Investigating the Effect of the Body's Spatial Representation on Gestural Interaction

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Abstract
Recent research has shown that the body provides an interactive surface suitable for eyes-free interaction. However, when relying on proprioception and kinesthesia alone, performing gestures on the surface of the body may not be universal among users. We argue that the way users perform gestures on the body depends on their body's spatial representation. This representation may also affect the perception of haptic feedbacks on the skin of the body. To demonstrate our argument, we report a study investigating gestures on the surface of the stomach. We then discuss how our results can also benefit to haptic output techniques and consider new research opportunities.

Author Keywords
Spatial body representation; Gestural interaction; On-body interaction; Haptic feedback

ACM Classification Keywords
H.5.2. User Interfaces — Input devices and strategies — Haptic I/O.

Introduction
On-body interaction provides an always available surface to support gestural interaction, especially in

mobile contexts. While most of the research in the HCI community has focused on designing new gestural interaction techniques driven by visual feedback, mobile context usually requires visual attention to be dedicated to maneuver our way around obstacles or avoid any potentially harmful situations. When the visual sense is unavailable, performing gestures relies on proprioception and kinesthesia alone. They provide users with information to build a mental representation of their body shape necessary to the coordination of their limbs. However, because of the dynamic nature of movements, the space configuration of the limbs can be unpredictable. In this paper, we investigate the potential effect of the limbs' spatial configuration on performing gestures on the body surface and on the perception of ultrasonic haptic feedback on the skin of the body.

We first present existing evidence of the effect of spatial body configuration on cutaneous stimuli perception. We then investigate the effect of spatial body representation on gestures with a study on perception on the surface of the stomach. We show that users follow different representations that are stable when using simple gestures such as directional strokes but more subject to change with more complex gestures such as drawing a digit's shape. We then discuss how our results suggest that the body's spatial representation may as well affect the perception of haptic feedbacks.

The Body's Spatial Representation

Cutaneous pattern perception depends on the position and the skin surface orientation. Parson *et al.* [4] have reported that the head, the upper body and the hands have different spatial frames of reference depending on their spatial configuration. In particular, the upper chest has special frames associated with it because it is a general zone for referencing information about objects in front of the body [4]. Previous experimental studies also report that the perception of spatial orientation relies on the internal gravity representation of the user and on perceptive information collected about the orientation of the surface supporting the interaction [3]. Interestingly, no rule governing the perception of orientation for vertical surfaces located below the chest has emerged.

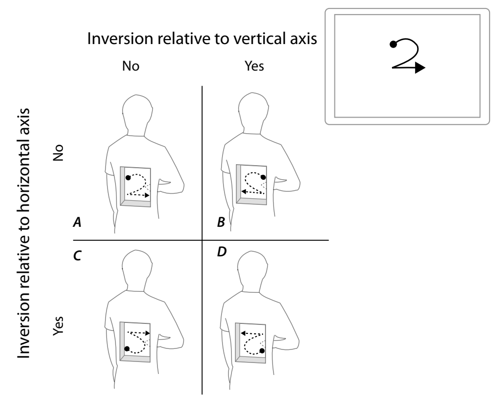

Figure 1. Spatial mental representations of the digit "2". The participant is facing the screen where the stimulus is displayed. A) No inversion. B) Inversion relative to vertical axis. C) Inversion relative to horizontal axis. D) Inversion relative to both axes.

On-Stomach Gestures

Without visual feedback, users need to build a spatial frame of reference that will guide them for controlling the orientations and the directions of the gestures. In order to understand how users perceive their stomach as an interactive surface, we invited participants to draw directions and digits on the surface of their stomach and observed the horizontal (towards the left or right side) and vertical directions (top or bottom) of the gestures to identify the internal user's spatial representation of their stomach surface (Figure 1).

We designed an experiment considering two factors: the *presentation* mode and the *nature* of the stimulus. The stimulus was either displayed graphically with directional cues facilitating its reproduction or textually without any information about how to draw it (Figure 2). The stimulus could either be a direction, which was considered as a simple gesture, or a digit, which we believe was more complex to draw and could affect the way the users would perceive spatial orientation.

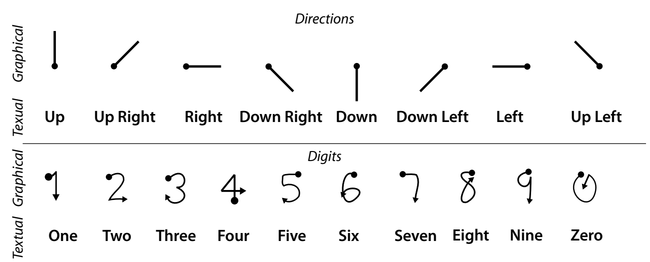

Figure 2. Graphical and textual stimuli used during the experiment.

By convention, we consider there is a "direct mapping" when the experimenter, located behind the participant, sees the symbol through the participant's stomach surface as depicted on the screen (Figure 1A). Three other mental representations are however possible depending on whether there is a horizontal (Figure 1B), vertical (Figure 1C), or horizontal and vertical (Figure 1D) inversion.

Twenty to 25% of the samples showed inversions relative to the horizontal axis whatever the experimental condition. This result is interesting since the psychology literature suggests that spatial representation of up/down direction is relative to the perception of gravity by the vestibular and somatic nervous system, and through sight [4]. These contradictory results can be explained by the mental representation of the spatial configuration of the body and the position of the head relative to the ground [4].

Our results additionally showed that the more complex the gesture, the less stable the orientation. Three of our participants changed their spatial mental representation over time when *digits* were presented *textually*. They emphasized the difficulty to select a unique representation: "*I tried to pay attention but for the digit 3 in particular I could not decide on an orientation. For digit 5 and 2, it was easier*".

The Effect of Spatial Body Representation on Gesture Learning

Recently, devices such as Ultrahaptics have made it possible to produce contactless haptic feedback on users' hands or body using ultrasounds [2]. Wilson *et al.* have shown that users are able to perceive motion of ultrasonic patterns on the skin of the hands [6]. In particular, participants could recognize the direction of movements towards the four cardinal points.

Building on these results, it is then conceivable to use such systems to support the learning and the execution of gestures on different parts of the body. For instance, with more complex haptic patterns, one could design feedforward techniques to draw a dynamic haptic pattern depicting the whole gesture on the skin of the body. The drawing could then be updated with the remaining path as the user is performing the gesture [1]. However, for this technique to work properly, the perception of the haptic patterns has to remain consistent through the different spatial configurations of the body part that is being targeted.

During the Wilson's experiment, participants experienced ultrasound haptic feedbacks on their hand with the palm facing up. Based on our results, we suggest that spatial representation of the body could also affect the spatial perception of haptic feedback that moves on the skin. The understanding of this phenomenon is necessary in order to provide correct and useful haptic feedbacks to users.

Conclusion & Research Agenda

We have discussed the effect of the body's spatial representation on gestural interaction. Our study has shown that users follow different representations that are stable when using simple gestures but more subject to change with more complex gestures. However, our study was limited to gestures performed on the abdominal surface. Spatial representations could be different when performing gestures on other limbs with different spatial configurations. Furthermore, while our research has only focused on input, we think that spatial representation of our body could also affect the perception of haptic feedback on the skin and thus the performance of promising output techniques to support gesture learning.

We plan to investigate the effect of spatial representation of other limbs on gestural interaction and moving haptic feedback. The ultimate objective is to draw a map of spatial representations of the body for each limb and propose a model of body spatial representation for on-body gestural interaction and haptic feedback on the skin.

Acknowledgements

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