# TACTILE GUIDANCE OF THE HAND IN A BLIND POINTING TASK: “THE TACTILE COMPASS”

## *Tactile Compass in a Blind Pointing Task*

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Abstract: Using tactile skin receptors that are sensitive to vibrations thereby allowing the use of a “tactile compass” made up of a matrix of micro-vibrators that reproduce tactile encoding on the skin surface to orient the wearer. The tactile compass used in this study consisted in 49 microvibrators laid out in a 7x7 matrix. The 49 microvibrators contained inertial vibrators activated by micromotors. The tactile messages were provided in a dynamic way by the successive activation of each microvibrators. The present study investigated the efficiency of the tactile compass in guiding the hand in a blind pointing task when inserted into an abdominal girdle. More specifically, the performances obtained using tactile coding are compared to those obtained using verbal instructions. The participants had to point, from the central target towards one of the four other targets each corresponding to one of the six directions (upwards, downwards, left, right, backwards and forwards) located either in the frontal plane or in the horizontal plane. Overall, the results reveal the efficiency for gesture guidance of providing tactile messages in a dynamic way, without involving learning. In addition, they establish that tactile information transmitted via our vibrotactile device is involved in the processes of both motor control and production of movement in tridimensional space.

## 1 INTRODUCTION

The tactile compass is based on the well-known clinical test of “skin writing” which consists in tracing different characters (letters or digits) on the body surface of the subject. If this test can reveal changes at the level of tactile receptors, as well as changes in the central nervous system (CNS) at low level, by contrast, the tactile compass test can yield valuable data about mechanisms underlying perceptual and gnostic functions at a higher level of the CNS (Natsoulas and Dubanoski, 1964; Caffara et al., 1976; Parsons and Shimojo, 1987; Gurfinkel et al., 1993).

Taking into account that: (1) localisation of the skin’s mechanoreceptors is quite well represented in the CNS (Phillips, 1988), (2) the brain’s processing of the tactile signal is characterised by a high level of sensitivity, acuity and rapidity (Johansson et al., 1982; Johnson and Phillips, 1981), the vibrostimulation of the skin is a useful way to present information in tactile form, instead of visually or in auditory form (Bliss et al., 1970; Jagacinski et al., 1979).

The use of a “tactile retina” as a substitute of the retina of the eye in the blind has been extensively studied over several years. For example, early pioneering work in the *Tactile Vision Substitution System* (TVSS) was performed by Paul Bach-y-Rita and colleagues in the late 1960s. The TVSS displayed visual information captured by a tripod mounted TV camera to a vibrotactile display on the user’s back (Bach-y-Rita, 1982, 2004).

According to the ‘tap-on-the-shoulder’ principle (Van Erp, 2005), vibrotactile devices consisting in fitting vibrating elements to various body locations allow spatial guidance (Lepelley et al., 2005; Lepelley, 2008). Among successful applications with relatively simple displays is Van Erp’s device, which presented directions from an in-car navigation system by means of vibrating elements located under the left and right legs (Van Erp and Van Veen, 2004). In the same vein, we have to mention the studies of Rochlis and Newman (2000), who presented directional information during simulated

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extra-vehicular activity in space by means of vibrating elements located on the torso and the neck. More complex displays, consisted in 60 (or more) vibrating elements covering the entire torso of the user. These torso displays present not only the left and right directions, but also map eight or more external directions in the horizontal plane.

This paper is devoted to investigating the efficiency of a prototype of vibrotactile device called the "Tactile Compass" (TC), which is inserted into an abdominal belt, in perception and identification of tactile stimuli to convey appropriate spatial information. More precisely the TC, consisting in a 7x7 matrix of micro-electromechanical vibrators, provides tactile messages in a dynamic way. The trajectory and duration of the vibration was designed to develop tactile semantic encoding prescriptors such as directional, kinetic and kinesiological ones.

The present study investigated the efficiency of the TC in guiding the hand during a pointing task. More specifically, in a blind experiment, the performances obtained using tactile encoding focus on the directional prescriptors are compared here to those obtained using verbal instructions.

## 2 METHODS

### 2.1 Apparatus

The vibrotactile device (Caylar Society ©) consisted in 49 microvibrators (called "pins") laid out in a 7x7 matrix (Figure 1), a power unit, a micro-control unit MIcroship (PIC16F688) and a connector serial port.

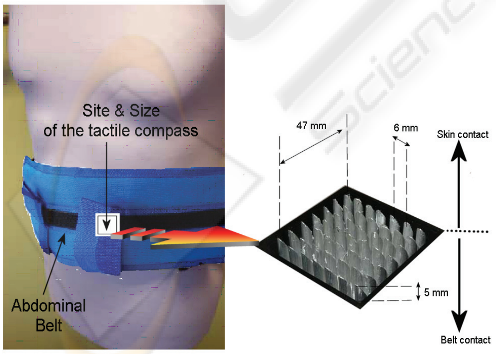


Figure 1: Prototype of the tactile compass (TC) (Caylar Society ©). Localisation of the centre of the TC was 50 mm above the ombilic.

Each pin consisted of an inertial vibrating element (VE) activated by micromotors (2 mm in diameter) based on classic technology. The shape of the VE was designed to have a conic section with a 1 square millimetre skin contact area. The distance between each pin was 6 mm. The oscillation frequency of the pins was 50-60 Hz with a magnitude of 2 mm. The 7x7 pins were mounted in a small PVC box with a square area of 63 mm. To ensure proper vibrational reception in each pin and to minimize the lateral propagation of the vibration, each pin was housed in a Plexiglas honey-comb specifically manufactured for this. The pin was glued to the cell by means of synthetic latex.

In the inactive state, all the 49 pins were in contact with the skin. In the active state, the tactile messages were provided in a dynamic way by the successive activation of each pin.

The TC was mounted in an adjustable abdominal belt. The locations of the TC in the belt were also adjustable so that they could easily be positioned regardless of the subject's body form.

### 2.2 Software of the Micro-Control Unit (MCU)

During tactile stimulus presentation, the pins were arranged in sequence to form the desired tactile pattern. For each pin, the duration (d) of activation of each pin and the time interval (t) between the activation of successive pins were specified using the *control library* of the MCU (see Figure 3).

#### 2.2.1 Pin Mapping

The MCU and the data collection software were written entirely in C++.

The MCU software is targeted primarily for use in an operating system that specifies the following by means of the *control library* of the MCU:
-the position of each pin individually in a Cartesian (x, y) plane (Figure 2 and the upper part of Figure 3), the individual pins being numbered from 1 to 49;
-the temporal characteristics (upper part of figure 3) of activation: duration (d) and time interval (t)
-pre-specified patterns of pin movement (bottom part of Figure 3).

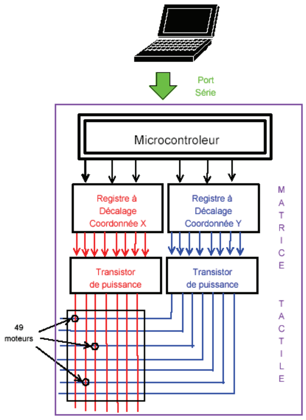
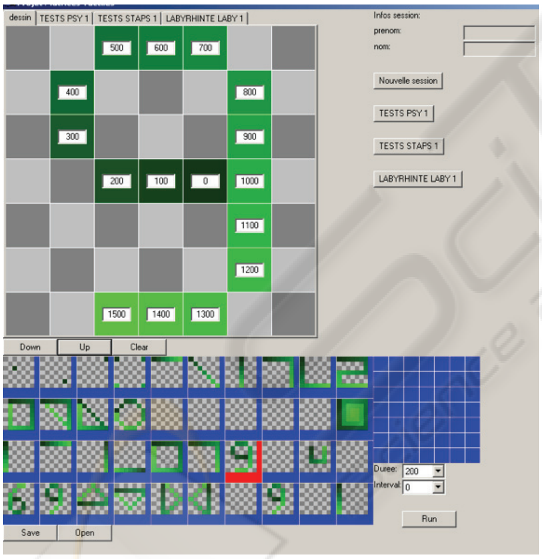


Figure 2: Schematic diagram of the generation of pin activation in a Cartesian plane (x, y).

### 2.2.2 Alpha-Numeric Screen

The alpha-numeric screen displays the *control library* that converts tactile prescriptors (directional, kinetic and kinesiological) provided by the experimenter into voltages that drive each of the 49 pins.



Duree: 200
Interval: 0

Figure 3: Overview of the alpha-numeric screen (see explanations in the text).

The upper part of the screen is an illustration of the sequential commands used to form the desired “tactile” character “9”. In this example the duration of the drawing of “9” was 1500 ms with d=100ms and t=0ms.

The bottom part of the screen depicts 40 pre-specified tactile patterns used as tactile semantic encoding *tactile prescriptor:*

-*Directional prescriptor:* Upwards, Downwards, Right, Left, Forwards, Backwards…

-*Kinetic prescriptor:* Stop, Accelerate, Brake…

-*Kinesiological prescriptor:* Ascend, Descend, Turn...

## 2.3 Protocol

### 2.3.1 Subjects

Twelve young subjects (6 males and 6 females) (29.23 ± 3.2 years) were tested in this study. They were all right-handed as ascertained according to the hand they preferred to use when writing and eating. They were recruited among students of Caen University. They had never participated in a tactile perception task.

All subjects gave informed consent to take part in the experiment according to the institutional procedures of our university.

### 2.3.2 Task and Experimental Procedure

During a familiarization phase, the participants had to point from the central target towards one of the four other targets, each target corresponding to one of the six directions (upwards, downwards, left, right, forwards and backwards) (Figure 4C and 5) located either in the frontal plane or in the horizontal plane (Figures 4A and 4B). In a test phase, the directional targets were removed and the participants had to point at the target, the direction of which was provided by either tactile instructions (on the abdomen) or verbal instructions. Both types of instruction (tactile and verbal) and types of plane (horizontal and frontal) were counterbalanced across participants.

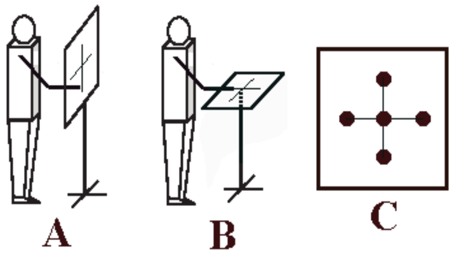


Figure 4: Schematisation of the two planes of the pointing task (A: frontal plane, B: horizontal plane) and of the positions of the targets (C).

Kinematic data were analysed to measure the precision and the velocity of the pointing task. For this purpose a motion capture system (Vicon MX-40, Oxford Metrics Ltd) including 4 cameras with

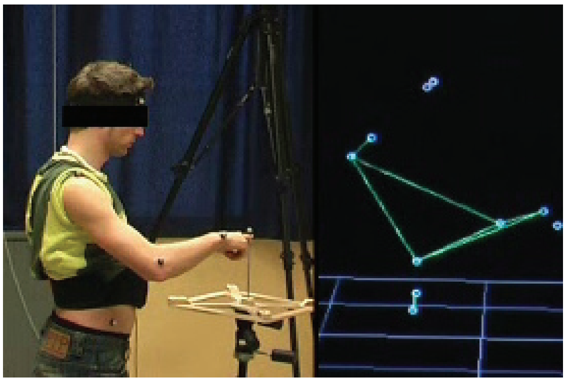


Figure 5: Experimental setup (on left), display of the 9 markers during pointing to the central target.

100 Hz visual sampling frequency allowed us to record the 3D position of 9 markers located on the fingertip, wrist, elbow, shoulders, hips and head (Figure 5).

## 3 RESULTS

The results support the proven effectiveness of TC in tactile guidance of the hand during a blind pointing task. The level of performance halfway between chance and perfect performance has therefore been clearly reached. Indeed, the participants identified 93.27 % of tactile directions (Figure 5). Moreover, no significant effect of type of instruction (verbal versus tactile) on the number of correctly identified directions ($\chi 2$ = 1.18; ddl = 1; ns) was noticed. Similarly, no significant interaction between type of instruction and precision of pointing (F(1,10) = 0,96 ; ns), nor between type of instruction and variability of pointing (F(1,10) = 1,24 ; ns) were noticed.

In addition, no significant effect of type of instruction was found in the kinematic data (mean velocity (F(1,10) = 0.28; ns); planes of motion (F(1,10) = 0.002; ns). Consequently, the prototype provides information about direction that is at least as well perceived as verbal instruction, and does so without disturbing the spatio-temporal organization of the movement.

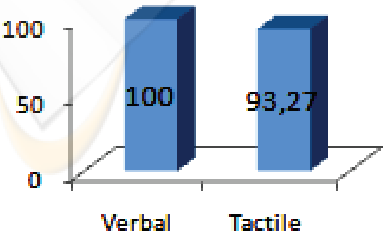


Figure 6: Percentage of correctly identified directions for verbal and tactile instructions.

It is of interest to notice in Figure 7 that pointing was faster in the horizontal plane than in the frontal plane (F(1,10) = 6.44; $p < 0.05$).

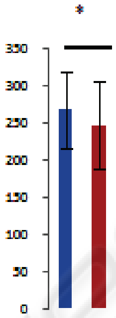


Figure 7: Mean velocity in mm.s$^{-1}$ for horizontal (blue) and frontal (red) planes during pointing.

Furthermore, the precision of pointing was better in the frontal plane than in the horizontal plane (F(1,10) = 6.59; $p < 0.05$). The mean deviations were greater in the horizontal plane than the frontal plane (F(1,10) = 39.52; $p < 0.05$). These results are in agreement with those obtained by Ghafouri and Lestienne (2006), which showed an under-representation of horizontal egocentric space in the internal representation of space.

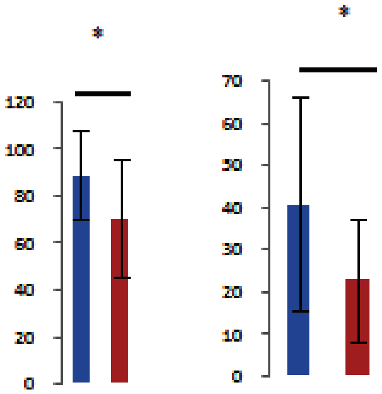


Figure 8: 3D constant error (left) and mean deviations (right) for horizontal (blue) and frontal (red) planes during pointing in mm.

## 4 DISCUSSION

Overall, the results of this study reveal the efficiency of providing tactile messages in a dynamic way.

Indeed, the present experiment confirms that subjects are able to indicate an external spatial orientation that matches successive vibrotactile point stimulus on a small surface (63x63 $mm^2$) of the skin of the abdomen. The tactile discrimination between the six directional prescriptors results in remarkably robust similarities across the 12 subjects. In other words, this study showed that a localized vibration on an abdominal belt could easily and accurately be interpreted as a direction in the horizontal and frontal plane and can be used to signal multi-directional motion and to guide hand movement.

Through these initial empirical findings, the results confirm that the skin surface of the human body (hand, arm, leg, neck, torso, abdomen) is very sensitive to temporal aspects of vibrotactile stimulation (Gurfinkel et al., 1993; Van Erp and Werkhoven, 2004; Lepelley et al., 2005; Lepelley, 2008; Asseman et al., 2008).

The primary goal of the present study was to gain insight into the characteristics of generation of the tactile message. Consequently, we tested the appropriate spatial and temporal resolution of the tactile pattern (see appendix) to generate the tactile semantic encoding:

a)-distance between each pin: 6 mm,
b)-vibration frequency: 50-60HZ,
c)-activation time (d) of the pin: 200 ms,
d)-step time (t) between the activation of successive pins: 150 ms.

It is of interest to stress that the precision of pointing was better in the frontal plane than in the horizontal plane. These results are in agreement with those obtained by Ghafouri and Lestienne (2006) during a pointing task involving pointing to virtual targets located in the sagittal, frontal and horizontal planes. Errors were minimal for the sagittal and frontal planes and maximal for horizontal plane. These disparities in errors were considerably reduced when subjects pointed using a visual guide. These findings imply that different planes are centrally represented, and are characterized, by different errors when subjects use a body-centered frame for performing the blind pointing and suggest that the representation of peripersonal space may be anisotropic. This study reveals the high stability of the egocentric reference system (Lestienne and Gurfinkel, 1988). This was consistent with the finding of our previous works performed in microgravity, dedicated to the perception and interpretation of complex tactile stimuli (Gurfinkel et al, 1993). Based on these findings we can assume that tactile patterns encoding prescriptors are perceived as a “local sign” taken into account in the information about the configuration of the body (Gurfinkel et al., 1994, and the appendix).

## 5 CONCLUSIONS

On the basis of the perceptual process of orientation in 3D space through the use of tactile cues, the results of this experiment establish the fact that tactile information transmitted via our TC is involved successfully in the processes of tactile guidance of the hand in tridimensional space.

One of major advantages foreseen in using the TC is its portability. This compact and lightweight TC can be comfortably incorporated in the user’s clothing without impairing movement.

On the basis of the positive experiences with the TC, our laboratory has recently been involved in an investigation into the potential of the TC in land navigation.

The key to successful implementation of the TC lies in the ability to convey effective directional information that provided the user with a major safety enhancement: “moving with hand and eye free”.

In future work, the TC presents a number of promising functional opportunities for use in clinical and rehabilitation applications. These include assistance in balancing and in coordinating movements, combining the TC and virtual reality techniques.

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-Ministère de la Défense: Délégation Générale pour l’Armement (DGA) Grant: REI (Exploratory and Innovative Research) No 2008 34 0030.

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## APPENDIX

Perception and interpretation of cutaneous stimuli applied to the same tactile receptive field for different posture and different orientation of the body segment in question can yield valuable data about the perceptual and gnostic functions during the learning process in order to achieve tactile shape recognition. The studies were conducted on 17 subjects. Two postures (see figure 9) were studied: the vertical (1, 2) and horizontal positions (3, 4).

For each posture two conditions were examined: with the right leg extended (1, 3) and during flexion of the right leg at 90° between hip and knee joints (2, 4).

In each situation, one of the 4 tactile stimuli was presented: digits and simple geometric shapes (see Figure 9). The TC was fixed on the frontal surface of the right tight with Velcro strips. The results show that the task of identification of complex tactile stimuli was not affected by modification of posture relative to the vertical gravitational body. However, an increase in the frequency of errors was observed when the leg was flexed: the part of the figure closest the knee was perceived as being on top. It is important to note that with more or less intensive training, we observed a related improvement in the task.

Information about the configuration of the body part is taken into account during the stages of processing the tactile signal.

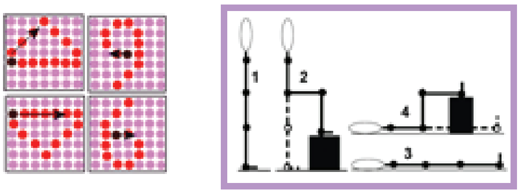

Figure 9: Schematisation of the tactile stimuli (left) and the postural conditions (right) (from Lepelley et al., 2005).