Perceptual strategies under constrained movements on a zoomable haptic mobile device

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Abstract. This study shows that zooming and pointing strategies are influenced by visual constraints when using a haptic mobile device. Participants were required to point on invisible targets that were only detectable via a tactile feedback. Movements were either constrained or unconstrained. Results revealed that pointing and zooming strategies depended on the order of training. Participants who started their training with unconstrained movements, kept using the same strategies even when constraints have been removed. This suggests that constrained movements allowed participants to explore other strategies that would have not been available and extended their repertoire of exploratory strategies related to the haptic zoom.

Keywords: Mobile devices, constrained movements, haptic zoom, perceptual strategies.

1 Introduction

Although visual and tactile senses are different, several research on perceptual illusions showed similarities between the two senses [7, 26, 27]. In this study, we focused on haptic zoom conditions that could resemble a visual zooming experience. Ziat et al. showed that when participants manipulated a haptic zoom to recognize objects, they differentiated easily the lowest and highest levels of zoom, but failed to use intermediate levels despite their availability [23]. When describing their haptic zooming experience, participants compared it truly to the visual experience: "I am getting close/far away to/from the object" or "the object is getting big/small relatively to me". However, they missed details that were only available with intermediate levels of Zoom. In a visual zooming user interface (ZUI), intermediate levels are relevant for displaying in-between information [8] and therefore are crucial for a zooming experience.

In this study, we assessed participants' abilities to detect invisible targets under constrained movements while using a mobile zoomable haptic device. Our aim was to investigate participant's abilities to develop new perceptual strategies when confronted to an obstacle during the interaction and whether the constraints afford them to use other

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alternatives available on the device, such as intermediate levels of zoom that would not have been used in an unconstrained situation.

Nowadays, the tactile modality is automatically associated with mobile technology and touch-screen displays occupy the biggest part of the market. One recurrent problem is the occlusion problem where the fingertip hides part of the screen and leads to pointing errors. As an alternative, Baudisch et al. proposed nanotouch, a method that allows the interaction with the back of the device [1]. Other methods such as programmable lateral fictions [12,16] or tactile feedback directly on the device [13, 18] improve the quality of haptic interaction. The stylus being one of the most popular accessories, researchers suggested to enhance stylus-screen interaction [9, 10, 25].

We designed the concept of haptic zoom as an alternative interaction [20]. Indeed, ZUI allows scrolling and panning, but this navigation is always incidental to a user's disorientation [5]. For a "visual" ZUI, the concepts of space and distance are very relevant. Furnas and Bederson defined the zoom as a navigation of the space of scale. The concept (Fig.1b) consists of piling several copies of the image of different sizes in an inverted pyramid, where the axis of the pyramid represents the scale dimension. Zooming consists of displacing a window (Fig.1a) on this axis [5]. For touch, it is very hard, if not impossible, to navigate on the scale of space because there is no space between the fingertip and the tactile display. The suggested haptic zoom is a reverse concept of Fig.1b, where the zooming window represents a virtual matrix of sensors that activates a tactile array. Moving the matrix consists of changing the tactile feedback under the finger and then create the illusion of depth navigating [22]. The matrix has a different size for each level of zoom (Fig.1c). To reach the details and increase the resolution, its size must be decreased. The concept is very similar to an eagle eye who can switch from one fovea to another. The first fovea is used to detect the prey; while during the swoop, the eagle switches to the highest resolution fovea that contains more dense receptors allowing it to focus on its prey. Similarly, increasing the matrix size decreases the resolution; while, decreasing its size increases the resolution. Ziat et al. showed that the two zooming techniques are equivalent for perceiving graphical objects [22-25].

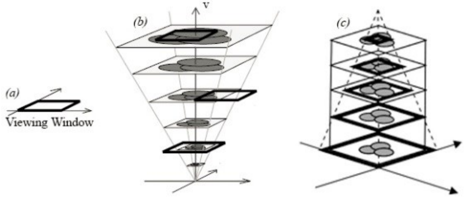

Fig. 1. a) the viewing window; b) the pyramid of scale (From Furnas and Bederson, 95); c) reverse concept of zoom (Ziat, 06)

2 Proposed Approach

Research showed that when confronted to new perceptual experience [21] or visuomotor conflicts [3], participants learn and adapt very quickly. Although some confusions might remain during the learning process, they are able to develop efficient exploratory procedures [11] allowing them to perceive correctly the surrounded environment. The same issues are risen when using a new device or new technique of interaction. Understand how human beings interact with objects has also been studied through the concept of affordance [6] and physical constraints [15]. Human beings are surrounded by constraints imposed either by the environment or the task to perform. For example, when walking in a confined space, the walls act as an environmental constraints that restricts the locomotion along the walls. When opening a door, the hand movements differ depending on the door handle. Indeed, a doorknob affords the way the door should be opened. If it is a round operating mechanism, it affords to turn the knob; while if it is a lever-operated system, it affords swinging the handle.

Several studies [2, 17] showed that physically constrained and unconstrained movements involve different control strategies while reaching or pointing a target. In addition, other studies showed that visual constraints may influence movement production, resulting in variable trajectories [4, 14, 19]. In the present study, the constraints were created by changing the size of the zoom window. Constraining participants' movements might help to dissect the perceptual process of zoom into several components and understand the different strategies involved in this process when using a small display.

2.1 Haptic Zoom

Mobitact, the mobile interface consists of an IPAQ PDA running under Linux and uses TactiPen, a tactile pen with two Braille cells (for more details see [9]). The zoom window consists of a matrix of sensors controlled by the pen. Each of the eight sensors corresponds to an area on the screen and the corresponding tactile dot is activated if an object is detected in this area (Fig. 2). The matrix moves with the cursor, which is controlled by the Tactipen. The required level of zoom, z, is obtained by changing the size of the "window" i.e. the size of the matrix. This "matrix-window" can be considered as a virtual screen of variable sizes which moves with respect to fixed digital objects. In order to obtain a high resolution, the size of the matrix must be decreased; to obtain a low resolution (i.e. backward zoom), the size of the matrix must be increased. Thus, the same image will be perceived differently depending on the level of zoom of the matrix (all 8 dots can be activated or only some of them) (Fig. 2).

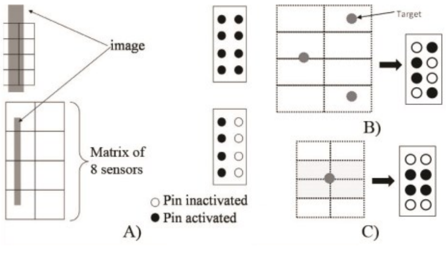

Fig. 2. a) The same image perceived differently depending on the size of the matrix and activates a different pattern of dots; Each sensor activate a dot on the cell, b) four sensors are all in contract the target, c) four central dots are activated and the target becomes visible.

In a previous study [23], participants developed simple and efficient strategies to distinguish the lowest and the highest levels of zoom. However, they failed to use intermediate levels while navigating on the axis of scale. A visual clue such as an edge that gives feedback on the intermediate levels might encourage participants to explore other perceptual strategies that would allow a fully haptic zoom experience.

3 Pilot Study

3.1 Participants, Materials, and Methods

Ten participants took part in this study. They were all members of UTC, with ages ranging between 27 and 64 years old. The task consisted of detecting non-visible targets on MobiTact screen as rapidly as possible by using tactile feedback to detect the targets and visual feedback to perceive the bold cursor.

As shown in Fig. 2b, several non-visible targets are present at different positions on the PDA screen. In order to detect these targets, participants must manipulate the "zooming matrix" by using a slider that is displayed on the upper part of the PDA screen (for forward and backward zoom) to change its size. The largest size of the matrix (minimum forward zoom) covers the whole PDA screen by giving a global tactile perception of the several positions of the targets. Except the cursor cross (see Fig. 3), the matrices are also invisible on the screen, so the decision to adjust their size and to make a target appears on the screen can only be made on the basis of the tactile feedback and the position of the cursor on the screen.

Hiding the matrices during the interaction is important since the only available feedback should be obtained through the vibrotactile input. The concept has been inspired by the slide positions on the trombone. The trombone is a unique instrument that use movable slide to change the pitch. This skill is not easy to master for a beginner due to the infinite possibilities for adjustments of the slide. The very important aspect is that there are no visual marks that indicate the slide positions and it is only with practice that the person associate that, for instance, the sixth position is when the arm is completely extended and the third position is when the brace is equal with the bell. The slides positions are similar to the levels of zoom defined by matrix sizes. The only feedback is only giving by the position of the arm on the slide in the former and the position of the pen relatively to the screen's edges in the later. Similarly to the Trombone's brace, the cursor (the bold cross in Fig. 3) is visible to help participants to "point" very precisely on the targets. "Pointing" requires a light downward pressure while the four central sensors are activated by the target. An attempted point, i.e. downward pressure alone, would fail if all four central sensors were not activated.

In the "constrained" condition (C), participants use the screen borders as a clue information to adjust the size of the matrices and manipulate intermediate levels of zoom. Although it constrains participants' movement, it gives supplementary information on the distance between the cross and the edges of the screen. By opposition to the unconstrained condition (NC), where the matrix can exceed the limits of the screen, the matrix edges cannot exceed the PDA screen in a C condition. Thus, as shown in Fig. 3}, it is quite impossible for the participant to point on the target with matrices 1 and 2 because they reach the edge before the cross reaches the target; In order to reach the target, the matrix size must be reduced (forward zoom) to point on the target as shown with matrix 3. In other words, the target is only accessible for pointing when $d_m \leq d_c$ (d_c: the distance between the target and the nearest edge of the screen, d_m: the size of a sensor).

To make this operational, we distinguished two cursors: a real cursor and a virtual cursor. The virtual cursor was linked to the matrix and thus directly related to the tactile feedback. The "real cursor" corresponds to the usual cursor on the PDA screen; it was deliberately made invisible to avoid distracting the users. The constraint arise when the virtual cursor is blocked at a distance of d_m from the edge of the PDA screen (Fig. 3). When the participant succeeds in pointing on a target (Fig. 2b), the four central dots of the TactiPen are activated (Fig. 2c) and the target becomes visible on the screen. The game is over when the participant has found all the targets. In the NC condition, the matrix can move off the screen; here, the virtual cursor and the real cursor are equivalent.

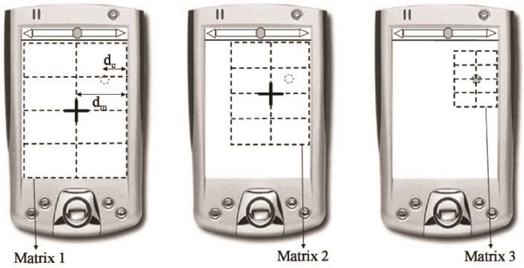

Fig. 3. "Constrained" condition: the matrices 1 and 2 have reached the limit of the PDA edges and cannot reach the target; the size of the matrix must be reduced until $d_m \leq d_c$. With Matrix 3, the participant can point on the target.

3.2 Procedure

All participants performed the experiment with both conditions: C and NC. The conditions were equally counterbalanced between participants. In each condition, the participant performs three trials without a time limit. The starting level of zoom was the maximum level of zoom (largest matrix size) with the number of targets increasing from trial to another (3 in the first trial, 5 in the second and 8 in the third). The trial ends when all the targets has been found. A message was displayed to inform participants that they found all the targets and ask them to start the next trial. They were also informed that the matrix-window is divided into 8 zones, and that each zone can contain only a single target at a time. To avoid any effect of memorization of target locations, the target positions were different for each trial. At the end of the two conditions, participants were asked to fill out a questionnaire where they reported their preferred condition, the reason of their choice, and explained the strategy they used to point on the targets.

One of the objectives of this experiment is identify the factors which lead participants to select intermediate levels of zoom to point on the targets. The present study might provide further understanding of how participants manage to choose these levels.

Our hypothesis is that participants will make much greater use of intermediate levels of zoom to point on the target in the C condition than in the NC condition, because C condition provides the user with additional information about the distances d_m and d_c, which at first is not intuitive but is learned during the interaction.

4 Results and Discussion

4.1 Zooming and Pointing Strategies

While there is no significant difference for the C condition for levels of zoom used to display the targets, the NC condition showed a significant effect. Indeed, participants that started the experiment with the NC condition had a very simple strategy to detect the target that consisted of using either the minimum or the maximum level of zoom for both conditions. As expected, intermediate levels of zoom were only used by participants who started with the C condition. Interestingly, when constrains disappeared for the NC condition, they were still using several levels of zoom to point on the targets. This suggests that the zooming strategy used for the NC condition was the result of learning gained during the C condition.

Although the C condition limited participants' movements, it helped them to use alternative strategies when constrains disappear. We believe that the information about relative distances d_m and d_c was also gained during the C condition. When the cursor stops at the limit of the size of the matrices, participants were forced to explore other levels of zoom than the extreme levels. This fact was confirmed by feedback from three participants that preferred the C condition because it enabled them to rely on the visual feedback to adjust the zoom, based on the distance between the target and the closest edge.

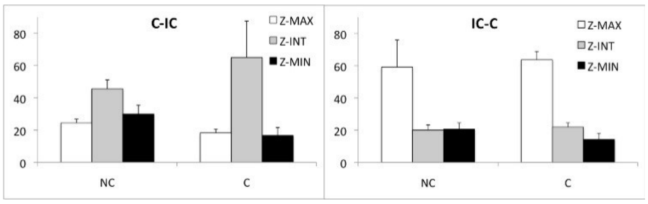

Fig. 4. Zoom use for intermediate and extreme levels (Z-Max and Z-Min) for C-NC and NC-C

Besides, all participants who used intermediate levels of zoom explained that the partial activation of the dots helped them to choose the most adequate level of zoom to navigate with the cursor and to point on the target. They described the steps as follows: "I chose a level of zoom and then felt the tactile feedback, moved until the cursor is blocked (i.e. visual feedback), felt again the dots and changed the level". In other words, their strategy is based on the combination of the tactile and visual feedback to locate the target. Finally, all participants agreed that they used the maximum level of zoom to detect the target position on the screen areas, which corresponds to whole activation of the dots. For those who did not rely on intermediate activation, they used the minimum level of zoom to get a better precision on the target location and which corresponds to one dot activated at the same time.

Mann-Withney tests showed that the number of pointing differs significantly ($p>.05$) according to the starting condition. Whatever the number of targets, participants who started their learning with the NC condition had a significant higher number of pointing than participants who started the task with the C condition. This high number of pointing (mean = 237.63) might suggest that most of the participants who started with the NC condition didn't have a real exploratory strategy. Indeed, reaching a target was only facilitated by the number of pointing. Besides, this behavior did not change when they switched to the C condition since the number of pointing (220) remains approximately the same. Conversely, participants who started with the C condition had a reasonable number of pointing (mean = 68.77) for both conditions.

5 Conclusion

We described how constrained movements allowed participants to develop efficient strategies to handle intermediate levels of zoom even when these constrains disappear. First, the strategy consisted of identifying visual-tactile cues to locate and reach invisible targets on a screen during constrained movements. Finally, participants kept using the same strategy developed during the C condition, i.e. they used the intermediate levels even though constrains were removed. This suggests that participants learned new perceptual strategies not necessary linked to constraints, since even when removed, they continued using the intermediate levels. Most importantly, it suggests that haptic zooming experience could be fully similar to a visual zooming experience, if one gives enough information on the axis of scale.

Constraining the cursor with the screen edges was a mean to understand the zooming experience within the haptic modality. However, in order to reach a more natural and intuitive movement, other graphical or physical tools need to be combined to fully "live" this experience. The second finding is that the C condition reduced significantly the number of pointing which suggests that participants were using efficiently the visuo-tactile feedback to detect the position of the targets. This corroborates previous findings [2, 4, 14, 17, 19] that argued that visual and physical constraints make participants opt for different strategies.

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