can be easily achieved via devices which provide a tactile feedback to the user. In fact, visual and auditory channels may be overloaded with information, thus resulting in a rapid error increase and a consequently diminution of overall user’s performance. Using cutaneous feedback, the assisted person remains in charge of the final decision on the direction to take and she/he can override the “suggestions” of the system. However, if she/he deviates significantly from the optimal route a more authoritative action can be taken by the Mechanical Guidance Support (MGS) [1], which relies on the brakes of the cart, to gently steer the user and avoid dangerous situations.

Several works have been developed in literature to assist people with limited and/or cognitive abilities [2], [3], [4], [5]. However, the majority of them focused on the mechanical guidance of the cart. To the best of our knowledge, there is no approach which blends vibrotactile feedback with a mechanical guidance support to deliver a system which smoothly guide the assisted person avoiding as much as possible aggressive corrections of its trajectory. In this work, we focus on the vibrotactile feedback: we present the guidelines which led to the design of haptic bracelets and the feedback policies used to provide simple directional cues. Finally, an experimental validation conducted with a group of older adults will show the validity of our approach.

The paper is organized as follows. Section II contains a review of the work related to vibrotactile feedback and the description of the haptic bracelets. Psicophysical experiments conducted on a group of older adults are reported in Section III. In Section IV conclusions are drawn and future directions of research are outlined.

II. HAPTIC BRACELET

Although wearable devices like the ones developed in [6] represent an effective way of displaying forces, they may result obtrusive for older adults. This represented the main motivation that let us investigate vibrotactile feedback, since vibrating motors can be easily inserted in bracelets, belts or dresses.

Studies have demonstrated that vibration is best on hairy skin due to skin thickness and nerve depth, and that vibrotactile stimuli are best detected in bony areas [7]. In particular, wrists and spine are generally preferred for detecting vibrations, with arms next in line [8]. Movement can decrease detection rate and increases response time of particular body parts. For example, walking affects lower body sites the most [8]. The effect of movement on vibrotactile sensitivity has been also investigated in [9].

In the design of the vibrotactile device, we have to keep in mind the reduced perception of vibrotactile feedback in older adults. Given that a decline in the main sensory modalities (i.e., vision, hearing, taste, and smell) is well reported to occur with advancing age, one would expect similar change to occur with touch sensation and perception. Studies on the effects of aging in the sense of touch have been reported in [10], [11], [12] where experimental results revealed that detection thresholds for several vibra-

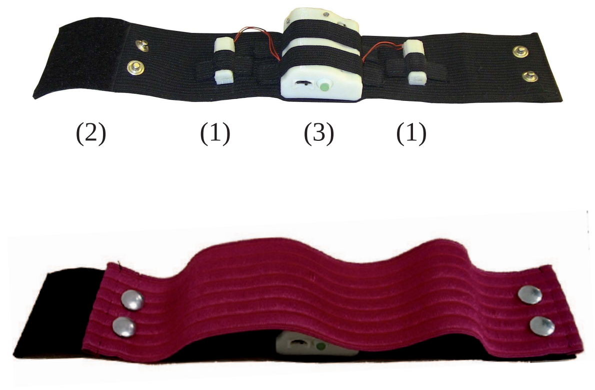


Fig. 1. The vibrotactile bracelet equipped with two vibrating motors (1) attached to an elastic wristband (2). The Li-Ion battery and the Arduino board are in (3).

tion intensities are higher in older subjects. In particular, vibration threshold is the most rapidly affected by age and is maximal after the age of 65 years.

Following these considerations, we designed a wearable haptic bracelet in which two cylindrical vibro-motors can be independently controlled via an external PC using the Bluetooth communication protocol, and generate vibratory signals to warn the user (Fig. 1). The subject wears one vibrotactile bracelet on each arm in order to maximize the stimuli separation while keeping the discrimination process as intuitive as possible. In particular vibration of the left wristband signaled the participant to turn left, and vice versa. The vibrotactile device was fitted to the arm, just below the elbow. This configuration was considered optimal to distinguish the haptic stimuli by the vibrations of the c-Walker induced when the cart moves along bumpy areas. On each bracelet the distance between the two motors is about 80 mm; the minimal distance between two stimuli to be differentiated is about 35 mm on the forearms. In two point discrimination perception, there is no evidence for differences among the left and right sides of the body and women are known to be more sensitive than men to skin stimulation [7], [13]. Note that the choice of using two vibrating motors was motivated by pilot studies in which a group of older adults tested bracelets with both one and two vibrating motors. Pilot studies were also performed in order to assess which vibrating frequency/amplitude was preferred by the users (see Sect. iii.).

The communication is realized with an RN42 Bluetooth module connected to an Arduino mini pro 3.3 V with a baud rate of 9600. An Atmega 328 microcontroller installed on the Arduino board is used to independently control the vibration amplitude of each motor. The maximal sensitivity is achieved around 200 Hz-300 Hz [14] (the human perceptibility range is between 20 Hz and 400 Hz). Two Precision Microdrives 303-100 Pico Vibe 3.2 mm vibration motors [15] were placed into two fabric pockets on the external surface of the bracelet (the width of the wristband is about 60 mm), with shafts aligned with the elbow bone. Since the rotating masses are exposed, we placed each motor inside a cylindrical case of ABS plastic in order to protect them from damage and guarantee their correct operation. The motors have a vibration frequency range of 100 Hz-280 Hz, lag time of 21 ms, rise time of 32 ms and stop time of 35 ms. Note that the proposed motors are controlled by applying a certain amount of voltage which determines both frequency and amplitude. Thus, users feel changes in both the intensity and pitch of perception when we vary frequency. The bracelet guarantees about 4 hours of battery life with one motor always turned on. The bracelets can be visible as in outerwear or accessories or invisible as with underwear. Each bracelet weights about 80 g.

III. EVALUATION OF THE HAPTIC BRACELET

In this section, we evaluate how the stimuli generated by the proposed bracelet are perceived by the subjects. Three different tests were performed. The first one was conducted in order to evaluate if the bracelets can elicit the intended causal chain of stimulus-perception-decision. In the second experiment, we analyzed if a single vibrotactile burst was sufficient to deliver directional cues. Finally, the third experiment was performed to evaluate the maximal stimuli duration that does not degrade the perception of the stimuli itself since vibration effects may persist after the end of the stimulation (*aftereffect* problem).

A. *Subjects*

The proposed device has been tested on 6 healthy subjects: 3 males, age range 73-80 (mean 75.3, standard deviation 2.9), all right-handed. None of them had previous experiences with vibrotactile interfaces.

B. *Methods*

In all the experiments, in order to maximize the vibrotactile perception, we displayed a periodic vibrational pattern with period $2\tau = 0.4$ s (instead of a continuous signal) with a frequency of 280 Hz and amplitude of about 0.6 g. On each bracelet the two motors are alternatively activated for 0.2 s, see Fig. 2.

In the first experiment, we evaluated a method of delivering haptic cues to participants using a wheeled walker when navigating around an obstacle in their path. The method used two wristbands, placed bilaterally. An attractive haptic feedback mechanism was adopted: vibration of the left wristband signaled the participant to navigate to

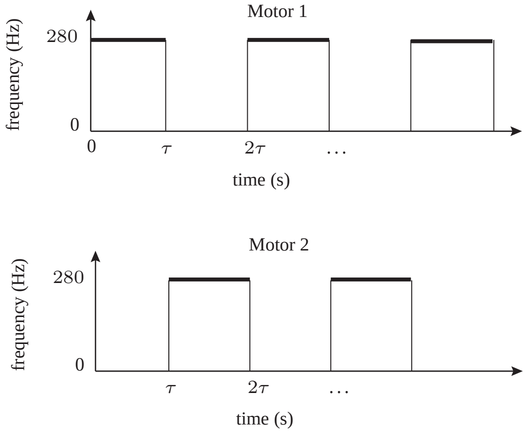


Fig. 2. In order to keep signal recognition as simple as possible, the two motors of the bracelet vibrate alternatively with period 2τ.

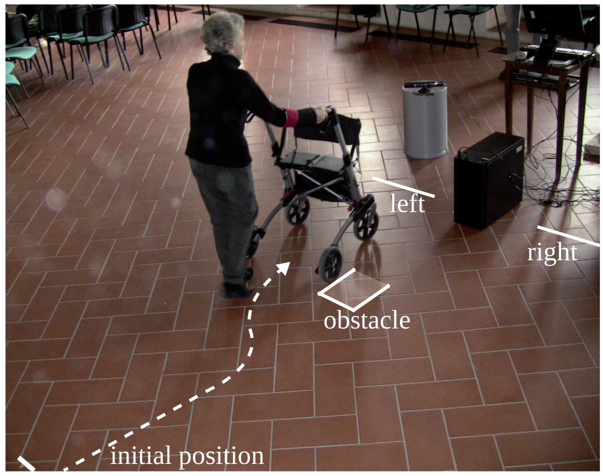


Fig. 3. The user had to avoid the obstacle by turning left or right, depending on the vibrating stimuli.

the left side of an obstacle, and vice versa. Participants were instructed to walk along a walkway using a wheeled walker whilst wearing the wristbands. The length of the walkways was about 4 m. The obstacle was placed 2.5 m in front of the initial position (see Fig. 3). The vibrotactile signal was provided as soon as the user was 1.7 m in front of the obstacle. The bracelet continued to vibrate until the person passed by the obstacle. Each subject performed 20 trials (10 left, 10 right) organized in a random order. Two RGB-D cameras tracked the motion of the human trunk using a custom designed tracking algorithm. The tracking algorithm retrieved the position and orientation of the human torso with respect to a global reference frame. We tracked the human torso since the shoulders can be considered as a sort of steering wheel that drives the human body with a short delay (of about one fifth of a second)[16].

In the second experiment, the evaluation set was composed of 20 trials (10 left, 10 right) organized in a random order. For each trial we delivered a single vibrational burst having a duration of 0.2 s. The users were asked to recognize the source of the stimulus (left or right).

Finally, in the third experiment we analyzed if signals with a long duration affected the perception of the signal itself (*aftereffect* problem). The person wore a single bracelet on his/her dominant arm. Each subject tested two sets of signals, each set was composed by signals with 4 different duration (2 s, 10 s, 30 s and 60 s). The users did not know the duration of each signal. The signal was displayed to the bracelet and the user had to recognize when the bracelet stops to vibrate. For each signal we recorded the perception time (interval of time between the end of the stimuli and the instant in which the user perceives the end of the vibrotactile signal).

C. Results

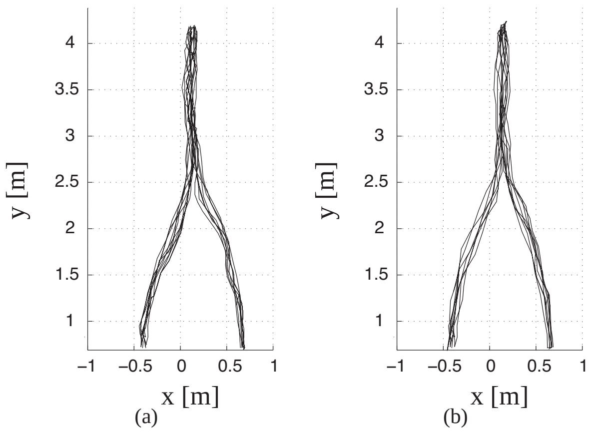
In the first experiment all the subjects correctly reacted to the vibrotactile stimuli. Fig. 4 presents the trajectories performed by the first and the second user (which are representative of our group of 6 people). It represents an overhead view of the body, as the participant walks from top to bottom. We evaluated the time elapsed between the sending of the signal and the time in which the users started to turn. Note that it also incorporates the communication time between the desktop and the bracelets and the activation time of the motors. Mean and standard deviation of the elapsed time for the left and right turn are 1.375 s $\pm$ 0.6017 s and 1.2875 s $\pm$ 0.4559 s, respectively. From the performed trajectories we did not notice unwanted oscillations in the walking when the signal is sent to the older adult so the users could easily and correctly recognize the given stimuli.

In the second experiment, 100% of stimuli were correctly recognized indicating that also a single burst of 0.2 s can be correctly recognized by the users.

In the third experiment, in order to evaluate the statistical significance of the differences between stimuli, we performed a repeated measures ANOVA on the perception time. The collected data passed the Kolmogorov-Smirnov normality test. Mauchly's Test of Sphericity indicated that the assumption of sphericity had not been violated ($\chi^2(5) = 5.255$, $p = 0.394$). A repeated measures ANOVA determined that perception time did not differ statistically significantly between stimuli durations ($F(3,18) = 1.453$, $p = 0.261$).

IV. CONCLUSION AND FUTURE WORK

In this paper we presented the design of vibrotactile devices to improve the navigation of older adults in large and



(a) (b)

Fig. 4. Trajectories performed by the first and second user (a)-(b), respectively.

crowded environments. The bracelets can be easily used in conjunction with an assistive walker in order to softly “suggest” to the older adult the optimal path decided by the walker. Experiments conducted on a group of older adults revealed the efficiency of the proposed vibrotactile feedback in terms of causal chain of stimulus-perception-decision and *aftereffect* problem.

In future works, we will validate the proposed device with a larger number of subjects. Future research lines include the implementation of a guidance strategy which blends the information delivered through the vibrotactile devices with the MGS. Experimental tests will be held in large, crowded and noisy environments.

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