

# Interacting with a Cubicle: is Calibration Vital in Playful Experience?

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**Abstract.** This paper reports an experiment on Cubicles, small cubic interaction devices. These were used to control a virtual cube a screen and hence the selection of a movie trailer. This was designed to investigate whether users are able to understand 'soft', re-programmable mappings and also the playfulness of the Cubicle. Four designs were compared differing in the cognitive complexity of the mapping between physical cube and on-screen cube. Although the designs differed markedly there was no measurable difference between them and instead in all cases participants failed completely to understand the mapping. However, surprisingly, the users were able successfully to manipulate the cube to select a movie and furthermore enjoyed the process. We believe this is partly because although the cognitive mappings were complex all the designs preserved a key visceral quality in that opposite movement of the physical cube resulted in opposite movements of the virtual cube.

## 1 Introduction

Effective interaction through control/input devices requires precision and calibration. This is, of course, particularly important for dedicated controllers in games like Star Wars X-Wing Alliance, in which the joystick is used to fly the ship and to fire at enemies [6]. However, it is equally true in more mundane interfaces where the device is used to control and manipulate functions: try to operate a mouse when rotated through 90 degrees, or on a dirty surface where the ball does not rotate freely.

In fact we do have remarkable abilities to cope with unusual mappings, for example, the experiments with prismatic glasses that invert the wearer's image of the world, or the ability to reverse an automobile. However, considerable practice is required and in the early stages those affected often have to very slowly think about the effects of each movement.

For novel tangible devices this is particularly difficult as by their nature they are not familiar to users, who therefore need to learn the mappings between physical actions on the tangible devices and their effects on the digital world. Furthermore, the limitations of sensor technology, both in precision and in attributes sensed, constrain the accuracy of calibration between physical attributes of devices and their digital effects. Even worse, where the sensing technology measures some form of relative change or velocity, the mappings may drift over time. Again given sufficient feedback

and understanding people do cope with this. For example, shifting the hole used with a buckle as a leather belt gradually stretches over time.

In this paper we describe the results of an experiment originally intended to assess the ease with which users could infer different kinds of physical-digital mapping and the usefulness of various visual guides. The device used was a cubicle – a small cube with accelerometers in it allowing it to be used to control appliances such as a TV [1]. The expectation was that certain mappings and cues would enable the user to more easily understand the virtual effects of the cubicle. In particular, the properties meant that calibration drift does occur and users need to establish and maintain calibration between the cubicle and its virtual representation.

In fact *none* of the participants managed to comprehend the mappings in any of the conditions. This sounds like a failure. However, remarkably, despite completely failing to establish calibration or to achieve any explicit understanding of the mappings, the users were able to successfully complete tasks. What is more they enjoyed it!

The fact that the participants were able to succeed in tasks without explicit understanding is perhaps not remarkable. If you are a bicyclist can you say which hand to move in order to turn the bike to the left or how they move your body if the bike starts to tip to the right, without imagining doing it. Tacit knowledge dominates many physical tasks. What is interesting in this experiment is the short timescale and the range of different mappings used in the time. If you have ever tried to ride a tricycle or one of those trick bicycles where the handles need to move in the opposite direction, you will realize how difficult this normally is.

The reason we believe for this apparently counterintuitive result is that all the cubicle mappings, whilst requiring different cognitive models all obeyed laws of ‘natural’ visceral interaction. Whilst the participants were not able to plan or predict their actions they were able to respond appropriately to feedback.

In the following section we will describe the cubicle as used in this experiment and related devices and interfaces. In section 3 we will look at physical-digital mappings, the way humans make sense of them and the ways in which they can be designed. Section 4 moves on to the experiment proper, its methods and tasks followed by quantitative and qualitative results in section 5. Finally we will discuss the potential reasons for the behaviours observed, the lessons thus teach us the questions raised.

## **2 The Cubicle and Related Devices**

### **The Cube as an Input Device**

The cube is a simple and familiar shape and yet also affords a wide range of actions and interpretations. Earlier studies of cubes with different kinds of colourings, textures etc. demonstrated the wide range of ways in which people would manipulate this apparently simple solid [11], Even on a solid unmarked cube the faces suggest ‘stable’ configurations where it can sit on a flat surface, and also natural direction to tum-

ble or twist the shape. Decorations, differences between the sides etc., all influence these basic affordances.

A Cubicle is a wireless tangible cube that uses Smart-Its technology to allow rapid prototyping of sensor-based systems [12]. The Cubicle was first built for the purpose of basic navigation and input [16]. The Cubicle has been studied in related work, such as cube affordances for wearable computing [11], and applications including an augmented die for playing games and a controller for a radio tuner [3].

There are also a number of related devices that exploit the physicality of cube. These including the Cubical Mouse, a 6-DOF manipulation device [4], the ActiveCube [13, 10] used to construct and interact with three-dimensional (3D) environments, Cube [15] used in a virtual environment and a foldable 3D cube [17] used as an interactive tangible interface for storytelling. In the Chromarium, a pair of cube with coloured faces are used to help children understand colour mixing in a mixed-reality experience [9]. In the purely digital world, an on-screen cube called the 'Communication Cube' has been used as navigation support for advisers in a customer-service centre (part of the Motivational User Interface [7]).

### **Understanding physical–digital mappings**

Although this paper is about future tangible devices, in fact we are surrounded by devices such as light switches, central heating dials, microwave controls. These all in different ways take our physical actions and produce indirect effects in electronic or digital domains. Probably the most well known work on the relationship between the physical and the digital is Norman's analysis of such devices in terms of perceived affordances and the naturalness of the mapping between the device and the controlled effect [8]. More recently work on tangible devices and mixed reality has led to conceptual developments, for example, Benford et al. [2] Sensible–Sensable–Desirable framework targeted at more effectively using the capabilities of tangible devices, and Wensveen et al. [14] looking at similar issues, but from an industrial design perspective.

In earlier work we have examined everyday consumer devices to uncover some of the ways in which designers tacitly or knowingly exploit users understanding of the physical world [5]. This, like Norman's work and the SSD framework, regards the relationship between device and controlled state as important, but is more focused on the properties of physicality that are an intrinsic part of human understanding whether innate or learnt early in life. In particular we distinguish between the cognitive understanding of the relationship between physical device state and digital state and the more visceral interactions we have with the device purely based on its own properties. One of these properties of physicality is the *natural inverse*: when we push something in one direction we naturally pull it back to 'undo' our action, or if we are pointing with a stick and move the tip a little too much in one direction we simply move it back. We will return to this later in the paper as one of the fascinating results of this study was the way in which the participants managed to cope even when they had no understanding of the physical-digital mappings, but where this crucial physicality principle held.

### 3 Experimental device and application

#### 3.1 Accelerometer-based sensing

The Cubicle used in these experiments contains two 2d accelerometers allowing the vertical direction to be detected and also movements such as shaking. This means it is easy to detect which face is on top, but not the relative or compass direction of faces in the horizontal plane. So, for example, it is impossible to determine with confidence which face is pointing towards the user of the cube, or a television screen in the room.

Other variants of the cubicle incorporate a gyroscope, allowing compass directions to be determined, or other sorts of sensors allowing to detect squeezing etc. The advantage of pure accelerometer-based sensing is that accelerometers are comparatively cheap compared with, for example, gyroscopes or other forms of electronic compass, and do not require modifications to the environment as would, for example, ultrasonic or RF location systems.

Although it is not possible to determine the cube's orientation given a single reading, the accelerometers do allow rotations around the non-vertical axis to be detected and thus, in many circumstances, maintain a model of which direction is which. If this model of 'forward' is determined in an initial calibration stage it drifts only slowly so long as the user only 'tumbles' the cube and does not twist it around the vertical axis (y-axis) (see Fig. 1a)

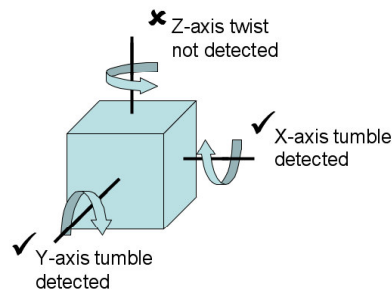


Fig. 1a. Detected rotations.



Fig. 1b. Wooden Cubicle

#### 3.2 The Cubicle as a TV Control

Some applications are possible just using purely the detection of the upper face. For example, the initial Cubicle application used the cube to select between AV modes for a large plasma screen. Each face had the name and icon for a mode on it and the upper face determined the mode [16]. However, in this mode of use the cube has to be decorated differently for each application.

In this study, we used a Cubicle application developed by Block et al., [1] intended as an input device for playfully changing between different TV-channels. In particular, the Cubicle was used to select movie trailers for Alien, Die Hard, James Bond, Love

Actually, Lord of the Rings: return of the Kings and Matrix, from a screen by manipulating the cube. Table 1 shows the ways in which a user could manipulate the cube to control the TV image.

The Cubicle itself constructed of wood with sides approximately 3 in (7.5 cm). As previously noted it was augmented with accelerometers hidden within the wooden case. The sides were numbered 1 to 6, but without any images of the movies or other indications of meaning. This meant that the mapping between the cubes movements and its digital effects could be ‘soft’ and reprogrammable. In order to help the user to understand the effects of the Cubicle, it also has an on-screen representation of itself. In this digital representation the sides each display a title image for the associated movie.

Whilst this indirect representation of the Cubicle means it can be used to manipulate arbitrary content, the effects of manipulations on the cube are far less obvious. The Cubicle is intended to be a fun device to pick up and use, so it is important to know whether users are able to successfully manipulate the virtual representation and hence digital effects of the device. In particular we expected that the user would have to be able to calibrate the cube so that rotations on the wooden Cubicle had well understood effects on the virtual cube.

**Table 1.** Cubicle actions and the associated GUI output

<b>Action</b>	<b>GUI output</b>
Rotation	Display different movie trailers’ images Full image of a movie trailer being displayed selects a movie trailer
No action (cube is placed on a table, or is held parallel to the ground)	Zoom out and play a movie trailer, provided that at that time the screen was showing just one side of the cube (one full image of movie theme)
Shake	Return to initial orientation (correct the calibration), or, zoom out the display if the application was playing a trailer (thus stop/pause the trailer)

### 3.3 Manipulating the Cubicle

In order to explore the users ability to understand and control the digital representation of the Cubicle, four different mappings were designed for the experiment. Each condition independently manipulates a viewpoint (front-aligned vs. top-aligned) and a visual cue (numbered vs. unnumbered), giving a range of different calibration challenges for the user.

The front aligned view (fig. 2a) is a condition where the virtual cube that faces the user represents the front side of the physical cube. The top aligned view (fig. 2b) is a condition where the virtual cube that faces the user represents the top side of the physical cube. This is highly significant when a user is trying to calibrate the physical cube with the virtual cube on the screen. Because the sensor in the cube is an acceler-

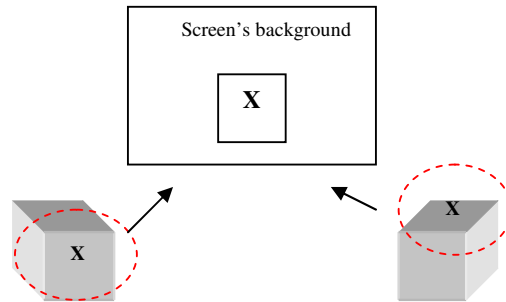
ometer, it can tell unambiguously which side is up, but not other aspects of the orientation of the cube.

When the virtual cube's sides are numbered, respectively from one to six, the condition is known as numbered. The unnumbered condition is when the virtual cube shows only the image of the movie trailers – no number being displayed. Displaying the numbers of one to six on the sides of the virtual cube (on top of the movie images) is expected to aid calibration, as the physical cube is also numbered (fig. 1).

Users can thus interact with the Cubicle by orienting the physical cube against the virtual cube on screen according to these four conditions:

- (i) front aligned and numbered
- (ii) front aligned and unnumbered
- (iii) top aligned and numbered
- (iv) top aligned and unnumbered

Because we conducted a within participants experiment users would encounter all conditions. Whilst the difference between numbered and unnumbered conditions is obvious that between the front aligned and top aligned is not visually apparent. To help reduce cross-over effects different background colours (blue and red) were used for face and top aligned conditions. Otherwise the interfaces were identical.



**Fig. 2a.** Front aligned

**Fig. 2b.** Top aligned

## 4 The Study

The study was designed to study the Cubicle's performance as an input device in terms of ease of calibration and manipulations, and also experience and user preference. Furthermore, a within subjects design was used in order to investigate to which type of mapping of control surface led to the best the calibration and manipulation performance, and also to examine whether this type in any way influences the playful experience.

## 4.1 Participants

We solicited volunteers from within our department and posted a call for participation on a university-wide mailing list. We required that our study not include anyone under the age of 17. The majority of our participants were postgraduate students, most of them coming from the Computing Department (8), and others from Psychology (3 participants) and Accounting Finance (1 participant) departments. Two participants were in their A-Levels. More than half our participants were men (9 male, 5 female). Five participants have used alternative input devices, such as haptic gloves, and two of them have used the Cubicle interface before the test. Volunteers were informed prior to the test that they were participating in a user study that will assist in determining guidelines for tangible device design.

## 4.2 Procedure

The study to be semi-exploratory, hence the instructions given to the participants (Table 2) included some prescriptive tasks, but also space for exploration. Out of 14 participants, eight come from the Computing department (8), three from Psychology, one from Accounting Finance department and two participants were in their A-Levels. More than half our participants were men - 9 male, 5 female. Five participants have used alternative input devices, such as haptic gloves, and two of them have used the Cubicle interface before.

Participants were first given time to familiarize themselves with the Cubicle interface. The next two steps were to give participants the idea of selecting a movie trailer by carefully rotating the Cubicle. The rest of the instructions/tasks were carefully designed to observe how participants manipulate the Cubicle, i.e. the calibration (if any), expressions, as they selecting the requested movie trailers.

Nonetheless, because of the novel nature of the Cubicle and the limitations of the technology, we realized that these tasks were more likely to explore the limits of interaction rather than to provide solid quantitative data.

Participants were asked to complete four sets of test by using the same list of instructions. The four sets are as follows:

- NF – Numbered cube with front-aligned view
- UF – Unnumbered cube with front-aligned view
- NT – Numbered cube with top-aligned view
- UT – Unnumbered cube with top-aligned view

The order of these four sets was varied and partially balanced in order to measure and compensate for order effects. However, to avoid confusion the two face aligned and two top aligned variants were always together. That is the possible orders were:

- NF-UF-NT-UT    NF-UF-UT-NT    UF-NF-NT-UT    UF-NF-UT-NT
- NT-UT-NF-UF    NT-UT-UF-NF    UT-NT-NF-UF    UT-NT-UF-NF

**Table 2.** List of instructions

1. Pick up the cube
2. Play around with the cube, until you feel comfortable
3. Then, manipulate the cube in your hand(s) so that any three sides of the cube visible on the screen
4. From 3, make one of its side (left or right) visible on the screen  
*Please tell instructor when you are done*
5. Select Matrix trailer
6. Place the cube on the table
7. Watch the movie for a few seconds
8. Pick the cube up again
9. Select a different movie trailer
10. Then place the cube on the table, or make the cube parallel to the floor
11. Watch the trailer that you just selected for a few seconds
12. If you placed the cube on the table, pick the cube up again, or continue moving the cube
13. Now, resume the Matrix trailer
14. Place the cube on the table once you select this
15. You can now browse to any other trailers available if you are interested  
*Please tell instructor once you finished*

#### 4.3 Measures

To record our data, we use a combination of recording to allow post-test qualitative and quantitative analysis and also collected qualitative data during the experiment including observations and questionnaires. All tests were recorded with a video camera and log files were used to record the data about the cube's orientation. These two results were then synchronized with a small purpose built tool to allow the video of the participants physical movements to be reviewed alongside the on-screen representation. Volunteers were asked to fill out a background questionnaire prior to the study and they were informed before beginning the test that they were going to be videotaped. Investigators recorded, via pen and papers, participants' non-verbal manipulation. At the end of the design study, users completed a short post-questionnaire. Using multiple forms of observation and data collection allowed for detailed evaluation and analysis of user behavior.

The post-test questionnaire was designed to provide us general information about users' acceptance towards the Cubicle application as an input device. There are ten attributes that we wished the participants to evaluate on a scale 1 to 7, with 1 being poor and 7 being good. The following table (Table 3) gives an overview of the attributes and the items that were intended to test.

**Table 3.** Attributes and their descriptions.

Smoothness	Wireless transmitting Speed of driver processing 3D rendering
Physical effort	Weight and measures of the Cubicle
Mental effort	Application usage Miscalibration
Reaction time	Wireless transmitting Speed of driver processing Usability of full screen toggling
Physical fatigue	Design of full screen toggling Weight and measure of cubicle
General comfort	Checking overall impression of the handling (comfort wise)
Overall operation	Checking overall impression of the handling (technology wise)
Fun	Playfulness of interaction
Frustration	Application design
Reliability	Whether the Cubicle was perceived to behave reliably

## 5 Quantitative and Qualitative Results

### 5.1. Performance results

All participants were (eventually) able to manipulate the cube to achieve the fixed goals of the test procedure. This there are no error rates to compare. However participants did vary in how long they took to perform the central (non exploratory) stages of the experiment. These measurements were obtained by using the video and log records.

This data was analysed using a multi-way ANOVA of log data. Log data was used as we expect timing data to have multiplicative effects (e.g. one participant may be 50% slower than another on all tasks). The ANOVA fitted for participant effect, the presentation order and the main effect of cube mapping. Whilst initial by eye analysis of graphs seemed to suggest an order effect, in fact none of the effects were statistically significant at 5%.

**Table 1.** Analysis of performance data

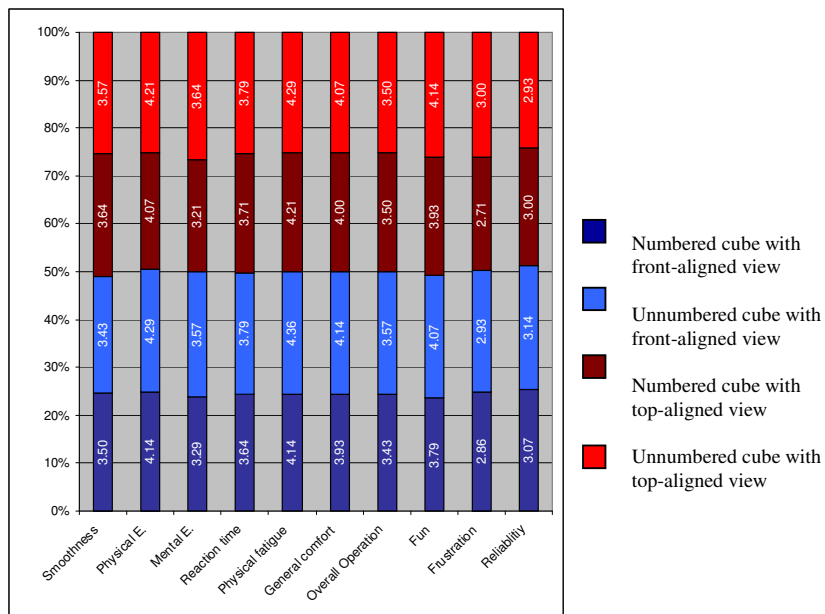
	Sum Sq.	F	d.f.	Sig. Level
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Presentation order	0.042	0.797	3	n.s.
Main Effect (mapping)	0.008	0.149	3	n.s.
Residual	0.630	–	36	–

Given the number of participants we would not have been able to detect small differences between mappings and order. However, given the apparently large differences in ease of use between the different mappings we were expecting to perhaps see substantial differences between, say, the numbered top facing mapping (NT) where once participants realised that the face they could see was always the top face they could simply use it rather like the fixed image cube. A larger number of participants, or, longer experiments might resolve fine differences between the conditions, but we can be confident from these results that there are no substantial effects.

## 5.2. Participants subjective assessment

The insignificance effects of the four conditions as mentioned above is reiterated in the post-test Dependent rating scale results. The scales of four sets were rated almost identical to one another (see fig. 3). Participants did not distinguish in these assessments between the front and top alignment, or the numbered and unnumbered cube.

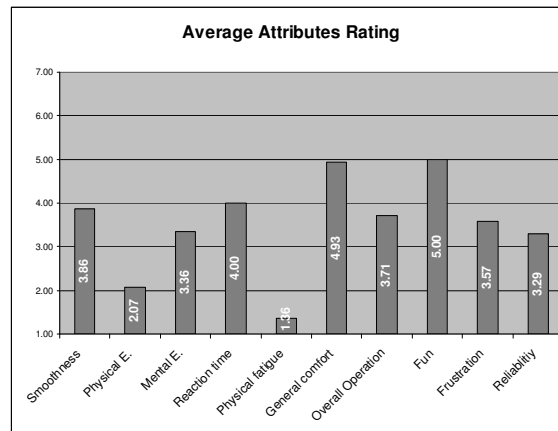


**Fig. 3.** Dependent Rating attributes against four conditions

Whilst they made no distinction between the conditions the participants did give substantially different ratings to each attribute. Figure 4 summarises the average rating for each attribute. Not that the device was rated very poorly for physical effort and fatigue. This reflects the fact that they needed to keep the cube supported for long periods during the experiment. Although this would not be representative of real use. In contrast, when asked to rate ‘general comfort’ however the ratings amongst the highest suggesting that other aspects of the Cubicle ameliorated the physical effort required to operate it.

Most other ratings were in middle range with no strong positive or negative reactions. Given as we shall discuss below, the participants total inability to reliably calibrate the Cubicle during the experiment the ratings for ‘frustration’ were remarkable no negative. Again this suggests that other more enjoyable parts of the experiment outweighed these in the participant’s responses.

Most interesting though was that the rating for “Fun” was the highest of all. This would of course be largely connected to novelty, but given the many frustrating and difficult aspects of several of the conditions this was perhaps surprising and shows the potential for Cubicles for playful interactions reinforcing previous anecdotal work [1].



**Fig. 4.** Average property rating.

### Qualitative Results

We anticipated the act of calibration between the Cubicle in their hands with the virtual cube on the screen from the participants – but this was hardly occurred. Instead, what we observed was a similar pattern of manipulation act toward the Cubicle –

participants heavily relied on visceral interaction (focused more on the screen rather than on the physical device) and responded appropriately to feedback.

Participants commenced the first few steps of each condition with an attempt to establish a correct mapping between the physical and its effect on the screen. But this act didn't sustain very long. Together with the fact that the condition they were in was not disclosed, we could see the participants struggled when trying to cope/match their movement with the movement of the virtual cube on the screen, even with the numbered cube. And, even though in few occasions they were able to establish calibration, we cannot deny that participants were quite frustrated when they could not cope with the mappings. But despite all this, they still managed to successfully complete tasks, and enjoyed it at the same time! (see Fig. 4)

From our observations, participants preferred not to dwell too much time on understanding the mapping, especially when their attempts never seem to make any differences. They, rather, remarkably, found it easier to manipulate the Cubicle by just paying attention to the visceral interaction. By doing so, the participants didn't need to plan their action. All they had to do was responded to feedback. And even though the mapping established was rather unusual, it was impressive enough to see how their mind works in comprehending two movements and able to complete all tasks.

This 'carefree' act definitely changed their attitudes toward the Cubicle. We observed participants enjoyed their interaction with the Cubicle and this resulted to more playful, fun experience. A few of participants commented on this,

*"Good fun :-)"*

*"Great device, enjoyable experience (would like to use again!)"*

These participants also spent a longer time watching the trailers.

## 6 Conclusions

Originally the experiment was carried out to investigate and to identify the most suitable condition of the four conditions for a Cubicle to be designed as an input media application, by incorporating numbered and unnumbered cube, and top- and front-aligned views of the cube. The four conditions were presumed to be able to establish and maintain calibration of the Cubicle with the virtual cube.

Outcome of this experiment told us a different story. Instead of shedding some lights on the matters we wished to answer, our quantitative results showed that there were hardly any significant effects if we designed the condition of the Cubicle with numbered or unnumbered, or with top-aligned view or front-aligned view. We also observed many users who tried to establish calibration between the physical cube and the virtual cube only resulted to frustration. In addition, the fact that the conditions of view alignment never been disclosed to the participants worsen the scenario. And yet, they able to complete tasks, and enjoyed it!

This study revealed that tasks completion didn't completely and entirely rely on correct calibration between the physical cube and virtual cube. We witnessed as the more effort they put in to establish calibration, the more frustrated they became. With-

out having to plan ahead, or trying to understand about the mapping (calibration) resulted to more playful, fun experience. As noted early in the paper, whilst the mappings differed in the cognitive complexity of the mapping, they all shared basic visceral properties where natural physical inverse actions mapped to opposite actions on screen. There is something about the intuitiveness of this that despite a lack of understanding of the unusual mappings, the participants were able to respond appropriately enough to feedback by merely focusing on the visceral interaction. In this case, playful experience has nothing to do with effectiveness of a device!

We also able to recognize, from the feedback received, features that would enrich and enhance the positive experience when users manipulate the Cubicle. This reinforces previous studies of tangible affordances [11] and suggests that aesthetic plays a big part in the design of a tangible device, potentially adding textures, incorporating sounds, different weight and visual effects may make it more fun to use.

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