Belly Gestures: Body Centric Gestures on the Abdomen

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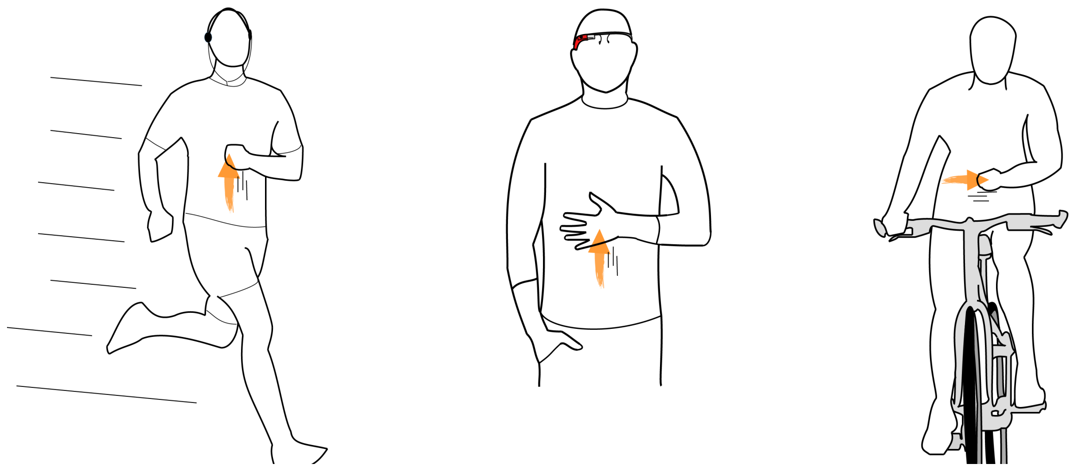

Figure 1: Examples of situations where Belly Gestures could allow for quick interactions: to skip a song while jogging (left), to control smart glasses (middle), to reject a phone call while riding a bike (right).

ABSTRACT

Recent studies have shown that using the body as an interactive surface is particularly well adapted for eyes-free interaction. While researchers have focused on using arms and hand they have not considered using the belly. We argue this surface is especially appropriate for eyes-free interaction because the belly offers a large surface, which is relatively stable even when walking or running. In addition, users can easily reach this surface with their two hands without fatigue or having to adjust the position or orientation of the abdomen. We highlight the advantages of interacting with this surface and present a study that evaluates how users perform gestures on their abdomen. We observed that users use different mental spatial orientations depending on the type of gesture (digits and directional strokes) they have to draw. In particular, our results show that users draw gestures following symmetries relative to a horizontal or vertical axis when they are not provided with visual orientation hints. The more complex the gesture was, the less stability in orientation was observed. Then, we focus on directional strokes and find that, despite the fact that the abdomen is not perfectly linear, users are able to draw almost linear gestures. Especially, they performed very well in cardinal directions. Finally, we propose some guidelines to inform the design of interaction techniques.

Author Keywords

Gestural interaction, on-body interaction, gestures, belly, abdomen, spatial orientation.

ACM Classification Keywords

H.5.2 User Interfaces: Input devices and strategies

INTRODUCTION

Some recent studies have proposed to use the *body* as an interactive surface. On-body interaction has several advantages: (1) body parts are by essence always available, (2) they offer a convenient surface for gestural interaction and (3) they provide tactile feedback, not only from the body part acting as an interactive surface but also from the limb which is interacting with it. Moreover, thanks to proprioception, users can sense the position and the orientation of their limbs without looking at them. Taking advantage of this property, users can thus interact eyes-free.

On-body gestures can hence ease interaction in usage contexts where users are engaged in activities that would

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suffer from interruptions. For example, users, devote a large part of their attention to avoid obstacles when they are walking or running. Such situations make it difficult to interact with mobile devices [2], especially if the user must look at them, and thus lead to undesired interruptions.

In this paper, we investigate how belly interaction can serve to facilitate interaction. Previous literature has mostly focused on interaction techniques that rely on using the hands and the arms. While [11,27] report that the abdomen should be suitable for interacting, no exploratory study has been conducted so far. The abdomen surface has several interesting advantages in comparison with other body areas: it offers a large and relatively stable area (even when walking and running), enables easy access from both hands and does not require tiring movements because hands do no need to be moved far from their rest position. Such advantages are beneficial for rapid simple gestures that do not require important attention. Moreover, by being out of sight, belly interaction naturally encourages eyes-free interaction.

To understand belly interaction, we observed how users perform gestures on the abdomen in eyes-free mode. In particular, we were interested in understanding the users' perception of the spatial orientation of the abdomen surface when performing gestures. Our results show that users can have three different mental spatial orientations of the belly surface when they draw directional and digit strokes on it. .Depending on the nature of the gestures they perform, they generally rely on one or two of them and the mental representation is less stable for complex gestures. We found out that 42.9% of the gestures involving digits were left/right inverted and 24.5% upside down. Moreover, unlike simpler gestures such as directional strokes, these gestures required an important cognitive effort. Building on these results, we analyzed how users performed directional strokes. While the belly surface is not perfectly flat, our results show that gesture traces are almost linear. Moreover, gestures on the cardinal directions and those going towards the left side of the belly were especially easy to perform when interacting with the right hand.

RELATED WORK

Research on on-body interaction has been blossoming recently. Many efforts have been devoted to explore new to ways to capture body touch [2,9,16,25] and to adapt existing interaction techniques [8] whereas relatively little attention has been dedicated for understanding human factors that influence interaction on body parts [7,14].

On-body interaction

Our body is always noticeable. Muscle spindles, joint and skin receptors play a substantial role in motor control and for building a mental representation of the body's shape. By providing feedback, they contribute to maneuver our way around obstacles in the dark and to manipulate objects which are out of our view [20]. Thanks to kinesthesia, we are continuously aware of our limb positions and their movements, this allowing, for instance to interact on our belly without requiring visual attention. The skin also provides a sensitive surface. While the degree of skin sensitivity depend on body parts [25], combining tactile information from several parts improves precision, especially in eyes-free contexts [14].

To our knowledge, most of the previous research has focused on using the arms and the hands as an interactive surface. One reason may be that these parts are especially convenient for displaying information since they are in the user's field of view.

On-arms interaction

Not only arms offer advantages such as video- [2,7,8] or bioacoustic recognition [9,14] but also they enable easy access with the opposite hand, which allows performing discrete gestures [2]. However, these techniques require cognitive efforts to coordinate active and passive limbs to interact together and they may be tiring since they require keeping one arm up in the air near to the other limb to improve reachability. Moreover, arms are subject to involuntary contact.

On-hands interaction

Hands provide several landmarks helping user to interact without visual feedback. For instance, Imaginary Phone [7] takes advantage of hands' *memorable landmarks* such as phalange marks to transfer a mobile phone grid interface to the user's hand. Body landmarks aid to select the right location but may require visual attention. Moreover, when hands are busy manipulating or holding objects, their surface remains unavailable for touch input. Finally, palm and finger are relatively small surfaces, interacting on them with both hands requires small precise gestures.

On-belly interaction

Using the trunk and the abdomen seems especially convenient for body interaction [11, 27]. Karrer et al. conducted a study to determine the best body parts for performing gestures [11]. Asked to grade how conveniently they were able to perform gestures on different limbs, participants favored the arms, the forearms and the sternum. Wagner et al. [27] reported similar results in a study evaluating the reaching performance of on-body target locations when combining on-body touch and mid-air pointing. Participants preferred passive body parts such as the torso then the dominant arm for reaching targets with the non-dominant hand. Finally, Gemperle et al. [5] have suggested that an appropriate area for wearable computing should minimize movement, and maximize the available surface, especially when the body is in motion. However, surprisingly, using the belly as an interactive surface has yet received relatively little attention.

Eyes-free interaction

When in a mobile context, users divide their attention span between interacting with their mobile device and glancing to the environment surrounding them with periods from 4 to 8 seconds [17]. These short laps of time require interaction with devices to be as quick and simple as possible. *Microinteractions* [1] which must not require more than 4 seconds to access and use a device, are one such example.

While appropriate for eyes-free interaction, on-body interaction have some limitations. For instance, eyes-free spatial tapping requires attention for precise pointing. In Lin et al.'s experiment, participants had to slide their finger trough their arm or tap the wrist or the elbow joint to increase spatial intelligence before tapping on their arm [14]. Thanks to its large surface, the belly requires less precise movements, thus allowing inexact or inattentive interactions [10] using less cognitive resources.

In conclusion the abdomen area carries interesting characteristics for interacting eyes-free or with limited visual attention. Gestures on the belly are convenient in a mobile context (Figure 1). They also offer a simple mean to perform commands without the burden of retrieving any device. Belly interaction thus seems well suited for interacting with a distant system, in a mobile context or/and when the attention is already engaged in another activity.

ABDOMEN AS AN INTERACTIVE SURFACE

Using the belly as an interactive surface provides several advantages. First, the belly provides a large surface compared to others body limbs such as the arms and the legs. While arms are well suited for 1D sliding tasks [14], the belly provides enough space for two-dimensional gestures such as symbols [29] or 2D directional marks [13]. Furthermore, it can serve as a trackpad for pointing tasks.

The belly is easily accessible most of the time. This body part is located in proximity of the location where hands usually operate or rest. Small amplitude movements are needed to reach its surface, which moderates the fatigue usually caused by free-hand gestures or gestures performed on a vertical touchscreen [26]. Moreover, the abdomen is uncluttered. During daily activities, hands and arms are busy with grasping, holding or manipulating objects and upper limbs are constantly moving in situations such as walking or jogging. Interacting on the hand or the arm may result in a disengagement from the main activity. Since the belly is not an active body part, it is not engaged in any action. That makes it ideal to support touch input in most situations.

The abdomen seems especially appropriate for interacting while moving. Its surface is remarkably stable. The human trunk plays an important role in equilibrium when standing, walking or running since it possesses the largest mass of any body segment [12]. As noticed in [11], with a range of motion between 2 to 17.5° across all planes during gait [12], this part of the body is particularly well suited for interacting while walking or running.

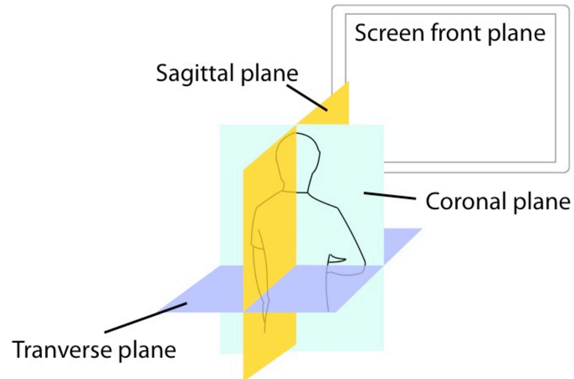

Figure 2. Body and screen planes. Users interact on the coronal body plane oriented in the same direction as the user's glance. The screen plane is oriented towards the user's glance.

The belly should be less prone to interpersonal or accidental touch compared to other body part such as the arms. Skin contact provides an implicit gesture delimiter for on-body interaction. While our body is subject to contacts with surrounding daily objects and other people, the belly is considered as a private area. Depending on specific parts of the body, the perception of touch may convey negative emotion feelings. For example, being touched by another person in the waist region is considered as being inappropriate and harassing in work environment [4].

Interacting with the belly area offers a novel and interesting scope of research. No previous research exploring belly interaction has been published so far. Because of the spatial configuration of the belly relative to the head, interaction techniques should extensively rely on proprioception and proprioceptive feedbacks from the supportive and active body parts. We are interested in understanding how users' perception of spatial orientation of the belly surface influences how they perform gestures.

Understanding interaction on the abdomen

Contrary to usual vertical interactive surfaces the belly is not located in the user's field of view but in the body mid-coronal plane (Figure 2). This configuration differs from common interaction situations such as when interacting with a whiteboard located in a distant frontal plane from the user. Because of this spatial configuration, proprioceptive information from the hands, arms and their contacts with the abdomen are essential to interact with the belly. Vertical orientation affects touch interaction. According to Forelines et *al.*, the shape of a finger contact area on a surface depends on whether the surface is horizontal or vertical and this impacts precision performance [3]. Surface orientation thus impacts which interaction technique a designer should select. Pedersen et *al.* found out that tapping was faster on horizontal surfaces whereas dragging was faster on vertical surfaces [19].

Belly interaction is governed by spatial frames of reference. Parsons *et al.* have found that cutaneous pattern perception depends on the position and the skin surface orientation [18]. The authors report 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 [18]. 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. However, it is unclear to which extent the abdomen's spatial configuration might influence the users' spatial mental representation of its surface, especially when interacting eyes-free.

Previous experimental studies [6] 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. The orientation and the position of the skin surface influence the perception of cutaneous stimuli [18]. Interestingly, in this paper the authors did not find any rule governing the perception of orientation for vertical surfaces located below the chest. Also, their findings did not take sensorimotor activity into account, which is known to provide more spatial information to users. Because of the spatial configuration of the abdomen, the user must interact with his hands and arms backwardly to reach the surface. We think that this configuration influences the users' spatial frame of reference of the belly. The question of how this body surface is perceived remains open and is essential for using it efficiently as an interactive surface.

In addition, we are concerned about the execution of gestures on the belly. In contrast with common interactive surfaces (tabletops, tablets, mobile phones or boards), the abdomen has an ellipsoid configuration that requires investigation. Interacting with curved surfaces involves some special considerations. For example, previous work has shown that the error offset when pointing on curve surfaces depends on curvature and slope [22]. Moreover sliding gestures performance is lower on curved surfaces than on horizontal surfaces [26]. Because the abdomen surface is not perfectly flat, the traces of the intended gestures are likely to be deformed compared to those on a perfectly flat surface. Studying these traces may thus provide insights for designing a belly gestures recognizer.

EXPERIMENT: INVESTIGATING SPATIAL ORIENTATION AND LINEARITY OF BELLY GESTURES

In order to understand how users perform belly gestures, we conducted an experiment to investigate spatial mental representation of the belly surface and belly gestures curvatures. First, we collected data from users' gestures on the belly surface. Then, we analyzed the orientation of the gestures to understand user's spatial perception of their belly surface. Considering these results, we finally analyzed the characteristics of these gestures to inform the design of potential interaction techniques.

Spatial orientation of alphanumeric gestures and directional strokes

This study aims at understanding how users perceive their belly as an interactive surface. Especially, we were interested in observing 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 belly surface (Figure 3).

The experiment was designed by following several hypotheses. We conjectured that participants would have different internal spatial orientation representations (H1) and that these representations would differ if participants were given visual orientation hints (H2).

Previous literature [6] reports that reproducing directional strokes involving two dimensions (such as diagonals strokes) blindfold is cognitively more demanding than strokes involving only one dimension (i.e. horizontal or vertical strokes). We were also interested in understanding users' spatial representation with more complex stroke paths. We assumed that gestures for directional strokes would perform better and demand less effort to participants than gestures for more complex symbols (H3). To present the results, we introduce the following conventions. Let suppose that the participant performs a stroke on his belly according to the stimulus displayed on the screen (Figure 3A) and that an observer is located behind the user with the power to see through the user's abdomen.

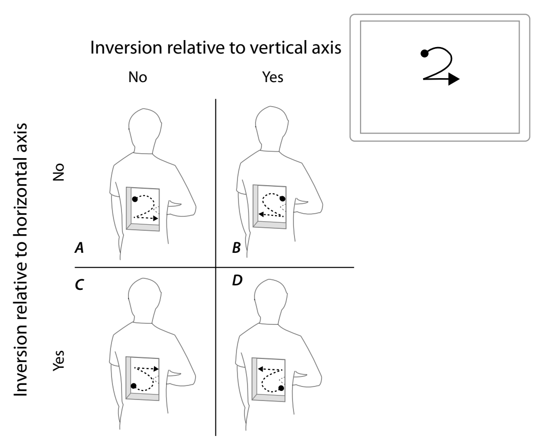

Figure 3. Spatial mental representations of the digit "2". A) No inversion. B) Inversion relative to vertical axis. C) Inversion relative to horizontal axis. D) Inversion relative to both axes.

By convention, we consider there is a "direct mapping" when the observer sees the symbol on the user belly surface as depicted on the screen. Three other mental representations are however possible depending on whether there is a horizontal (Figure 3B), vertical (Figure 3C), or horizontal and vertical (Figure 3D) inversion.

Experimental design

We designed an experiment with a 2x2 study considering two factors: the *presentation* mode and the *nature* of the stimulus.

The *presentation* condition was considered for mobile interaction (Figure 1). In such context, visual attention is often dedicated to navigate a way around obstacles, which considerably limits the usage of visual feedback. In accordance with these situations, we selected two different representations for the stimuli. A *graphical* representation was pictured by a symbol with a starting point and a direction to draw. This condition illustrates the case where users would have the possibility to look at visual information during the interaction similarly to the novice mode of a command menu. In the opposite case, users would have to remember the command to perform likewise the expert mode of a command menu. To cover this scenario we proposed a *textual* representation. Its purpose was to trigger participant's memory of the stimulus shape. The *textual* stimuli indicated the stroke to perform to the participant while withdrawing any graphical hints relative to the orientation (Figure 4).

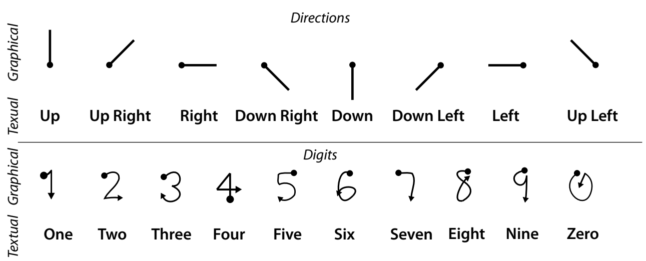

Figure 4. Stimulus used during the experiment.

The *nature* of the stimulus was either a *directional stroke* or a *digit*. Directional strokes were similar to those used in Marking menus, a technique known for its efficiency [13] while digits were selected in the [0, 9] interval. We chose to work with digits because the mapping with commands may be easy to learn as they are already widely used in symbol-digit substitution tasks to assess the general intellectual ability of patients in psychology [23]. In addition, familiarity with digits prevented from any learning effect that could have affected the participant's gesture performances. While more appropriate symbols could be used as input commands for mobile context [28], we assumed that digit stroke paths were complex enough compared to directional stroke paths to affect the way users would perceive spatial orientation.

Procedure

The task consisted in performing a gesture on the belly. Participants approximately stood up at a distance of 3 meters (10 feet) from the display. The experimenter was observing the experiment from behind the user to avoid any perturbation. Before the experiment started, participants were told to perform a unistroke gesture for each trial. We asked participants (1) to reproduce the stimulus displayed on the screen in the *graphical condition*, or (2) to perform a gesture corresponding to how they imagine symbols associated to the stimuli in the *textual condition*. This allowed participants to draw digits the way they were used to write them. Participants were not allowed to watch at the abdomen during the experiment, forcing them to only rely on proprioceptive feedback. The experimenter made sure that the participants were only looking at the screen while performing gestures. Finally, they were told to take as much time as needed.

The stimulus was displayed in the center of the screen to avoid orientation bias. A wireless mouse was used as a mean to provide a delimiter. We instructed participants to first put their dominant-hand on the belly, when they were ready, press the mouse button with their non-dominant hand, and then perform the gesture. When they felt that the gesture was achieved, they released the mouse button to stop the recording. We divided the experiment into 5 blocks of 18 trials so the participants could take a break after each block. Participants were able to practice each gesture during an additional block before the experiment. Gestures were captured by our system and by a camcorder.

We measured the *reaction time* as the duration between the stimulus appearance and the mouse button press. It informed us about the cognitive load of building a spatial frame of reference. Since we instructed participants to take as much time as they needed, execution time was not representative of the real performance of gestures.

The order of the four conditions was counter-balanced between participants using a partial Latin Square design. For each condition, participants performed 18 gestures for each of the 5 blocks. In summary, the design of the experiment was: 12 participants × 2 conditions × 5 blocks ×18 gestures (10 symbols and 8 numerical symbols) = 2160 trials.

At the end of the experiment, participants filled a questionnaire addressing subjective preferences and strategies they followed.

Apparatus

We used a Microsoft Kinect to capture participants' hand gestures. Participants stood in front of the screen at 6.5 feet from the Kinect sensor to optimize data capture. Because of the limitations of the Kinect for capturing small depth differences, we asked participants to wear a white T-shirt to improve tracking. The experiment software was running on a 2.66 GHz Intel Core 2 Duo Macbook Pro. It was implemented in C++ with Qt libraries. The display used in the experiment was a 64" screen with a resolution of 1024×768px. An Apple Magic Mouse was used to control the gesture recording state.

Participants

Twelve right-handed participants (3 females), aged from 25-38 years old (m=28.83, sd=4.02), were recruited from the local community. None had prior experience with on-body interaction.

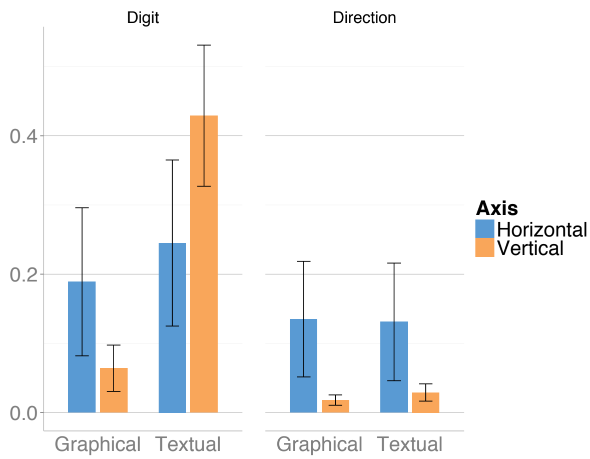

Figure 5. Ratios of inversion relative to horizontal and vertical axes. Error bars represent confidence intervals at 95% level.

RESULTS

Before data analysis, we discarded 8.27 % of the trials where the orientation could not be identified. Some digits (0, 8 or 1 when drawn only with a vertical bar) showed symmetry invariances, preventing a correct classification. A few trials were also discarded because of improper data acquisition. As said above, we identified four different spatial orientation representations (Figure 3) and classified them manually.

Mental representation of spatial orientations

In order to characterize the mental instability of spatial orientations, we investigated the frequency of inversions introduced earlier. We took into account three different kinds of inversions. While B illustrates an inversion of the representation of reference relatively to the vertical axis, C shows an inversion regarding the horizontal axis. Finally, D portrays an inversion relatively to both axes.

Our hypotheses (H1 & H2) were supported by the results. We found that 13.5% of the samples were inverted relatively to the *vertical axis* across all experimental conditions. In the *digit* condition 42.9% of the samples were inverted relatively to this axis for *textual* stimuli and only 6.4% for *graphical* stimuli. These figures were lower in the *direction* condition: 2.9% for *textual* stimuli and 1.8% for *graphical* stimuli (Figure 5).

Inversions relative to the *horizontal axis* gathered 17.5% of all samples across all conditions. More precisely, 18.9% of the *digit* samples presented this type of inversion for *graphical* presentation and 24.5% for *textual* presentation. For *directions* the results were, respectively, 13.5% and 13.1%.

A Breslow-Day test on our categorical variables (*presentation, nature, orientation)* did not reveal any homogenous association (χ^2=40.69, $p<0.001$). Therefore, we concluded that our data presented a main effect for the *presentation* mode, a main effect for the stimulus *nature* and an interaction of the two factors.

Reaction times

Reaction times and subjective preferences data supported our hypothesis (H3).

In *graphical* presentation mode, mean reaction time reached 1.562s when participants performed *directions* and 2.134s when they performed *digits*. In *textual* presentation mode, mean reaction time was 1.65s with *directions* and 1.953s with *digit*s. An ANOVA showed a significant effect of the *nature* ($F_{1,11}$=6.79; $p<0.0125$) but no significant effect of the *presentation* was found.

Subjective preferences

In the post-study questionnaire, participants ranked from 1 to 5 *direction* and *digit* gestures on a Likert scale. Regarding the *direction* gestures, the median reached 5.0 for the criterion “easy”, 5.0 for “fast”, 4.0 for “precise”, 4.0 for “pleasant” and 1.0 for “tiring”. As for the *digit* gestures, we assessed a median of 3.5 for the criterion “easy”, 3.0 for “fast”, 3.0 for “precise”, 3.5 for “pleasant” and 2.5 for “tiring”.

A Wilcoxon signed-rank test revealed that *direction* gestures were significantly perceived as easier (Z=2.8893, $p<0.01$), faster (Z=2.8823, $p<0.01$), more precise (Z=2.7544, $p<0.01$) and less tiring (Z=-2.4228, $p<0.05$) than *digit* gestures. Despite the absence of significant difference, they also found the *direction* gestures slightly more pleasant than the *digit* ones (Figure).

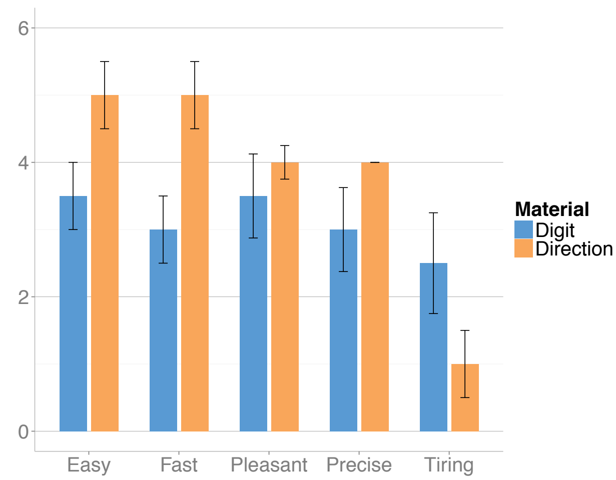

Figure 6. Qualitative median rankings from 1 to 5. Error bars represent interquartile ranges.

Compared to *digits*, the results relative to *directions* are especially promising since they show shorter reaction times and benefit from a stable mental representation. In the next section, we analyze *directional* strokes to extract characteristics that can help design a simple recognizer for such gestures.

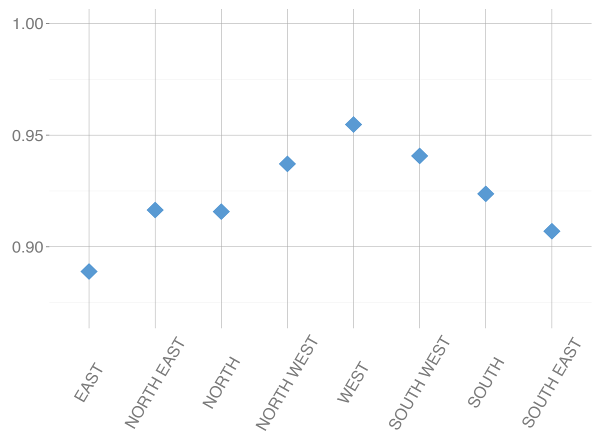

Figure 7. Mean coefficient of determination of linear regression from gesture traces.

Linearity of directional strokes

Of course the traces from directional strokes drawn on the belly were not perfectly straight. The ability of users to differentiate a set of directions is an obvious concern in belly gestures just as it is in a marking menu. Our preliminary results will help in designing such techniques on the abdomen surface.

For this analysis, we only considered the samples with no inversion, which was the largest homogenous sample set (701 items) in our previous study. For each sample, we considered four independent variables: *execution time*, *amplitude*, *linearity*, and *directional bias*. The *execution time* was simply the time elapsed with the mouse button pressed. The *amplitude* was the linear distance between hand positions at the start (mouse button press) and at the end (mouse button release) of the gesture. Our estimate of *linearity* was the coefficient of determination (r^2) of the linear regression computed on the successive X and Y coordinates of the gesture path. More specifically, we estimated the linearity as the maximum value reached by r^2 for each rotation of the trace degree by degree over a total rotation of 360°. The *directional bias* was computed as the mean difference in degrees between the orientation of the line running through the movement starting point and ending point and the nominal direction indicated by the stimulus.

The results follow the convention defined in the previous section (Figure 3A). If the gesture and the stimulus are both oriented to the right, the gesture is considered oriented to the EAST direction.

Median *execution time* fell between 1 and 1.2 second for all directions. *Execution times* tended to be faster for canonical directions (EAST, NORTH and WEST) than for diagonal directions. We did not find any significant difference for the presentation mode. Median *amplitude* showed slight variations from 15 to 20 cm across all directions with no significant effect of the presentation mode.

Since no significant effect was found for the previous variables, we discarded the *presentation* factor to increase the set of samples for analyzing the *directional error*.

A paired-sample t-test was conducted to compare the *linearity* in EAST directions and WEST directions. While the EAST set included EAST, NORTHEAST and SOUTHEAST data, the WEST set included WEST, NORTHWEST, and SOUTHWEST data. Results showed that traces oriented towards the WEST direction ($M=0.94, SD=0.04$) were significantly more *linear* than traces oriented towards the EAST direction ($M=0.9, SD=0.04$); $t(11)=-3.93$, $p<0.05$, $d=1.13$. No significant difference was found for the comparison of the *linearity* in NORTH and SOUTH sets.

Mean *directional bias* showed that NORTHWEST, WEST and SOUTH directions have very little bias (resp. 0.33, 0.51 and 0.67°) (Figure 8). The largest bias was found for the EAST direction with a bias towards SOUTH direction (10.5°). While NORTHEAST and NORTH directions showed an anticlockwise bias (resp. 4.61° and 8.19°), SOUTHWEST and SOUTHEAST showed a clockwise bias (resp. -4.66° and -5.13°).

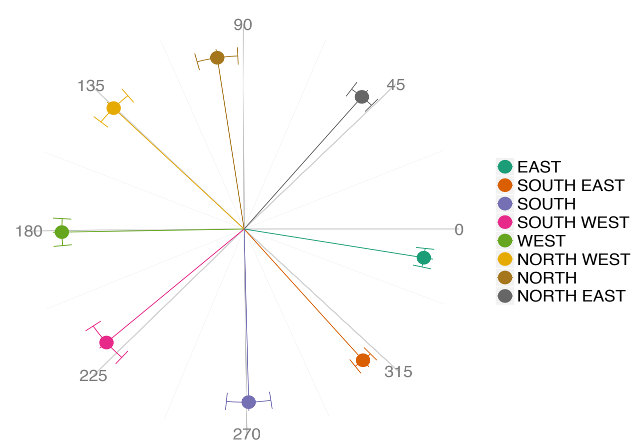

Figure 8. Mean directional biases. Error bars represent confidence interval at the 95% level.

DISCUSSION

Mental representation of spatial orientations

Generally, there were more inversions relative to the horizontal axis than inversions relative to the vertical axis, except when *digits* were shown *textually*.

Twenty to 25% of the samples showed inversions relative to the horizontal axis whatever the experimental condition. This result is interesting since previous 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 [15]. 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 [15]. Some participants reported performing gestures while picturing themselves watching at their abdomen: "*I did not think about writing direction. I did it naturally. It might strongly be possible that I write on my belly as if I was looking at it*". Another participant commented: "*[...] as if I was looking at my belly because it looked like it was easier whether there was no geometrical operation to perform*".

The sample rate showing an inversion relative to the vertical axis was generally low for *directions* in both presentation modes. For *digit*s, while the sample rate was also low when presented *graphically,* it was 6,5 times higher when presented *textually*. Spatial representation is influenced by the presentation mode. The *graphical* presentation mode provides a spatial referential that mentally aids participant to perform their gestures. In this condition, each stimulus is composed of a starting and an ending point, and an oriented path. These hints cognitively ease the planning of gesture paths. No replication information is provided during *textual* presentation forcing users to build a mental representation to perform the gesture. For instance, a participant said: "*[...] I was not used to write that way. However, I did not think when the digit was displayed on the screen.*"

Three of our participants changed their spatial mental representation when *digits* were presented *textually*. They emphasized the difficulty to select a unique representation: "*The orientation came naturally, but it may have changed during the session without me noticing it*". Another participant added: "*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"*.

According to the post-test questionnaires, participants followed three different strategies. Some followed a "mirror" strategy. Participant 1 (P1) reported: "*In case of letters, I performed the gesture if I was in front of a mirror without thinking too much"*. Some of them were performing gestures as if they were communicating a symbol to an external entity. P4 stated: "*I put myself in a spectator place (in front of me)* and P12 told us: "*For me it was easier to perform from the device point of view*". Finally, as quoted previously, some participants drew on their abdomen as if they were looking at it.

It is worth noticing that no participant adopted a representation with an inversion relative to both horizontal and vertical axes. Because this representation involves two transformations, it might be cognitively too demanding.

Direction vs. digit gestures

Reaction times and subjective preferences expressed the significant cognitive demand for *digits*. The difference of the mean values of *graphical* and *textual* conditions was significantly lower for *directions* than for *digits*. In addition, participants rated performing *directions* easier and more pleasant than *digits*.

Participants tended to select the same representation for *directions* in both presentation conditions. While most of the participants consistently used a representation with no inversion, only two followed a representation with an inversion relative to the horizontal axis (and this in both presentation modes). No participant applied an upside down inversion in this case.

In comparison, the mental representation for performing *digit* gestures was unstable. Selecting only one representation for *digits* without glancing at the abdomen was difficult for our participants.

Directional strokes

The analysis of the data on directional strokes indicates that interaction on the belly space is not homogenous. Most of the mean r^2 coefficient values were ranged between 0.93 and 0.98 meaning that the traces were almost linear. Traces towards WEST directions were the most linear which suggests that performing a gesture to the WEST with the right hand is easier than to the EAST. While gestures towards EAST rely on elbow flexion, gestures towards WEST are performed by naturally pushing the arm with an elbow extension.

Except for the EAST direction, mean bias absolute values suggest that canonical directions were easier to perform than diagonal directions. Mean bias for diagonals was 20% higher than for cardinal directions. The high mean error for EAST direction reveals that performing this gesture is uncomfortable, thus forcing users to deviate from an ideal trajectory. More generally, gestures that allowed user to extent their arm gave better results. However, mean bias errors were small enough (inferior to 10°) to distinguish at least 8 directions.

BELLY GESTURES IMPLEMENTATION

The actual implementation of an interactive system based on belly gestures may depend on the usage context. For instance, a video based system is appropriate for a living room. We used a Kinect in our study, a device that was reliable enough to collect data for our experiment. However, the precision of this device is currently too limited to provide a good gesture recognition rate. But this is likely to be solved in the near future, making belly gestures actually usable in the context of a living room.

In a mobile context, devices need to be small enough and non intrusive so that users will not bother wearing them all day long. Smart textile has been shown its efficiency. For example, using Pinstripe [11] participants can interact with the folds of their clothes. Devices such as Magic Finger's ring [30] provide recognition on many types of surface such as skin or textile. In the present case, a capacitive surface made of conductive threads directly sewed into fabric could for instance serve to support belly gestures.

SOCIAL ACCEPTANCE

Despite being promising, belly gestures raise some concerns as to inconvenient situations and social acceptance.

Some situations do not allow interacting on the abdomen comfortably. For instance, pregnancy favors hand contacts with belly and prevents from using its area as an interactive surface. Similarly, stoutness might slow down the adoption of such interaction techniques.

Belly interaction may also raise some privacy concerns. In the living room, 3D gestures are generally well accepted socially thanks to their widespread use in video games. Moreover, the living room is a private space where only friends and family (people that know each other) enjoy spending time together. Belly Gestures in this context should thus not pose particular concern.

Rico et al. [21] suggest that the appearance of gestures are influencing social acceptance in public spaces and that familiar gestures should be more sociably acceptable in this context. Belly gestures fall into two categories. Digits require space and relatively large movements of the arm, which are noticeable in public spaces. These gestures are thus more suited for private spaces such as the living room. Conversely, directional gestures only require simple and small movements and should hence be usable in public spaces. They are as fast as scratching the belly since only a direction has to be determined. This makes them little noticeable especially when used as command shortcuts.

IMPLICATIONS FOR DESIGN

Despite being an exploratory study, our results show interesting insights that could help designers. Here is a summary of the implications for designers of systems exploiting the belly as an interactive surface:

- Linear gestures were easier to perform, especially towards directions allowing the users to push rather than to pull the arm for performing gestures;
- When performing directional gestures on the belly some participants inverted up and down directions. They may want to choose their up/down mapping preferences;
- Performing digit gestures were cognitively demanding for our participants. When possible, a designer may want to lighten user's cognitive demand by favoring rotation invariant symbols. This is especially the case when cognitive resources might be required by other activities such as avoiding objects while walking down a street;
- Complex gestures should rely on a direction that allows user to perform the easiest arm movement to draw the associated input symbol.

CONCLUSION

We have presented a new way to perform micro-interactions relying on gestures on the belly surface. We have investigated the mental spatial representation that users follow for interacting with the belly surface without looking at it. Results showed that users follow three different representations depending on mental images. This mental representation is stable when using simple gestures such as directional strokes but more subject to change with more complex gestures such as digits. Accordingly, we analyzed directional gesture traces and found out that they were fast and efficiently done, and required little cognitive cost. Our results showed users could easily distinguish eight directions and that canonical directions should be preferred as well as gestures towards the WEST side of the body when users are interacting with their right hand.

For further research, we plan to build a wearable prototype capable to exploit Belly Gestures. We also would like to conduct further studies to determine the performance of this technique in a mobile context, especially when walking or running and in situations where hands are busy.

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