

Investigating Intuitiveness and Effectiveness of Gestures for Free Spatial Interaction with Large Displays

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ABSTRACT

A key challenge for creating large interactive displays in public spaces is in the definition of ways for the user to interact that are effective and easy to learn. This paper presents the outcomes of user evaluation sessions designed to test a series of different gestures for people interacting with large displays in the public space. It is an initial step towards the broader goal of establishing a natural means for immersive interactions. The paper proposes a set of simple gestures for the execution of the basic actions of selecting and rearranging items in a large-scale dashboard. We performed a comparative analysis of the gestures, leading to a more in-depth understanding of the nature of spatial interaction between people and large public displays. More specifically, the analysis focuses on the scenarios when the interaction is restricted to an individual's own body, without any further assistance from associated devices. The findings converge into the elaboration of a model for assisting with the applicability of spatial gestures in response to both the context and the content they are applied to.

Categories and Subject Descriptors

H.5.2 [User Interfaces]: Interaction Styles; H.5.2 [User Interfaces]: User-centered Design; I.3.6 [Methodology and Techniques]: Interaction Techniques

General Terms

Design, Experimentation, Human Factors.

Keywords

Large Displays, Natural User Interaction, Techniques, Gestures.

1. INTRODUCTION

Media walls and other large-scale displays have traditionally relied upon the assistance of either haptic technologies or coarse-grained video input analysis (e.g. 2D blob tracking) to enable

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interaction with an audience. The popularisation of video devices capable of capturing the depth of a scene – such as the Microsoft Xbox Kinect – has opened up the possibilities for tracking gestures based on moving the body and limbs freely in space, without the assistance of devices or tracking markers attached to the user. To date, little attention seems to have been placed on the analysis of what a natural interaction in such contexts would actually be.

As Nancel et al. pointed out, the transition from direct interaction with a device (e.g. a laptop) to interaction in space through a device (e.g. mouse operated large display) and then eventually to unassisted spatial interaction “corresponds to a decreasing amount of haptic passive feedback for the performance of input gestures” [7]. In other words, tactile feedback about the actions being performed reduces until eventually, on free spatial interactions, it completely disappears. The loss of the sense of touch has direct implications on the nature of the feedback loop between human and computer. In such an environment, the interactive wall can communicate with the user only through visual and auditory means. Thus, any system response to a user's actions must be communicated by images and sounds alone. In the opposite direction – from the user to the system – information is restricted to the tracking of physical movements performed by the user in front of the display. The scope of such communication is therefore limited almost by definition due to environmental constraints. In order to ensure that messages are communicated clearly and unambiguously in both directions, visual and audio cues must be created in ways that help guide the user through the task at hand whilst not being distracting.

The work discussed in this paper considers the possibility of a language for natural spatial interaction being established through comparative analyses of different interactive approaches. It focuses, in particular, on attempting to identify some of the basic blocks of such a language, which more complex interactions can then be built upon. To that end, it considers two ubiquitous actions – selection and rearrangement of items – involved in the communication between human and computers, investigating them in the context of an interactive wall. Different gestures are then proposed for carrying out such actions, with a user evaluation to contrast the intuitiveness and effectiveness of each gesture.

2. RELATED WORK

Spatial interaction techniques were first studied in virtual environments, typically involving gloves or high degree of

freedom devices. More recently, there is a growing body of research that investigates interaction with large displays over a distance. Previous research in this area can be classified into the following approaches for selecting virtual objects: indirect cursor control [3], direct cursor control [2], device-based direct pointing [1][6], free direct pointing through finger [9], hand [7][8], or body movement. The remainder of this section describes previously studied techniques that support selection tasks as well as other interaction with virtual objects, such as moving objects.

Vogel and Balakrishnan studied *freehand pointing and clicking* interaction with very large high-resolution displays [9]. They developed three techniques for gestural pointing and two techniques for clicking using a combination of hand and finger gestures – tapping with the index finger and moving the thumb in and out towards the index finger. For their prototype they used a commercially available tracking system and users had to wear reflective markers attached to fingers and hand. Despite recent advances in technology it is still difficult to implement the subtle gestures they proposed for clicking for complete free gesture interaction using today’s hardware. The focus of their study was primarily on usability measures and accuracy of the interaction, neglecting intuitiveness and effectiveness aspects of the gestures.

Malik et al. [3] developed and evaluated a system that recognises hand postures and gestures over a tabletop surface to support a range of interaction techniques with an interactive wall. They reported that the *grabbing* gesture, in particular, was well received by users for picking up virtual objects. Their prototype used vision tracking and was envisioned for collaborative or extensive individual work in an environment where the users are sitting at a table in front of a large display.

Nancel et al. [7] carried out a thorough comparison of different gestures for the execution of *pan* and *zoom* actions for multiscale navigation in an interactive wall environment. Their study focussed on exploring factors like number of hands involved in the movement (one or two), path of movement (linear or circular) and level of guidance (1D path, 2D surface or 3D free hand). They found that free hand gestures were less efficient and quickly led to fatigue (compared to device-based techniques), and that bimanual input techniques performed better than one-handed interaction.

Jota et al. [2] investigated *the effect of distance* on interaction with large displays. Drawing on related work they developed three interaction techniques: grab, point, and mouse. Their implementation of the techniques allows *selecting and moving* virtual objects over a distance. They reported that the point interaction was most efficient regardless of distance, while grab and mouse were dependant on distance to the display. No findings regarding intuitiveness and effectiveness were reported and their prototype relied on a marker-based tracking system.

Despite these endeavours, there is still a lack of research findings regarding interaction techniques with large *situated* displays [4] in public environments. Compared to screens in work environments, public display usage is much more *opportunistic* [5], which needs to be carefully addressed in the design of interaction techniques. The work presented in this paper aims to address this gap by investigating free spatial interaction with a digital wall that is 1) relatively short in duration and 2) performed in an environment where nothing else is available for communication but the user’s own body. It aims to investigate patterns of behaviour under circumstances where little or no cues are provided, therefore testing intuitiveness and effectiveness of a set of proposed free spatial interaction gestures.

3. STUDY DESIGN

3.1 Gestures

The study focused on two fundamental actions often involved in interactive experiences:

- *Selection*: the act of picking an object among a set of equally available objects;
- *Rearrangement*: the repositioning of objects in a (virtual) space by selecting an object, carrying it across the space to its new position and then releasing it.

The main reason for singling out such actions – and excluding related ones such as *zooming* and *panning*, for instance – was their character as two of the most basic intentional acts humans perform in the real world when attempting to make sense of our surroundings. In fact, in order to perform any intentional action on an object, it must first be consciously placed as the focus of our attention. After this process of selection, a common follow-up action is to manipulate the object’s position in space by moving it around. By addressing these two fundamental actions that are common in the real world, we expected to test the level of intuition associated with different gestures when applied for those actions in a virtual space.

Given that the execution of a rearrangement action presupposes the selection of the item to be moved around, we first narrowed down the number of gestures well suited to general selection of objects. Four gestures emerged from this process, in which we used the criteria that there is at least one context where each gesture stands as the most intuitive mechanism to perform the action. For the rearrangement of objects in space, we added a fifth gesture, again based on a physical metaphor for carrying objects across the space. Table 1 lists the five proposed gestures as well as examples of real world scenarios where each gesture would be regarded as the natural action for performing a selection. Figure 1 illustrates the design of each gesture for the proposed interface.

Table 1. Proposed gestures and real world scenarios where they are commonly used.

Gesture	Scenario
1. Pushing	Pressing a physical button.
2. Dwelling	Directing gaze; focusing visual attention.
3. Drawing a lasso	Using a pen to mark a day in a calendar or an option in a form.
4. Grabbing	Grabbing physical objects with one hand to hold or move them around.
5. Enclosing	Holding large physical objects with two hands in order to carry them around.

3.2 Testing platform

In order to isolate the intuitiveness and effectiveness of the gestures from the process of understanding the interface used in the tests, we chose familiar and simple tasks for the study. For that purpose, we devised two simple card games, the first to test selection of objects and the second their rearrangement in space. We would then ask the participants to play multiple rounds of each game, one for each gesture. To test selection, we developed a simple memory game involving three pairs of cards, each of those matched by a unique icon: blue circles, red squares, or yellow triangles. The six cards were arranged on a virtual board, distributed into three columns with two cards each. The game

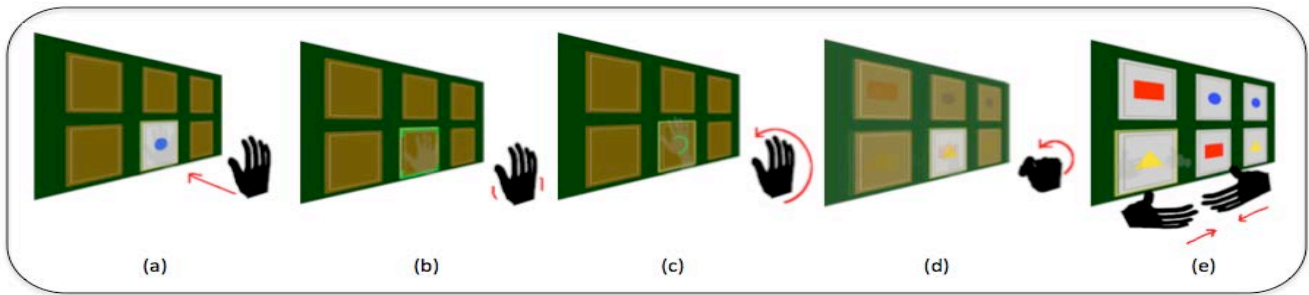


Figure 1: Proposed gestures: (a) pushing; (b) dwelling; (c) lassoing; (d) grabbing; (e) enclosing.

started with all cards facing down and it was the participant's task to flip two of them over in each turn. If the pair matched, the cards remained facing up; otherwise, they were automatically flipped back down and the participant received the chance to try again. The game ended when all cards were facing up. Figure 2 illustrates the interface when the participant had matched a pair successfully but got a mismatch on his second attempt.

In this first game, "flipping" a card over was achieved by performing the designated *selection* gesture, similar to a mouse click in a desktop computer environment. It is worth noting that the actual gesture a person would usually perform when flipping a physical card over on a real table was not formally defined in the study. Yet, it can be argued that this gesture performed in the real world may include elements of both *grabbing* the border of a card and *pushing* it back to the board. Those two gestures become then potential candidates for fitting the user's mental model of *flipping*.

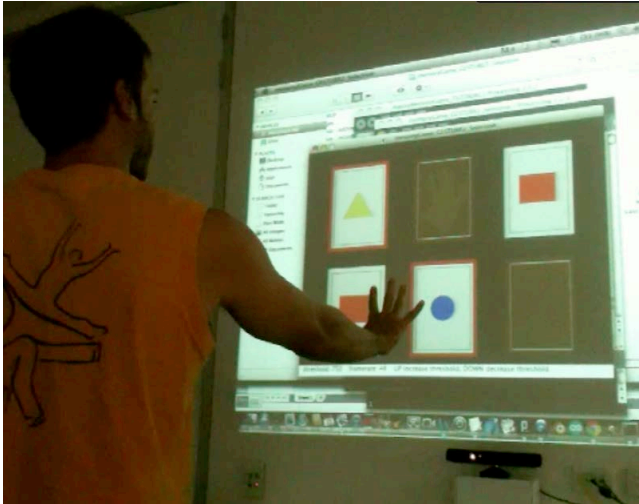


Figure 2: A participant playing during the evaluation session.

The second game was designed to test rearrangement of items in space. It was important that participants played it immediately after the first game, so that the challenge posed to them was not so much to learn the gestures again but rather to adapt them to a new purpose. Having already become familiar with the basic gestures, participants were then presented with a slight variation of the first game: all the cards were displayed facing up from the start. The end goal then became to rearrange them in space so that they formed three columns, each being a matching pair. The same gestures used in the first round were repeated, with the participants having to perform them twice per movement: first to select the card to be moved, then to select the card the former would be swapped with (i.e. the place to drop the selected card). Once both selections were performed, the two cards swapped

positions. For any given combination, only two swapping movements were thus needed to complete the task. In addition to the four uni-manual gestures previously employed for selection, an extra bimanual gesture of *enclosing* items in order to carry them around was defined for rearranging objects in space.

Both games were written in Processing, making use of the Kinect as tracking device (and therefore ensuring six degrees of freedom) and a projector to display the amplified images onto a wall. A shadow outlining the position of the participant's hand was constantly displayed on the screen along with a yellow outline drawn around the card in focus. To eliminate effects between user sessions due to the arrangement of the cards, the application was programmed so that the cards were always shuffled the same way through the session. In other words, all participants were presented with the same game setting. Moreover, all rounds on each game were identical, except from the code handling its corresponding gesture. In that respect, a few design decisions were deliberately made upfront. The *dwelling* gesture was designed to be quite sensitive in order not to slow the flow down too much. It would therefore trigger the action after a participant kept their hand over a single card for one second (a progress bar hint was provided as a visual cue for timing). Once the action was performed, if the selected card remained in focus the system would interpret it as if the participant was dwelling over it again, triggering another selection after about another second and ultimately undoing the previous selection. The *lassoing* gesture was also given a visual cue: a circle initially faded out and progressively highlighted as the participant drew an anticlockwise lasso over the card. The first quarter of the circle automatically appeared as soon as the card was in focus, as an indication to the participant about the movement to be performed.

The *grabbing* gesture had to be simulated by the researcher conducting the evaluation sessions through the click of a specific key on the computer running the program. It is important to note that only the *activation* of the gesture was simulated – the actual positioning of the participant's hand was still tracked with the Kinect. The reason for simulating this gesture was twofold. Firstly, accurately implementing the open/close fist movement with blob tracking alone is not straightforward and posed an unnecessary technical impediment to the user sessions – after all, if the gesture actually turns out as relevant from a usability viewpoint, it can be more easily coded with the use of the skeleton tracking feature available with the Xbox Kinect SDK. Also relatively complex, reliable implementations are achievable with currently available technologies and can be realistically developed in a later stage of the project. More importantly, however, informal preliminary experiments indicated the *grabbing* gesture as the preferred option for selecting virtual objects on a display. This can be explained with the intuitive metaphor underlying the gesture: grabbing physical objects in space. It was therefore

important to test this hypothesis by offering the participants the illusion of total smoothness when performing an open/close fist gesture, regardless of its angle, direction or magnitude. A Wizard-of-Oz prototype quickly emerged as the natural approach for this gesture, enabling a truly interactive experience without the need of traditional programming of a technically complex feature [10]. The same rationale applied to the extra gesture – *enclosing* card with both hands – designed for rearranging items in space.

3.3 User sessions and evaluation criteria

The study was conducted over three days in an isolated room equipped with a laptop connected to a Microsoft Xbox Kinect and a wall projector. Ten participants were recruited internally within our research group. Ages ranged from 20 to 36 years, with a median of 26. Three of the participants have been actively involved in previous research with the Kinect and large displays, albeit unrelated to the present study.

We began a test session by giving the participant an introduction about the general goals of the experiment. This was followed by a short tutorial session, which explained the game and its rules based on a mockup implementation where selection was performed via a regular mouse click. Each session lasted for approximately 20 minutes and started with the participant being asked to play the memory game four times, each one trying to use a different undisclosed gesture to select the cards. Eventually, all four of the predefined gestures were tested: *pushing*, *dwelling*, *drawing a lasso* and *grabbing* (Figure 1). To minimise bias due to the sequence the gestures were presented, we divided the participants into four groups and switched the gestures in a different order for each group, as displayed in Table 2. After the four rounds of the memory game were played, we explained the rearranging game to the participant, advising them that the same gestures – presented in exactly the same order as in the first game – would now be used for the purpose of rearranging pairs of cards in different columns. The four rounds of the rearranging game were then played. Finally, we asked the participant to play a fifth round, this time trying to use two hands to select each card. Again, no information was given about what the nature of this extra gesture actually was, only that, contrarily to the previous ones, this involved two hands.

Table 2: The different sequences in which the gestures were presented to participants.

Gesture sequence	Participants
Pushing, dwelling, lassoing, grabbing	3
Grabbing, lassoing, dwelling, pushing	3
Dwelling, lassoing, pushing, grabbing	2
Lassoing, grabbing, pushing, dwelling	2

Throughout the session, the participant was encouraged to think aloud so that their impressions could be recorded as they emerged. Given that no information about each gesture was provided upfront, the moment when a participant realised the nature of each gesture and managed to intentionally reproduce it successfully was of particular interest to the study. In order for that to be measured, we constantly probed the participants about their evolving understanding of the gestures performed as they played the games. Early accidental executions of a gesture were thus

discarded, interpreted instead as exploratory attempts to figure out how each gesture actually worked. For each session we measured the following factors:

- **Total time to learn gesture (in seconds)**, as an indication of *intuitiveness*. The quicker a gesture can be grasped, the more intuitive it arguably is.
- **Number of failures after learning the gesture until the end of the task**, as an indication of the gesture’s *effectiveness* [11].

The *end of the task* was characterised by the participant completing the game or giving up. *Failure* was defined as: (a) unsuccessfully trying to select a card; (b) a card being selected unintentionally; or (c) moving out of the zone tracked by the Kinect while still holding a card. It is worthy of note that the metrics for effectiveness of a gesture based on the numbers of failed attempts to execute it is comparative by nature. If the number of failures for one gesture is higher than the same metric for another even after they both have been understood, this can be seen as an indication that the former is less effective and demands more effort to be fully mastered than the latter. In contrast, we discarded the total time taken to finish the task as it would not have provided a reliable metric for measuring effectiveness. The time to complete a game is highly dependent on luck selecting the right sequence of cards as well as individual strategies and traits (e.g. speed) employed when playing the game. It is therefore better as an indicator of *individual* performance than of *gesture* effectiveness and was consequently not considered in the analysis.

4. FINDINGS

The results of the measures taken indicate that – for the purposes of *selecting* an item and in the absence of any additional guidance – the *dwelling* gesture seems to be the most intuitive of the group. Figuring out how *grabbing* works, for example, took more than twice the time, while understanding *pushing* or *lassoing* took more than three times longer (Figure 3). This result was somewhat expected, since *dwelling* is the only gesture among those tested which provides immediate feedback as soon as participants place their hand on top of a card: an animated bar progressively surrounds the card in focus; after about one second, it completes its outline and the selection is then performed. Such high responsiveness, however, comes at a price: based solely on the position of the hand over time, the action may be triggered regardless of the participant’s intention. In fact, participants consistently remarked that while *dwelling* was easy to understand, it was also too sensitive. As a result, cards could often be turned unexpectedly or kept flipping back and forth for as long as the hand rested on top of it. Even after grasping the gesture, participants could not avoid incidental mistakes, since moving the hand from one card to another sometimes took longer than the dwelling threshold. Such ambiguity between *translation* and *action* movements therefore contributes to the diminished effectiveness of the gesture. This is clearly reflected by the recurrent mistakes observed until completion of the first task (Figure 5) as well as the long time taken to adapt its use to a new purpose (Figure 4). Besides, *dwelling* involves waiting times and is therefore inherently slow. Visually, the display was perceived as too busy, with many participants remarking they were paying more attention to the animated progress bars than to the content itself. Over time, however, participants seemed to work around the gesture’s limitations (Figure 6), which indicates those were also clearly identifiable.

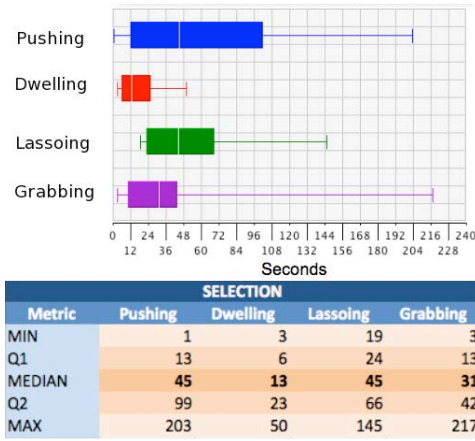


Figure 3: Time in seconds to learn the gesture for the first time while selecting items in the board

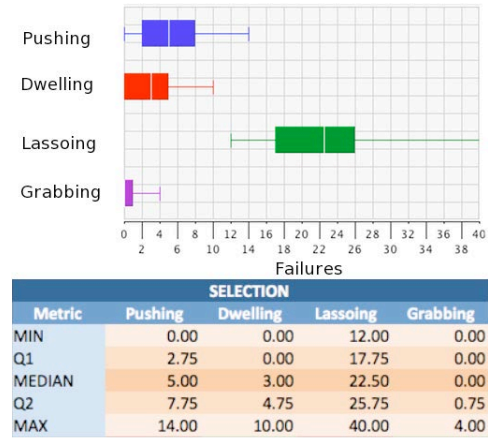


Figure 5: Number of failures until completion of the task of selecting items in the board

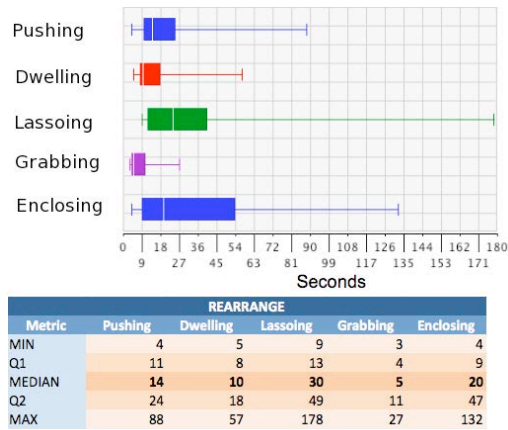


Figure 4: Time in seconds to learn gestures when applied to the second game of rearranging cards

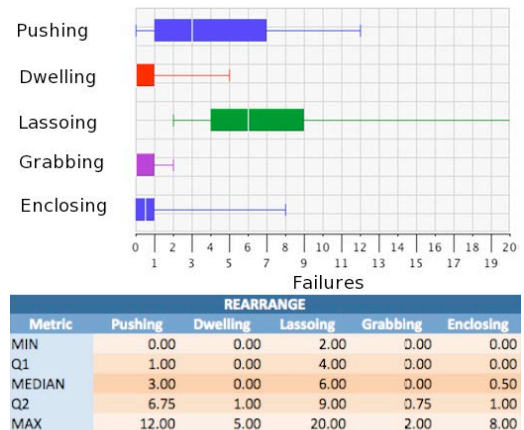


Figure 6: Number of failures until completion of the task of rearranging cards

Lassoing was also designed to provide a visual cue about the nature of the movement to be performed but unlike to *dwelling* – which was only partially activated upfront – the participant needed to actually start executing an anticlockwise circular movement in order to receive any further feedback. This type of feedback proved to be largely insufficient, with participants taking on average 45 seconds to figure out what the gesture was about (Figure 3). It was also highly ineffective, with all participants incurring a reasonable number of errors to complete the tasks (Figures 5 and 6). The general feedback was that *lassoing* was “extremely annoying” and “physically exhausting”, with 4 out of 10 participants failing to finish the first task. Yet, some participants praised the greater level of control provided by the gesture, which could make it a good candidate for less frequent, higher risk actions.

For the remaining two gestures – *pushing* and *grabbing* – no visual hints were given, so that we could test the intuitiveness of equally freehand movements. The intention was to let participants figure them out just by exploring different hand movements until they got them right. The results for each of them were, however, strikingly different. Free hand *pushing* – like *dwelling* – is by nature ambiguous about the distinction between *translation* and *action* movements: the action is triggered any time the participant’s hand moves towards the screen for longer than a certain threshold. However that often happened accidentally when

participants were just repositioning themselves in space without the intention of actually selecting the cards.

As a result, cards frequently appeared to be “flickering” and the system seemingly reacted without any corresponding input from the participants. With all participants the gesture was eventually understood, but in general only after some time playing (Figures 3 and 4). An extreme example, observed for one of the participants, involved the *pushing* gesture only being grasped as the very last card was flipped. Nevertheless, although clearly not intuitive, the gesture was very effective – in fact, that particular participant managed to finish the game, even without knowing what the gesture really was for most of the time. A similar impression of that being an unreliable yet somewhat effective interface was verified with most participants, though all ultimately accomplished the tasks (Figures 5 and 6). *Grabbing*, in contrast, defines by nature a very clear separation between *translation* and *action* movements. The results show it does not seem to be highly intuitive (Figure 3), likely due to the absence of haptic feedback – it does not feel natural to grab the air in the first place. However, once the effects of the gesture are realised, they are reproduced with extreme ease and accuracy (Figures 5 and 6) and can be naturally reapplied to different purposes (Figure 4). A similar pattern can be observed for the bimanual *enclosing*, which offered no advantage over the uni-manual *grabbing* for this specific task (Figure 6).

5. CONCLUSION

The results from our user study suggest that *dwelling* is the most intuitive gesture for selection, although it needs to be tuned in terms of dwelling time to be made more effective. Alternatively, the selected object should be locked until it is no longer in focus. *Dwelling* also seems to be more suitable for scenarios where not many selections need to be made in a short period of time. Under those circumstances, *dwelling* was perceived to slow down the overall action, and was consequently thought to be an obstacle rather than a tool. In such scenarios, *grabbing* is likely to be preferred for selecting items, as long as a clear visual affordance is provided. *Grabbing* is also the clearly preferred gesture for rearranging items, once the participants become acquainted with its execution. In its absence, *dwelling* also performs well. A potential combination of both – *grabbing* for dragging followed by *dwelling* for dropping, as suggested by a few participants – might be an option to be tested in further studies. *Pushing* – a very common gesture in most other digital interfaces (like touchscreens and tabletops) – implies tactile feedback about the level of pressure exerted and consequently fails when transposed to an entirely non-haptic context.

The results corroborate the notion that a clear distinction between *translation* and *action* movements must be pursued. This implies that gestures designed to trigger actions over specific items should be *dynamically unambiguous*. In other words, they must be defined by movements of limbs and fingers that are a) specific enough not to be confused with general repositioning of the body in space, and b) meaningful enough to be uniquely associated with that particular action (i.e., gestures triggering specific actions should be sufficiently distinct from each other so that minor differences in the movement of fingers, hands and limbs do not cause the system to pick one gesture incorrectly). Care should be taken, however, to avoid making the gesture so restricted to the point of requiring unusual dexterity to be performed, as in the case of *lassoing*. The perception of having control over the consequences of executing the gestures without experiencing unjustified physical strain is essential for the interface to be trusted and consequently abstracted – a fundamental factor in making the interaction feeling *natural*.

Interpretation of actions carried out freely in space can only be based on two input parameters: *breadth of movement in space* and *trajectory of the movement*. The first presupposes that: 1) a “trackable target” is established as the subject executing the movement (i.e., blob centroid for blob tracking approaches, or specific bone joints if skeleton tracking is employed); 2) the precise identification of start and end points for a movement (i.e. what events happen to the “trackable target” in space which can be sufficiently singular as to be interpreted as signalling the start or end of a particular gesture); and consequently 3) the distance travelled in space by the “trackable target” between the moments the start and end events take place. The second presupposes the identification of the full path followed by the “trackable target” in the 4D space (axis x, y and z, plus time to execute the movement) as well as its parsing matching to a known trajectory predefined on a dictionary of paths, each of them associated with a specific meaning.

Gestures with specific, well-defined movements seem therefore to be highly suited to actions carried out on individual objects. A future study would involve extending such analysis to gestures encompassing general translative movements of the limbs (e.g.

waving, swapping, lassoing, etc.) and assess their intuitiveness and effectiveness when used for actions upon groups of items or the virtual space itself – like, for instance, zooming and panning.

6. ACKNOWLEDGMENTS

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