the prototypes themselves during the ranking exercise and the comments made were also captured, these will be brought into the discussion.

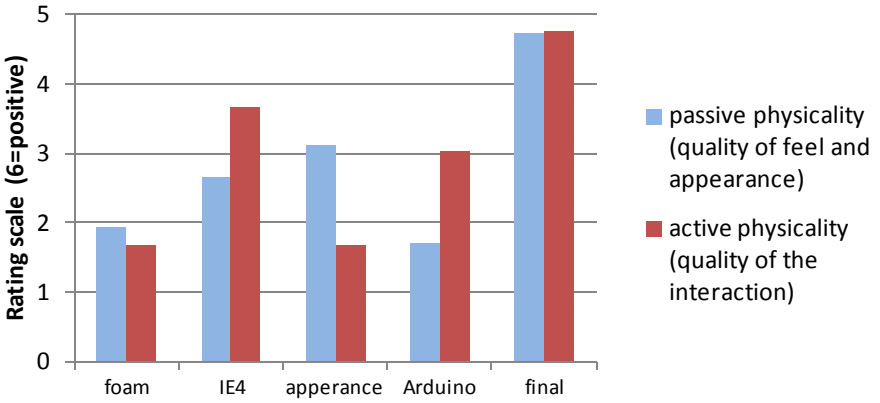


**Fig. 12.** Data from the ranking exercise; comparing the prototypes

## 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)