The Effect of Physicality on Low Fidelity Interactive Prototyping for Design Practice

Joanna Hare, Steve Gill, Gareth Loudon, Alan Lewis

The effect of physicality on low fidelity interactive prototyping for design practice

Joanna Hare[1,1], Steve Gill[2], Gareth Loudon[2] and Alan Lewis[3]

[1]Cardiff Metropolitan University, Cardiff, UK

[1]jhare@pdronline.co.uk
[2]{sjgill, gloudon}@cardiffmet.ac.uk
[3]profalan.lewis@wales.ac.uk

Abstract. (124)
In this paper we propose the concept of 'active' and 'passive' physicality as mental models to help in understanding the role of low fidelity prototypes in the design process for computer embedded products. We define ‘active physicality’ as how the prototype and its software react to users and ‘passive physicality’ as how the prototype looks and feels offline. User trials of four different types of ‘low fidelity’ prototypes were undertaken using an existing product as the datum. Each prototype was analysed in terms of active and passive physicality and user responses were collated and compared qualitatively and quantitatively. The results suggest that prototypes that balance both active and passive physicality produce data closer to the final device than those that are strong in one at the expense of the other.

Keywords: Physicality; interactive prototypes; computer embedded products; design, product design; iterative product development; information appliances

1 Introduction

This paper builds on previous research on physicality and low fidelity interactive prototypes. Virzi et al. [1] found that there was little difference in usability data for high and low fidelity models of standard two dimensional graphical interfaces and an interactive voice response system. Yet a number of researchers [2] [3] felt that the concept of low verses high fidelity is not quite enough to convey the whole manner of situations that prototypes are constructed for. McCurdy et al. [3] argued for a mixed approach that allowed various aspects of a prototype to be built at different fidelity levels according to the design component being prototyped. They go on to suggest that there are five ‘dimensions’ or fidelity aspects that can be defined as somewhere between high and low within the same prototype, namely, aesthetics, depth of functionality, breadth of functionality, richness of data and richness of interactivity. So far this concept of mixed fidelity has been trialled with software but not physical prototypes. Despite several authors conducting studies on prototypes of computer embed-

adfa, p. 1, 2011.

ded devices the physical properties of both the model and interaction have been largely ignored.

In 2008 we demonstrated that in order to trial an interactive device with users an interactive prototype must be constructed [4]. The same study went on to lower both the level of physical fidelity of the model and the visual fidelity of interface until usability data started to significantly differ from the results of the final device. It was proposed that subtle differences in physicality, in this case removing the tactile feedback of buttons, affected the results suggesting that considerations of physicality are more important than the level of fidelity. This poses the question of how we 'consider' physicality.

Later work however demonstrated that some effects of physicality on user trials were only apparent through in-depth analysis because the effects were often subtle and the picture sometimes confusing [5]. This study seeks to clarify the position physicality occupies in user interactions.

The 2009 study sought to uncover the resulting differences in physicality based on low, medium and high(er) fidelity prototypes. In this study physicality was considered to fall under two areas: the physicality of the device (e.g. form, finish, weight) and the physicality of the interaction (the feel of the buttons and wheel in this case). But this method only allows the prototypes to be described and not directly compared which is essential when using physicality to determine the differences between the prototypes on trial. The physicality of the device and interaction was an appropriate way to describe the prototypes and, with subsequent analysis, this has been adapted to form the concept of 'passive' and 'active' physicality where:

Passive Physicality is how the prototype looks and feels when turned off, for example the weight, finish and button locations.

Active Physicality is how the prototype reacts to the users, typically the reaction of the interface (software), the feel of the buttons when operated (or sliders, dials, screen etc.)

To explain these terms a useful starting point is that of Dix et al. [6] who regard the physical device removed from its context and 'separated' from its digital operation in order to consider the mapping of the device 'unplugged'. This is the basis of 'passive' physicality; the judgments that can be made about the device without switching it on. Do you grasp a cup by its handle or by the body? Decisions are made about the comfort of the cup's handle by its appearance and the perceived weight of the contents of the cup [7]. Passive physicality also has its roots in Gibson's description of affordances [8] which suggest ways of interaction. Affordances are not simply a property of the object; they are the way a specific user relates to that object. When Norman [9] applied Gibson's idea to design; he divided the idea of affordances into those of real and perceived affordances. Whilst real affordances tell the user what they could actually do with the device, meaningful or not, perceived affordances tell the user 'what actions can be performed on an object and, to some extent, how to do them'. Yet passive physicality is more than affordances, it includes the physical properties of the device, its weight, finish and locations of the interactions.

Active physicality is concerned with the interactive portion of the device; what happens when the device is being used. It is still the physical that is of concern but in relation to the device's purpose and ease of use; how buttons operate the interface and how those buttons (or any interactions) feel when operated.

The exact drivers behind active and passive physicality might differ depending on the product being prototyped but the essence of active and passive physicality will remain.

This study proposes that a prototype can be considered by its level of active and passive physicality. For example, a prototype that is driven by the technology of the experience rather than the proposed size of the design would have a high level of active physicality but low passive physicality.

By attempting to understand physicality and using this to drive the physicality of low fidelity prototypes we aim to draw out just how physicality can be used by the designer to create efficient low fidelity prototypes. The efficiency of a prototype is of great importance; an efficient prototype can supply reliable data for a fraction of the cost of a high fidelity prototype enabling an iterative process. The early stages of the typical user-centred design process are highly iterative in order to react to and inform the developing project. User trials are a key tool to gathering data needed to inform the project, techniques include rapid ethnography [10], usability evaluation [11] and task centered walkthroughs all of which can be supported by interactive prototypes, and these prototypes need to be fast, low-cost and stage appropriate. This paper presents an early stage study on four low fidelity prototypes of the same device.

2 Methodology

2.1 The prototypes

An existing product was chosen to provide a datum against which the retrospectively developed prototypes could be measured. The choice to retro-prototype an existing device as a method was taken after considerable thought. The alternative would have been the development of a new device. Both methods have been used in prototype evaluation studies [4] [12]. Retro-prototyping was chosen because it has the benefit of access to a real, mass produced product, identified by the manufacturer as a worthwhile idea and having successfully undergone a product development process. The finished device can be used to compare the results from the user study in a manner that is all but impossible to recreate in a research study.

Fig. 1. The iRiver SPINN

The product chosen was the iRiver Spinn (Figure 1), a personal music player. The main features and interactions of the iRiver Spinn are shown in Figure 2.

Four low fidelity prototypes were constructed using techniques currently in use in industry. Each prototype was planned giving due consideration to active and passive physicality levels, with the intention of placing one in each of the quadrants shown in the graph in Figure 3.

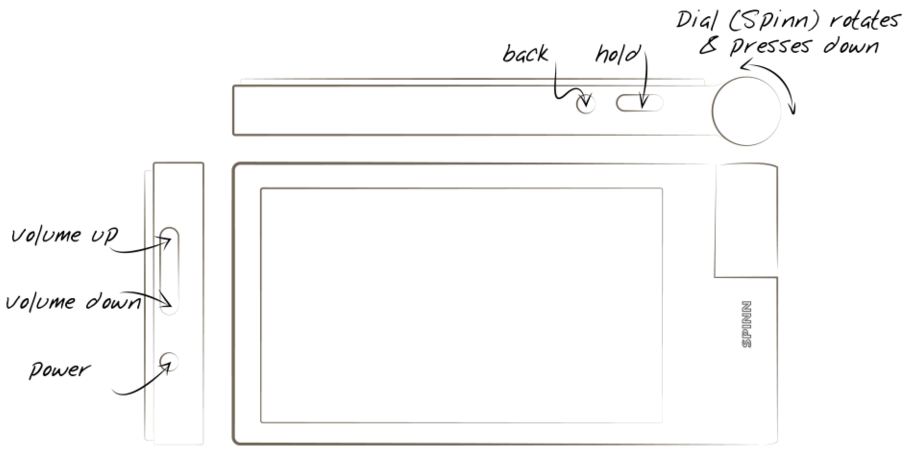

Fig. 2. The interactions of the iRiver Spinn

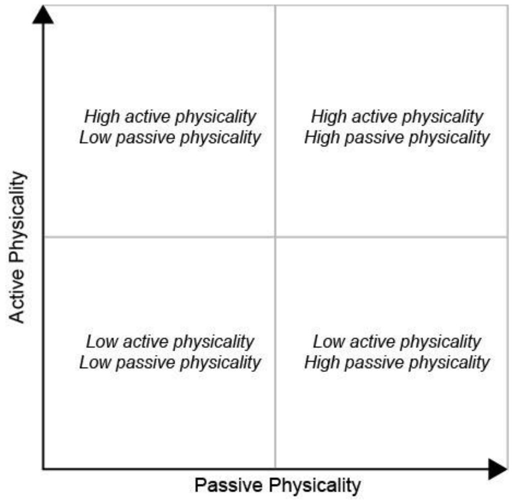

Fig. 3. Areas of physicality

The time taken to make each type of prototype is a critical issue. 'Time is money' and so we timed the building process and applied an hourly rate of £40 in order to cost each prototype. These are shown in Figure 4.

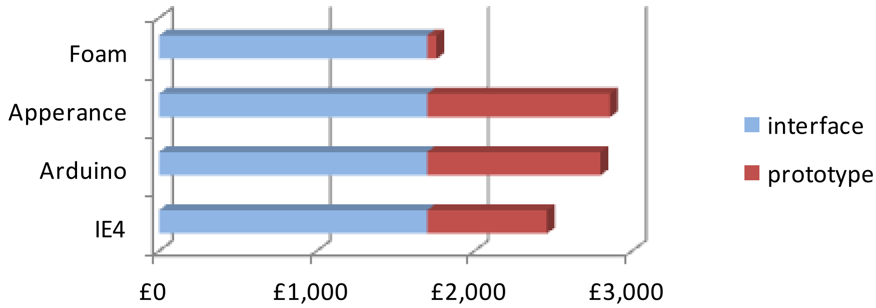

Fig. 4. The time taken to construct the prototypes

A single interface core was coded in Adobe Flash for all prototypes and adapted to the needs of each. Preparatory work ensured that this interface would be suitable for all prototypes and that the adaptation of the interface was possible for all. As is typical at this stage of the design process, only a limited selection of features were included in the software [11]. A single Computer Aided Design (CAD) model was created.

Prototype 1 (Figure 5; named 'blue foam') was constructed from model making foam board. Interaction was based on the Wizard of Oz technique [13], the Flash interface was operated remotely by the facilitator and viewed on the Tablet, the participant was asked to follow the 'think out loud' protocol [14], the facilitator could react to what the participant was saying and interacting with on the foam prototype.

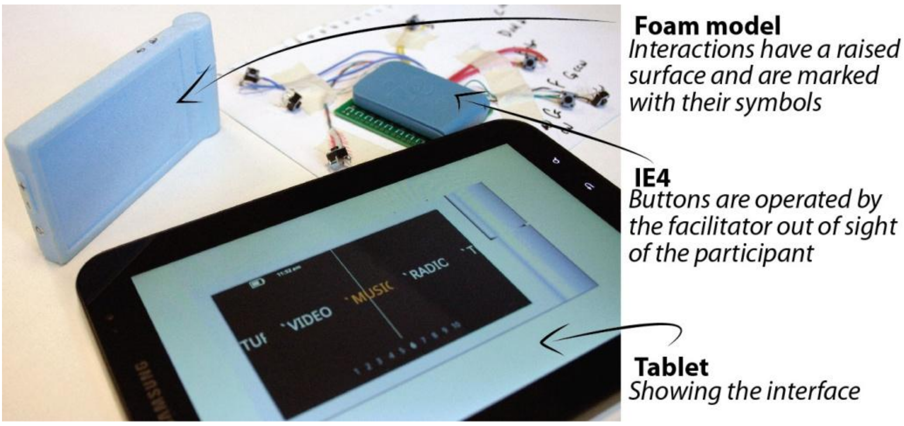

Fig. 5. Prototype 1: Foam prototype

The physical model for **Prototype 2** (Figure 6; named 'IE4') was constructed using rapid prototyping techniques (FDM). The CAD model was adjusted slightly to house the buttons and the dial which were integrated to make the prototype interactive. An IE4 [15][1] was used to connect the buttons to a laptop. The Flash interface, shown on a tablet, 'listens' for key presses from the IE4 and triggers changes in the interface when the participant interacts with the prototype.

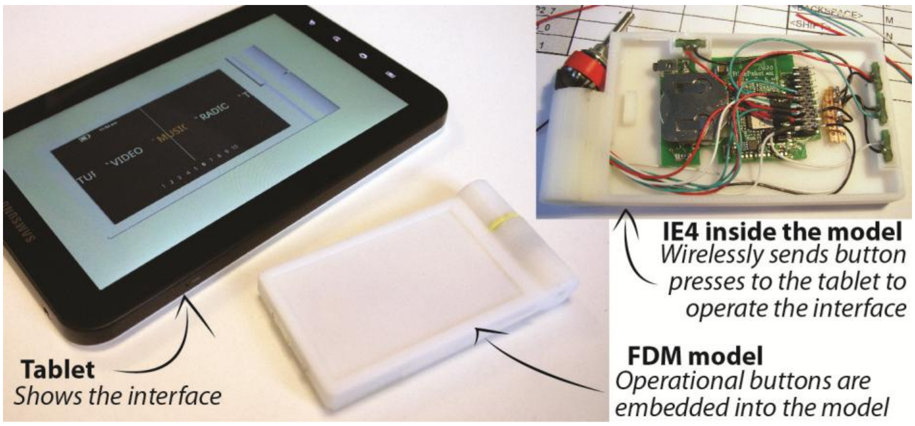

Fig. 6. Prototype 2: IE4

The physical model for **Prototype 3** (Figure 7; named 'appearance model') was intended to reflect the final device as accurately as possible. The form was rapid prototyped (using FDM) then finished to facsimile level. The Flash interface was operated by the participant on a touch screen tablet.

[1] The IE4 is a wireless device which converts buttons presses into keyboard presses

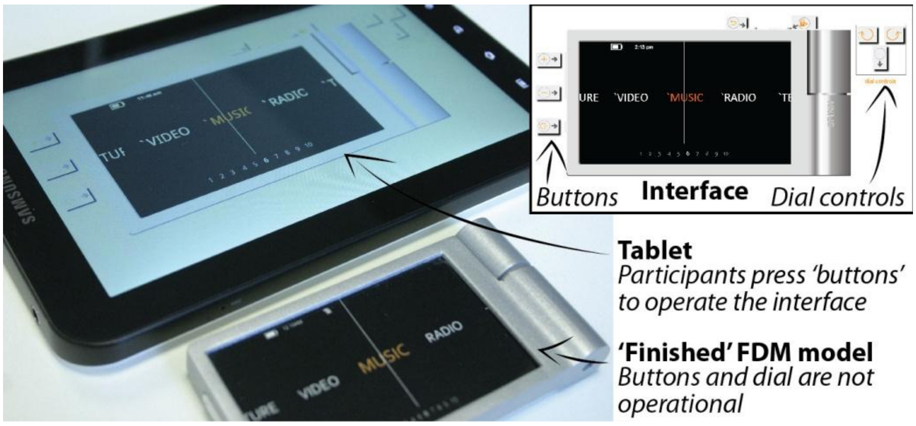

Fig. 7. Prototype 3: Appearance prototype

A rough foam model was constructed for **Prototype 4** (Figure 8; named 'Arduino') to accommodate the off-the-shelf buttons and dial. The dial was connected to an Arduino [16] which received the analogue signals and outputted them to the computer running the Flash interface. The buttons were connected to an IE4. Due to the extra code required for the Arduino, the interface was shown on a laptop rather than the touch screen tablet.

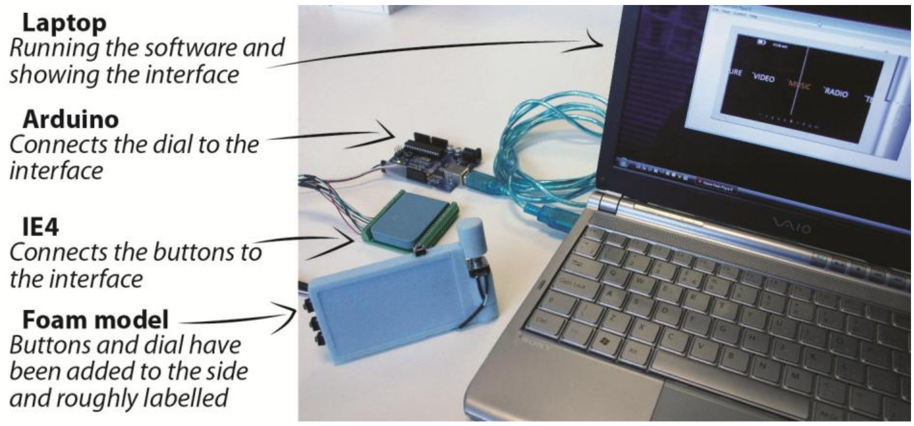

Fig. 8. Prototype 4: Arduino prototype

2.2 Assessing Physicality

Each of the prototypes was analyzed in terms of active and passive physicality. The main factors in the design that would determine the passive physicality levels of the prototype were determined to be: scale, form, finish and button location. For active physicality the main issues were: Spinn physical feedback, Spinn digital feedback, button physical feedback and button digital feedback. Initially a 'scoring' system was trialed but this was discarded, for when we call a prototype 'low' fidelity we do not assign that 'lowness' a value, as designers we intrinsically know when a prototype is low fidelity. It is only when conducting studies such as this that a prototype is considered lower or higher than another. Figure 9 shows the considerations for assessing each prototype.

Prototype	Passive physicality	Active physicality
Blue Foam	Low This prototype looks approximate and feels light, buttons are obviously cardboard and not working.	Low Buttons are obviously intangible and the participant is speaking through their expected interactions which are being interpreted by the facilitator who is operating the Flash based interface.
IE 4	Mid This prototype looks reasonable with no distracting wires. The prototype can be held comfortably yet it is very obviously an early stage prototype.	Mid Interactions mimic the design intent satisfactorily directly operating the interface which is a reasonable approximation of the design intent.
Appearance model	High The prototype looks and feels very similar to the final product.	Low The interactions are not obvious as the participant does not use the tangible prototype to operate the interface; instead the interface is operated on a touch screen breaking the link between the tangible product and its interface.
Arduino	Low The prototype has tacked on switches and wires are distractingly apparent in both the aesthetics and tangibility of this prototype.	High The prototype accurately mimics the way the final device feels when it is operated, both in the way the buttons work and the functionality of the interface.

Fig. 9. Assessing the levels of active and passive physicality of the prototypes

The Appearance and Arduino prototypes are high in one area of physicality at the expense of the other, whilst the Foam and IE4 prototypes 'balance' both active and passive physicality, as shown in Figure 10.

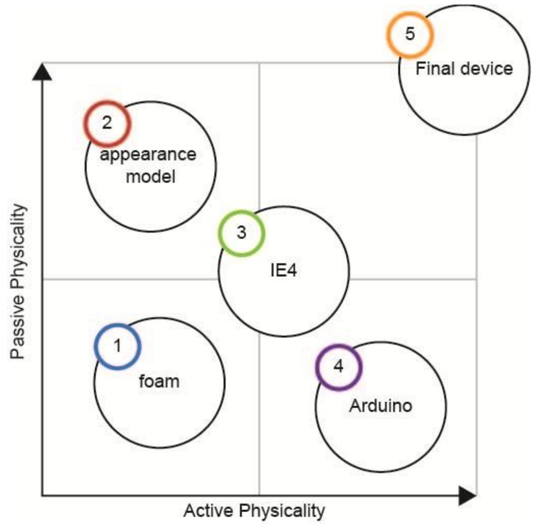

Fig. 10. The resulting physicality of each of the prototypes

2.3 The User Study

40 participants were recruited for the study (eight per prototype [17]), two did not turn up and three tests were rejected due to technical difficulties so the total number included in this analysis is 35.

16 of the participants were female and 19 were male. Participants were screened in accordance with the target market identified by iRiver to be between 23 and 45 years old; recruited participants fell predominately into the <28 (49%) or 29-33 (34%) age groups. All listened to music on a dedicated player or mobile phone and none had used the iRiver Spinn before.

Task-orientated trials, typical of usability trials, can be an effective way to demonstrate the product to a participant in a controlled manner and the participants were encouraged to 'think aloud' during the study to communicate their thought process [18]. Five tasks were chosen to introduce the participant sequentially to the device and no time constraint was imposed for the tasks. The tasks were:

Task 1: Turn the device on
Task 2: Find and play a specific track
Task 3: Adjust the volume of the track
Task 4: Stop the track and navigate to the first screen
Task 5: Turn the device off

Next, each participant was asked to scroll through the main menu titles and discuss what they expected within each menu. This user-led exploration ensured each participant had the same knowledge of the features of the device. After which a semi-structured interview sought to gain feedback about both the physical design and the users' interaction experience of the product. The explicit nature of the tasks and user-led exploration is one of the recommendations to reduce the evaluator effect on studies [19].

Finally, users were introduced to all the prototypes and asked to fill in a questionnaire ranking the quality of feel, appearance and quality of interaction for each of the prototypes. This enabled the participants to directly compare prototypes and offer an opinion about their construction.

Participants were bought into a controlled environment and the entire user trial was recorded on video. A facilitator ran the study with an observer monitoring the study via the video link. The observer was able to ensure continuity across the studies; this was deemed more suitable than introducing them as a second evaluator due to their level of experience with the prototypes and user testing methodologies. The Facilitator has conducted a number of similar studies before in a research and commercial context and is therefore able to reflect on techniques with colleagues of similar experience. Thus although the evaluator effect cannot be eliminated, it has been considered for this study [19].

3 Results of the user trial

The analysis was performed by the facilitator. Discourse analysis provided a framework to analyse the video footage of the tasks, menu exploration and semi-structured interview. The strength of this approach is that it gives the ability to structure the conversational feedback typical of this type of study in a rigorous manner. The video footage was reviewed with event logging software and comments were assigned 'codes' based on the type of comment. 50 comment groups were recorded in total. In order to compare the prototypes comments made by just one participant were removed. These comments were then reviewed and collated to form high-level design recommendations typical of a report from user trials [20]. Further recommendations could be drawn from the data produced by the studies that would be used in a commercial context. For the purpose of this study only the comments that have emerged through the formal discourse analysis are included. It is important to note that the recommendations themselves are not important to this study and have therefore been simplified for this paper; it is the number of recommendations identified for each prototype in relation to the final device that is of importance in this context. The ten key comments that the design recommendations address are:

1. Help required from the facilitator
2. Difficulties in finding the required interaction
3. Tried other interactions
4. Pressed back to stop track playing
5. Tried turning dial to get to pause icon
6. Observation that it looks like a touch screen device
7. Like the 'Spinn' interaction
8. Long-winded interface
9. No unique selling point
10. Vertical menu navigation not obvious

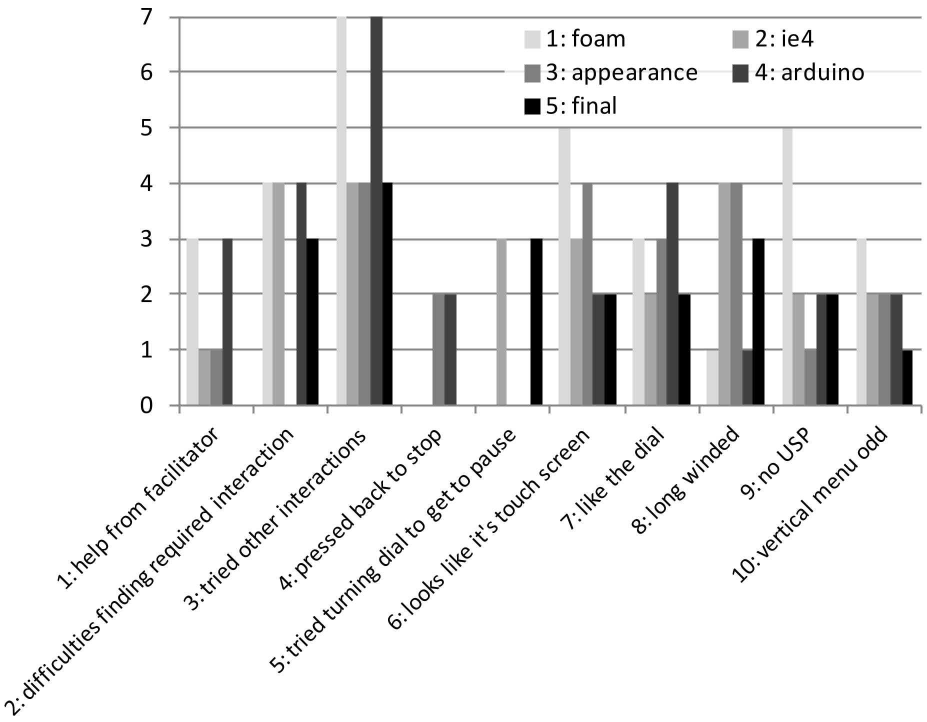

Fig. 11. The ten key comments addressed by the design recommendations

Figure 12 shows the results of the ranking exercise where each of the participants were introduced to all the prototypes and asked to give a rating where 6 is positive and 1 is negative. The participants were asked to rate three elements of the prototypes; the 'quality of feel' and 'appearance' which aimed to prompt the participant to consider the passive physicality elements and the 'quality of interaction' roughly equates to active physicality. Although these terms cannot be directly described as active and passive physicality, it goes some way to enable a comparison to the assessment of physicality shown in Figure 10. The data from the prototype the participant used for the study was not included to eliminate any bias from familiarity with the prototype. Figure 12 shows participants consider the foam prototype to have a low ranking but roughly equal for both elements which supports our assessment of the prototype to be low in both active and passive physicality. Likewise the appearance and Arduino are ranked in a similar way to our assessment. The IE4 gives interesting results with it being considered a higher quality of interaction than the Arduino and a more marked difference between active and passive physicality than anticipated. It could be that the visual aspects of physicality are undervalued in the current definition of passive physicality or that these questions are not adequate at obtaining participants views of active and passive physicality, this is beyond the scope of this paper but could be an interesting topic for further research. This exercise enabled participants to reflect on the prototypes themselves during the ranking exercise and the comments made were also captured, these will be brought into the discussion.

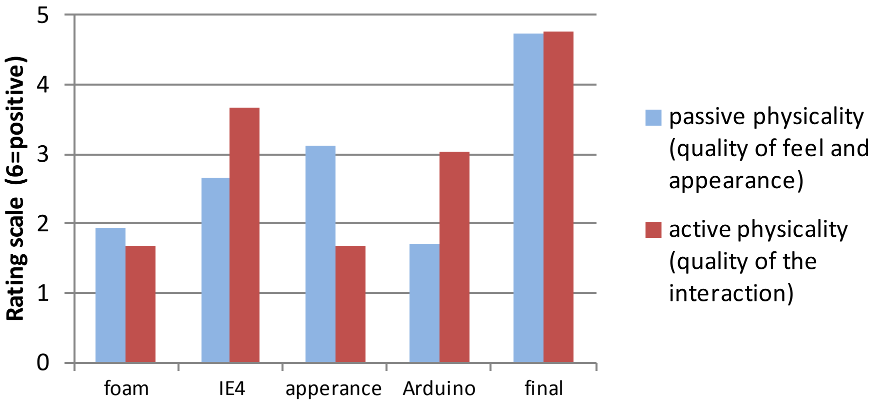

Fig. 12. Data from the ranking exercise; comparing the prototypes

4 Limitations of the study

This study is recognized to have limitations that could be addressed in future work. The study has been designed, conducted and analyzed by one of the authors; therefore presumptions concerning active and passive physicality will inevitably influence the outcomes. Future work would seek to determine if the notion of active and passive physicality are applicable beyond this study. This is planned in a number of ways; firstly by re-evaluating studies conducted prior to the active and passive physicality notion, secondly by seeking discussion with those involved with interactive prototyping from an academic and commercial context, and finally by evaluating future studies conducted by colleagues.

5 Discussion

In Figures 11 and 12 the IE4 prototype appears to give feedback that is closest to the final iRiver device. These will be discussed along with other, more subtle, differences across the prototypes bringing in comments from the ranking exercise. Observations fall into two categories; recommendations about the design and obstructions caused by the prototype. Recommendations positively help identify how the design can be improved whilst obstructions are caused by features of the prototype that hinder participants in giving meaningful feedback.

5.1 Recommendations about the design

Physicality of the dial.

The IE4 prototype was the only prototype that highlighted participants trying to turn the dial to get to the pause function. The physicality of the dial itself could be the cause of this, for the IE4 each rotation has a distinct 'click' which causes a reaction in the interface. However the Arduino prototype did not produce this feedback and its dial had a similar physicality to the final device. This suggests that there must be something else about the prototype that causes the participant to miss feedback for this design recommendation. Several users made comments about the wires of the Arduino prototype being "very distracting" and looking "messier" than the other prototypes, this 'messier' appearance could possibly be the cause of this.

Information architecture.
The feedback that the interface was longwinded was a common comment from participants of the trial with the final device. The IE4 and Appearance model were both good at drawing the same feedback. The Foam prototype was not able to elucidate this, possibly because the participant was not directly manipulating the prototype and therefore not creating the direct mental link between the physical and digital 'I did not like the fact that I couldn't control the device (interface) from the model'. Meanwhile the Arduino prototype produced few comments about this possibly because the novelty of the prototype itself suppressed the participant's potential frustration with the navigation of the interface "this thing (dial) works alright. I quite like the ability to click". The IE4 seems to give a very direct feel between the interface and interaction, mimicking the final device well. The Appearance model forced the participant to have to continually press the scroll button to navigate the interface, high lighting the sheer number of button presses required to navigate the interface "Very tedious going through all the songs like this".

5.2 Obstructions caused by the prototypes

Modeling physical interfaces on a touch screen.
The Appearance model used a touch screen for the interactive element of the prototype. This prototype gave participants the least difficulties in finding the interactions. Due to the need to represent all the buttons on a touch-screen this prototype clearly indicated where interactions were, even when they were on the side of the device. This made the interactions more obvious for those using this prototype than would otherwise have been. Paradoxically, the very usability of the touchscreen prototype devalues it given the issues users had with the real device.

Obstacles to the participants understanding the prototype.
Figure 11 shows the Foam and Arduino prototypes forced participants to ask for the most help from the facilitator. The Foam model requires the participant to fully engage with the 'speak aloud protocol' because the buttons provide no active feedback. The participant therefore has to wait for the facilitator to operate the interface. In contrast, the Arduino prototype allows the participant to operate it independently, but it may be that the appearance of the wires that seem to the biggest barrier to ac-

ceptance. It may also be that techniques which require the participant to understand the *way* in which the prototype works are not suited for this type of early stage trial.

5.3 Overview of the four prototypes

The IE4 prototype.

The real-time nature and simplicity of this prototype seem to be the important factors in making this prototype the most effective of the prototypes. Participants were able to operate and receive immediate feedback from the interface without an overly complicated looking prototype or altering the scale and form of the model. “I felt very little difference in terms of the final version and white model (IE4) for the quality of interaction - white model (IE4) had a few blips but nothing that is stopping me using the device successfully.” “The addition of working buttons on the prototypes increases the quality of the feel, as the ways in which interaction occurs can be more readily envisioned.”

The Foam prototype.

This prototype used the ‘speak out loud’ protocol for participants to engage with the interface. Results show that this prototype was less effective at enabling participants to build a mental model of the device resulting in reduced effectiveness of the comments received. “The colour, weight, size and cable connections play a big part of my initial interaction with a product, for this reason the blue foam compared to the final unit was clearly a visual aid as opposed to actual real product comparison.”

The Arduino prototype.

Participants required more assistance using this prototype. This was a surprise from the most interactive of the prototypes. Participants seemed to be affected by the wires and appearance of this prototype. “The model with blue foam & wires looks messier than the blue foam model but it looks a little bit more functional than the model with blue foam alone.”

The Appearance prototype.

This prototype used a touch screen to convey the interactions of the prototype. Participants did not identify as many usability errors and had the weakest performance in relation to the final device. This outcome supports Gill’s study in which it was proposed that interactions are easier for a participant to identify on a screen [4]. “Although the silver model (appearance model) looked more like the final version, it did not like the fact that I couldn't control the device from the model and I didn't think having the model alone, without much interaction, was very worthwhile.”

6 Conclusion and Application

The four prototypes trialled in this study explored different aspects of active and passive physicality. The results show that both active and passive physicality are important considerations for early stage user feedback; but it is an even balance of these that produces the most effective prototypes, as seen in the IE4 and Foam prototypes. Resources should not be used exclusively to ensure the prototype functions well in an electronics and interaction sense (active physicality) if it severely impacts the ways the prototype looks or can be held by the user (passive physicality). Likewise, resources spent creating a prototype that looks very close to a final device are not effective if interactions are not well supported.

The IE4 and Foam prototype provided the most accurate data compared to the user experience of the real device. Both the IE4 (£760) and Foam prototype (£60) were of balanced physicality. The Arduino (£1,100) was very strong on active physicality to the detriment of passive physicality whilst the Appearance model (£1,160) was very high on passive physicality but low on active physicality. This suggests that it is those prototypes that are well balanced that are the most effective in this study. Since they are also cheaper they represent strong value for money.[2]

The prototype has long been accepted as a valuable approach to creating valuable and insightful design outputs. However, for interactive devices that have both a physical and digital form, visual fidelity alone is clearly not enough to fully conceive the complete prototype and ensure it will accurately fulfil its purpose. Whilst visual and dimensional fidelity is very much the staple of prototyping, physical fidelity clearly has a role in creating a well-targeted prototype. This study indicates that for interactive prototyping, 'physicality' needs to be an even combination of active and passive physicality.

7 Future Work

Future work needs to be conducted to determine if active and passive physicality can be usefully used in assessing prototypes beyond those used in this study. The outcome of this study indicates that a balanced prototype is the most effective. The prototypes used in previous studies [4] [5] should now be assessed in terms of physicality to determine for example if notions of active and passive physicality aid in determining why the data for the 'flat-face' prototype differed considerably from the final device. In addition prototypes used in studies by other authors could be categorized to see how they relate to our prototypes.

8 References

1. Virzi, R. A., Sokolov, J. L., Karis, D.: Usability problem identification

[2] Costs are those shown in Figure 4 minus the software prototyping (shared by all prototypes).

using both low and high-fidelity prototypes. In : Proceedings of the SIGCHI conference on Human factors in computing systems: common ground, Vancouver, British Columbia, Canada (1996)

2. Lim, Y.-K., Stolterman, E., Tenenberg, J.: The Anatomy of Prototypes: Prototypes as Filters, Prototypes as Manifestations of Design Ideas. ACM Transactions on Computer-Human Interaction 15(2) (July 2008)

3. McCurdy, M., Connors, C., Pyrzak, G., Kanefsky, B., Vera, A.: Breaking the fidelity barrier: an examination of our current characterization of prototypes and an example of a mixed-fidelity success. In : Proceedings of the SIGCHI conference on Human Factors in computing systems, Montreal, Quebec, Canada (2006)

4. Gill, S., Walker, D., Loudon, G., Dix, A., Woolley, A., Ramduny-Ellis, D., Hare, J.: Rapid Development of Tangible Interactive Appliances: Achieving the Fidelity / Time balance. International Journal of Arts and Technology, 309-331 (2008)

5. Hare, J., Gill, S., Loudon, G., Ramduny-Ellis, D., Dix, A.: Physical Fidelity: Exploring the Importance of Physicality on Physical-Digital Conceptual Prototyping. In : Interact 2009, Uppsala, Sweden, pp.217-230 (2009)

6. Dix, A., Ghazali, M., Gill, S., Hare, J., Ramduny-Ellis, D.: Physigrams: Modelling Devices for Natural Interaction. Formal Aspects of Computing 21(6), 613-641 (2009)

7. Reeves, S.: Physicality, spatial configuration and computational objects. In : First International Workshop on Physicality (2006)

8. Gibson, J.: “The theory of affordances” in Perceiving, Acting, and Knowing. Hoboken, NJ: John Wiley & Sons Inc. (1977)

9. Norman, D.: The Design of Everyday Things. Basic Books, New York (1988)

10. Norman: The Invisible Computer: Why good products can fail, the Personal Computer is so complex, and information appliances are the answer. MIT Press, Cambridge, MA (1998)

11. Nielsen, J.: Usability Engineering. Academic Press Inc (1993)

12. Lim, Y., Pangam, A., Periyasami, S., Aneja, S.: Comparative Analysis of High- and Low-fidelity Prototypes for More Valid Usability Evaluations of Mobile Devices., Proceedings of NordiCHI '06 Proceedings of the 4th Nordic conference on Human-computer interaction: changing roles (2006)

13. Maudsley, Greenberg, Mander: Prototyping an intelligent agent through Wizard of Oz. In : Interchi 93, pp.277-284 (1993)

14. Gould, J., Lewis, C.: Designing for Usability -Key Principles and what Designers Think. In : CHI '83, Boston, pp.50-53 (1983)

15. Gill, S.: IN PRESS: PAIPR Prototyping: Some Thoughts on the Role of

the Prototype in the 21st Century. In : Prototype: Craft in the Future Tense. Berg (2013)

16. Burleson, W., Jensen, C. N., Raaschou, T., Frohold, S.: Sprock-it: a physically interactive play system. In : Proceedings of the 6th international conference on Interaction design, Aalborg, Denmark (2007)

17. Goodwin, K.: Designing for the Digital Age: How to create human-centered Products and Services. Wiley Publishing Inc. (2009)

18. Dumas, J., Redish, J.: A Practical Guide to Usability Testing (revised edition). Intellect, Exeter, UK (1999)

19. Hertzum, M., Jacobsen, N.: The Evaluator Effect: A Chilling Fact About Usability Evaluation Methods. International Journal of Human-Computer Interaction 15(1), 183-204 (2003)

20. Molich, R., Jefferies, R., Dumas, J.: Making Usability Recommendations Useful and Usable. Journal of Usability Studies, 162-179 (2007)

21. Buchenau, M., Suri, J.: Experience prototyping. In : Proceedings of the 3rd conference on Designing interactive systems: processes, practices, methods, and techniques, New York, pp.424-433 (2000)