Children's Haptic Experiences of Tangible Artifacts Varying in Hardness

Jeanine Kierkels, Elise van den Hoven
Industrial Design Department
Eindhoven University of Technology
Den Dolech 2, 5600 MB Eindhoven
The Netherlands
e.v.d.hoven@tue.nl

ABSTRACT
In this paper we describe our investigations on the role of material hardness in the haptic experience of tangible artifacts.
Without seeing the artifacts children had to rank their experience on a scale of two antonyms while touching and holding these artifacts. In this experiment it was shown that children have no problem ranking hardness. Two groups could be identified: soft artifacts were found to be cute, speedy and warm, e.g., and hard artifacts boring, sad and old-fashioned. We think that paying attention to this factor in the design of tangible user interfaces for children can improve their experience.

Categories and Subject Descriptors
C.0 [**Computer Systems Organization**]: General – *hardware / software interfaces.* H.5.2 [**Information Interfaces and Presentation (e.g. HCI)**]: User Interfaces - *Haptic I/O, Input devices and strategies (e.g., mouse, touchscreen), User-centered design.*K.8.0 [**Personal Computing**]: General – *games.*

General Terms
Design, Human Factors.

Keywords
Haptic experience, interaction design, tabletop gaming, tangible user interfaces.

1. INTRODUCTION
We can perceive a product or an artifact by seeing, hearing, tasting, smelling and touching it. These senses enable us to determine the value and meaning of an artifact. Vavik et al. [19] noticed that in the area of design for pleasure, inclusive design and interaction design, a shift can be seen from a focus on the visual perception of products to tactile perception.

Considering this rising role of haptics, the sense of touch, in (interaction) design, there is only limited knowledge about the tactile experience evoked by a material or surface structure. In order to create a stronger emotional connection with users of products or artifacts, the characteristics of those material and surface structures and the sense of touch should be highlighted [19].

The study described in this paper focuses on tangible artifacts used to interact with digital tabletop applications, more specifically gaming applications for children. Digital tabletops can create a social experience by providing the richness of natural interaction around a table with the advantages of computer technology. Digital tabletop gaming [3,4,11,13,14] can combine the benefits of computer and traditional games into a type of gaming that is able to provide new and engaging gaming experience. One of the main challenges in the design of those gaming applications is the integration of the social, virtual and physical domains [11]. Magerkurth et al. [11] present a conceptual framework in which the relations between these domains are modeled. Their vision emphasizes possibilities for future entertainment by expanding traditional computer games with physical and social aspects. One way of extending digital games into the physical world is by using tangible interaction. Those tangible interfaces effectively mediate between the virtual and the social domains.

We examined the relation between the haptic experience of such an artifact and the way it is perceived (and thus can be linked to the social and virtual aspects of digital tabletop game play). As research platform we developed the digital tabletop game called Flourishing Future: a multiplayer game to support the simultaneous play of four children (Figure 1). Collaboration is required to reach the goal of the game: create together a tree full of leaves by developing an environmentally friendly city. Players use tangible objects to interact with the digital screen embedded in the table. Flourishing Future is implemented and runs on a digital tabletop that detect the physical artifacts using ReactiVision [7]. The development and evaluation of the game itself is beyond the scope of this paper; instead we will focus on the tactile design and experience of one of the game artifacts used to interact with digital tabletops.

First, some research is presented involving tangible user interfaces, their material and surface properties and the way they are perceived through the sense of touch. Next, the experimental setup is described, followed by a description of the designed artifacts. We end with discussion and conclusions sections.

NordiCHI 2008: Using Bridges, 18-22 October, Lund, Sweden.

Figure 1. The multiplayer game “Flourishing Future” is developed on a digital tabletop using ReacTIVision [7].

2. RELATED WORK

2.1 Tangible Interaction

Different types of interactions can be supported by digital tabletops. Both touch as well as physical objects are common types of input. Interaction via touch screens is often restricted to 2D, whereas physical objects make the digital world tangible and graspable for the users [3]. Ullmer and Ishii describe the concept of tangible interaction as “giving physical form to digital information” [18, p. 916] and propose a conceptual framework for tangible user interfaces. Tangible interaction can couple physical objects to digital information, in which these tangible artifacts take up both the role of representation as well as control for the virtual environment [18]. Hornecker and Buur [6] suggested to widen this view on tangible interaction by adding different fields and viewpoints, including design, art, architecture, and at the same time integrating the importance of the user experience in interacting with the tangible artifacts. Here, also the material and physical properties of tangible user interfaces are of interest.

2.2 Tactile Properties

When using a tangible interface in a digital tabletop application, the user will have physical contact with the artifacts itself, and will feel and experience the artifact’s material and surface properties. Since we wanted to study the impact of artifact hardness on the tactile perception (see section 3 for more details), we studied materials first and found out that there are several relevant ways of describing materials. Both the engineering and perception dimension [2] will be explained below.

The engineering dimension [2] is based on the physics of a material and takes technical attributes, like physical, mechanical, thermal and electrical, to characterize the materials. Materials science has developed this kind of classification, which provides essential material information for enabling safe and technical design of products [2].

Another way to characterize materials is based on how they are perceived by the human sense. Within the perception dimension [2], materials are grouped according to their tactile attributes, which include texture (smooth-rough), hardness (soft-hard), temperature (warm-cold), flexibility (flexible-stiff), geometry (small-big, cube-sphere, far away-close).

Concluding from these two material dimensions we can say that we do not want to focus on objective measures of hardness, but instead on the subjective experience of the users. Therefore, we will focus on the perception dimension.

2.3 Tactile Experiences

Vavik et al. [19, p. 1] define tactility as “the capability of being touched or responsiveness to stimulation of the sense of touch”. Thinking in terms of the perception dimension of material characterization, tactility is an important aspect. Therefore we need to investigate how material and surface properties are perceived through the sense of touch.

The sense of touch is attractive and important for human life, since it gives strong emotional impulses. According to Ackerman [1], the most important aspect of tactility is its ability to inform humans about the feeling of safety and pleasure. Even though the whole human body is sensitive to tactile impulses, the hands are the key locations for the touch senses [16]. The impulses that are received through the tactile sense can be called the tactile experience. Since this study focuses on evaluating that tactile experience, we will highlight the working of this process. Sonneveld [17] makes a division into the two main aspects of this tactile experience, namely intelligent and rational vs. dreamy and emotional.

When a user first touches an artifact, he gets an immediate response. Sonneveld [17] calls this immediate response the intelligent and rational experience. Physical qualities of the artifact are the basis for this type of experience (e.g. shape, size, texture, weight, balance, temperature and material properties) This process is continued within the so called dreamy and emotional experience stage. The rational information about the product creates an affective response to the artifact. The dreamy and emotional experience involves associations with similar experiences and emotions connected to them. Users are most of the time unaware of the particular aspects of their tactile experiences, e.g. the hardness of the material, however, they are aware of the experience itself. The study described in this paper will examine this last described matter further by evaluating how the hardness of a tangible user interface influences the children’s tactile experiences.

2.3.1 Tactile Exploration

To haptically recognize and experience salient dimensions and properties of artifacts, people use different kinds of exploratory hand movements. In order to perform the experiment described in this paper and with that make appropriate designs of the test artifacts, we have to understand how people are able to perceive material and surface properties through the sense of touch.

Lederman and Klatzky [10] researched different exploratory procedures of the touch sense and eventually divided those into the following four distinguishing categories.

The *lateral motion* procedure is used by people to haptically encode textures. This rubbing movement over the artifact’s surface is fast to perform and can be executed with only a small surface sample. The *pressure* procedure is applied to perceive the hardness of an artifact through haptics. By expending normal force into an object, this movement can be performed quickly and locally on homogeneous artifacts. *Contour following* is a procedure that exists of a dynamic movement alongside the edge of an artifact, used to determine the artifact's shape. Since this movement is slow to perform and at the same time requires a good memory of the human performing, it is liable to inaccurate perceptions by haptics. For the haptic exploration of size, the procedure *enclosure* is used. This consists of a static molding to the contours of an artifact. The movement is relatively quick to perform, though it only provides the explorer with low-level information.

In their experiments, Lederman and Klatzky [10] did not include the sense of temperature. They acknowledge that, at that time, they did not take that in to account [16]. Nevertheless, the sense of temperature is significant in providing information regarding material qualities. In daily life, we use a variable mix of the above mentioned exploratory procedures to naturally explore physical objects through haptics [10].

2.3.2 Touch and Vision

As described earlier in this paper, physical objects own several material and surface qualities. Those are connected to different human senses. Interaction between users and materials happens through seeing, hearing, tasting, smelling and touching.

In a series of studies Patomäki et al. [15] designed multimodal applications for visually impaired children. This study proved a correct use of haptic and auditory features to be very important. From the physical objects they tested with the visually impaired children it turned out that hard surfaces were easier to recognize than soft surfaces (possibly caused by the additional auditory feedback that hard surfaces produce when touching them). Thereby they noticed that these children preferred touching the hard materials over the soft materials.

Nevertheless, haptics, the sense of touch, is often not regarded as a viable way of perception for sighted users. Klatzky et al. [9, p. 357] study whether "the haptic system has its own encoding processes and pathways, which may or may not be shared with vision". Vision and haptics can both be salient for encoding different material properties.

Texture is well encoded by both vision and haptics. If texture is encoded as "spatial distance", vision is more salient. If texture is encoded as "roughness", haptics is more salient. *Hardness* appears to be more readily encoded by haptics than by vision. Both *Size* (if hand-sized) and *shape* appear to be more readily encoded by vision than by haptics. The material property *temperature* was not included in the research of Klatzky et al. [9], but it might be assumed that temperature gets more readily encoded by haptics than by vision.

The material property hardness is selected for the experiment in this paper because it is an aspect that can be easily encoded through haptics [9]. Furthermore, hardness can often not be perceived other than through touch, making it particularly suitable for tangible interaction. We define the hardness of a tangible object as: "the distance a finger/hand penetrates a surface when applying normal force" [9, p. 358].

2.3.3 Evaluating Tactile Experiences

The tactile experience evoked by different material and surface properties can be evaluated in two ways, one is by measuring physiological changes, such as brain waves, blood pressure and skin conductivity, while the other option is to ask the participants themselves. The latter is done e.g. by Kaye and Brown [8] who created a range of artifacts covered with different fabrics. They asked their participants to associate freely when they saw and touched the artifacts and in addition they used a questionnaire to let participants describe how the artifacts felt. The results were that the authors thought participants were very descriptive in their explanations about the tactile experiences. They also noted that the visual appearance of the artifacts influenced the tactile experience greatly. Another example of user evaluations is by Choi et al. [5] who did evaluations by ranking preferences through a questionnaire, focusing on one aspect of the tactility, i.e. material roughness. They decided to use a box in order to prevent participants from seeing the material samples. In this box they placed the samples for the participants to touch. We also decided to use a similar procedure so the visual appearance would not interfere with the tactile experience.

3. EXPERIMENT

We assume that if the tactile experiences evoked by an artifact (physical representation) fit the game concept (digital representation), this can enhance the emotional connection between user and product/gaming application [18,19]. The context of this study was digital tabletop gaming applications for children aged 10 to 13 with tangible interaction. In this experiment we want to investigate the tactile aspects of these physical artifacts. The aim of the experiment is to study the following research question:

> How do children rank their haptic experiences with physical artifacts varying in hardness?

The participants are 30 children in the ages of 10 to 13 years old. Children of both sex are equally represented (15 girls and 15 boys). The main equipment for conducting this study are the four objects of different hardness to be tested, and a "blind box" (Figure 2). In Section 4 the design of the artifacts will be explained in more detail. The "blind box" serves to exclude the tangible objects from view, in order to focus purely on the haptic exploration. Although it has been stated in [9] that haptics is salient over vision in encoding hardness, it is not desired during the experiment that those two senses interfere with each other. Participants are able to touch the objects with both hands.

Figure 2. The physical setup of the experiment. The tangible objects were placed inside a "blind box". During the whole experiment the artifacts were invisible to the participants.

active	⟷	inactive	mature	⟷	childlike
*adventurous	⟷	timid	modern	⟷	old-fashioned
boyish	⟷	girlish	natural	⟷	artificial
*crazy	⟷	sensible	precise	⟷	vague
cute	⟷	brutal	refined	⟷	coarse
exciting	⟷	boring	*scary	⟷	soothing
*flashy	⟷	tasteful	simple	⟷	complicated
*funny	⟷	serious	speedy	⟷	slow
*happy	⟷	sad	sporty	⟷	unathletic
hard	⟷	soft	warm	⟷	cold

Figure 3. The 20 adjectives and their antonymous pairs regarding material hardness. (*) denotes the tactile adjectives we used that differ from research by Choi et al. [5]

3.1 Experimental Setup

To evaluate the experience of the participants when exploring the tangible objects, we made use of 20 pairs of tactile adjectives. For each of the four objects the children touched they were asked to rate the adjectives as shown in Figure 3.

The basic principle for this list of adjectives is the research performed by Choi et al. [5]. They evaluated the surface roughness of general polymer-based products with consumers. With help of a dictionary, thesaurus and linguistic experts, Choi et al. came to their selection of 37 pairs of antonymous adjectives. Since this research study is focusing on a different target group, namely children, and a different context, namely digital tabletop gaming, the list was adjusted to its purpose. We added *adventurous-timid, crazy-sensible, flashy-tasteful, funny-serious, happy-sad* and *scary-soothing*.

The process of the total experiment, which took about 15 minutes per child, is visualized in five consecutive steps in Figure 4. After a formal pre-set questionnaire (1), all four artifacts were placed inside the blind box. The participants had the opportunity to get acquainted with and haptically explore the tangible objects (2). Thereupon they were asked to arrange them in a logical order (3). Subsequently, the artifacts were placed inside the box one by one. The order of hardness was counterbalanced across participants. For each artifact with different hardness, the same list of 20 questions was presented (4). Answers to the questions were given in the form of a likert scale that ranges from 1 to 7, in which children had to choose a value between two antonyms representing their experience when touching these tangible artifacts. The experiment concluded with a short post-test interview (5). At this point, the children were free to actually view the tangible objects.

4. ARTIFACT DESIGN

The experiment described in this paper is used as input for the design of artifacts. To perform the study, four physical objects of different hardnesses were created. The tactile hardness had to be the only variable in between the artifacts, all other material and surface characteristics were completely identical.

The artifacts had the shape of a stamp, which was one of the playing pieces from the digital tabletop game Flourishing Future. The size of the artifacts was hand-sized (60*60*70 mm).

To make sure all artifacts had an identical texture, every object had a surface made out of silicone rubber (Smooth-on© product, Rebound25). The tactile temperature was the same for each of the tangible objects as well as their weight.

Each artifact had a different tactile hardness (except for the bases which were equally hard for all four, since we had to use this material to stabilize them). The resulting tangible artifacts range from: (I) very soft, (II) fairly soft, (III) fairly hard to (IV) very hard (see Figure 5 from top to bottom respectively).

I. The very soft one was filled with fiberfil (100% polyester). It was easily possible to completely penetrate the surface of the artifact till reaching its opposite side. The hardness bore comparison with that of a fluffy feather pillow.

II. The fairly soft one was filled with foam. Its hardness showed similarity to a cuddly toy. It was fairly easy to penetrate the surface of the artifact. However, it became impossible to completely squeeze the artifact.

III. The fairly hard one was filled with silicone rubber. Only a relative small distance could be covered when pressing the artifact, like with a full bike tire.

IV. The very hard one was filled with ABS plastic. No matter how hard the force one executed with his fingers/hands, it was impossible to penetrate the surface of this artifact.

These four artifacts were used in the experiment described in Section 3.

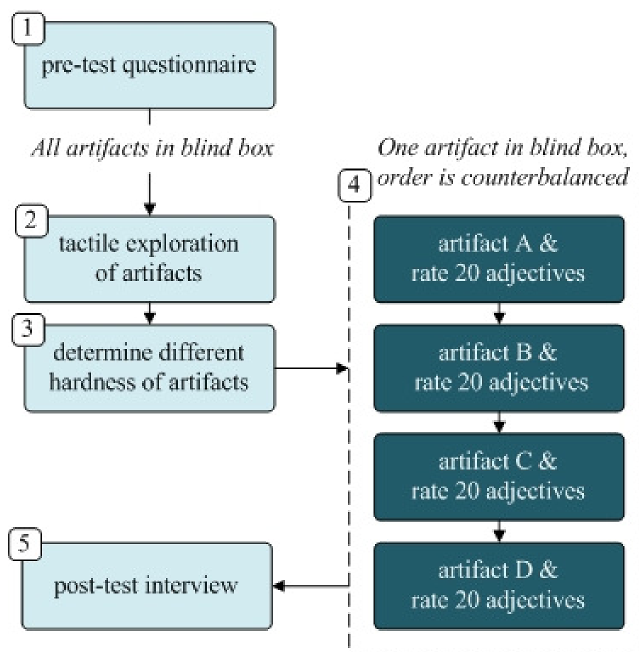

Figure 4. Visual representation of the different stages of the experimental setup.

5. RESULTS

The results of the experiment are as follows.

First the participants were allowed to touch and explore all tangible objects simultaneously.

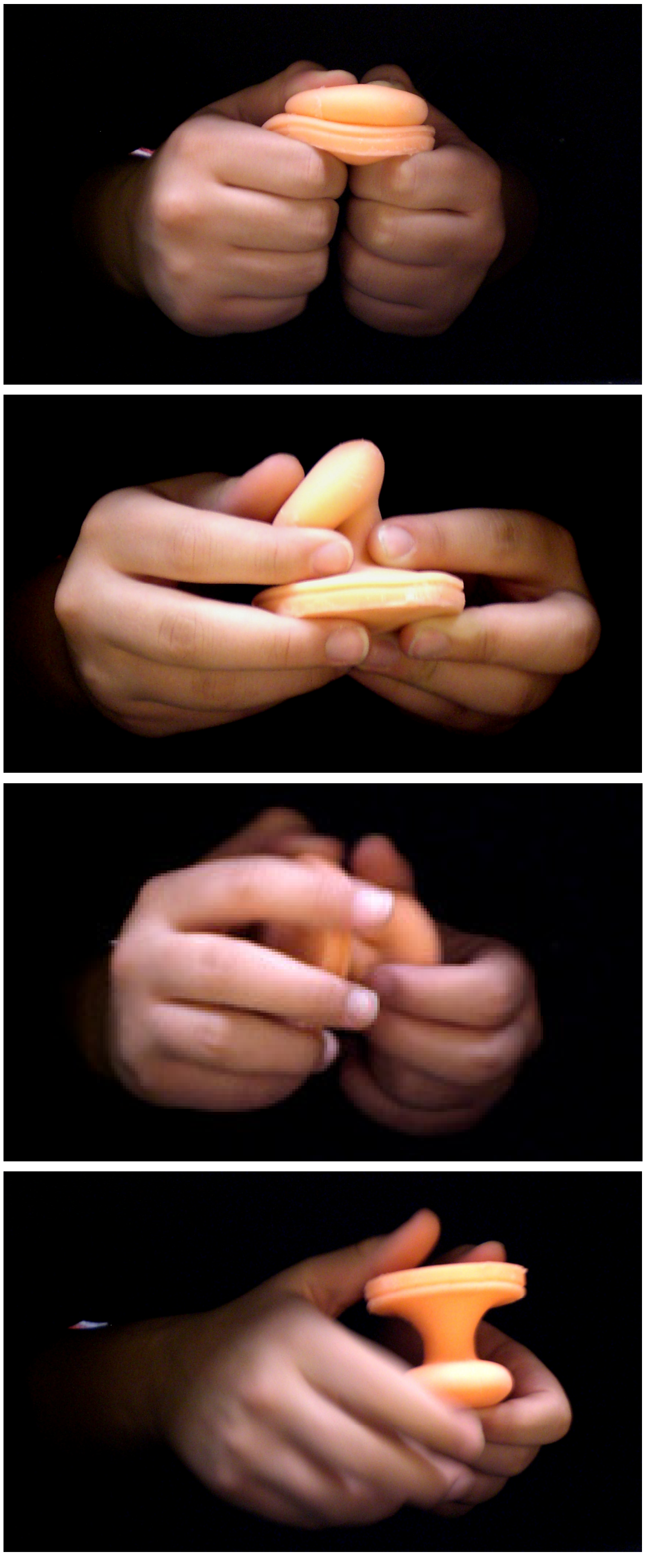

Figure 5. These pictures show the experimenter's view of exploring artifacts, one by one, with his hands in the blind box. The hardnesses of the artifacts ranged from very soft (top) to very hard (bottom).

They were asked to put them in a logic order, to see whether they were able to distinguish the differences in hardness. At a first try, 29 of the 30 participants completed this task successfully. The last subject recovered his choice well at the second attempt (the very soft and fairly soft artifacts were reversed).

Subsequently, the tactile experience was evaluated with a questionnaire. For each of the four tangible objects the participants had to rate 20 pairs of adjectives (as shown in Figure 3). For each of the evaluated 20 pairs, the F-test (multi-sample comparison, ANOVA) is performed to test whether there is a statistically significant difference between the responses evoked by the artifacts of different hardnesses. It turned out that with a 95.0% confidence level 5 out of these 20 adjectives were not influenced by the hardness of the artifact. The following adjectives turned out to be independent of the artifacts' hardnesses and are therefore left out of the results to come ($p > 0.05$): *adventurous-timid (p=0.44), natural-artificial (p=0.77), refined-coarse (p=0.91), simple-complicated (p=0.48), sporty-unathletic (p=0.13).*

All the remaining 15 pairs of adjectives show an upward or downward trend (depending on the chosen antonym) over the range of hardness. In order to see whether there are any differences in shapes of those curves, a principal components analysis is performed. The purpose of this analysis is to obtain a small number of linear combinations of the 15 variables which account for most of the variability in the data. In this case, one component has been extracted, since only one component had an eigenvalue greater than or equal to 1.0, which accounts for 95.5% of the variability in the original data.

Since there is only evidence for one component influencing the variability in the data, the course of the curves for all of the 15 pairs may be considered the same. This holds when we take the decreasing curves into account, because the curves can be mirrored when the antonyms are switched. All 15 pairs are included in the graph. The mean curve of those adjectives is shown in Figure 6. The x-axis plots different hardnesses of the artifacts and the y-axis represents the experiences of the different tactile adjectives (on a scale from 7= very '*adjective*' to 1= very '*antonym adjective*'). The softer the artifact the more *active, girlish, crazy, cute, exciting, flashy, funny, happy, soft, childlike, modern, vague, soothing, speedy* and *warm* it is experienced by the participants. Logically, their antonym adjectives are evoked more in case the artifact becomes harder (*inactive, boyish, sensible, brutal, boring, tasteful, serious, sad, hard, mature, old-fashioned, precise, scary, slow,* and *cold*), see also Figure 7.

Even though all 15 tactile adjectives show the same trend, there is a difference in the ranges that these adjectives cover. Some evoke more extreme experiences than others do. In Figure 8 the order of tactile adjectives is visualized from those experiences which are influenced but the least evoked by the design factor hardness, to the ones that are the most influenced by it. The adjectives with a higher F-ratio (and thus a smaller p-value), show more differences over the four hardnesses, they have a larger distribution.

6. DISCUSSION

The study presented in this paper, raised some points for discussion, including the design of the artifacts, the experimental setup and the experimental results.

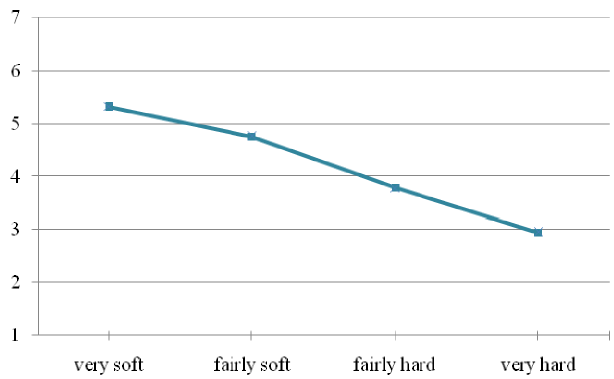

Figure 6. The average course of tactile experiences evoked by the tangible objects of different hardness (on a scale from 7= very '*adjective*', 6= '*adjective*', 5= fairly '*adjective*', 4= neutral, 3= fairly '*antonym adjective*', 2= '*antonym adjective*' to 1= very '*antonym adjective*').

6.1 Artifact Design

As can be seen from the results of the experiment, the design of the two softest tangible artifacts is a point for discussion. The participants ranked the artifacts' hardnesses not in a linear fashion. The differences in hardness between the very soft and fairly soft artifacts were ranked smaller than the other three artifact comparisons. This tells us that the artifact labeled as "very soft" should have been designed a little bit softer, if we wanted to achieve this linear relationship. However, this does not significantly influence the outcome of this study.

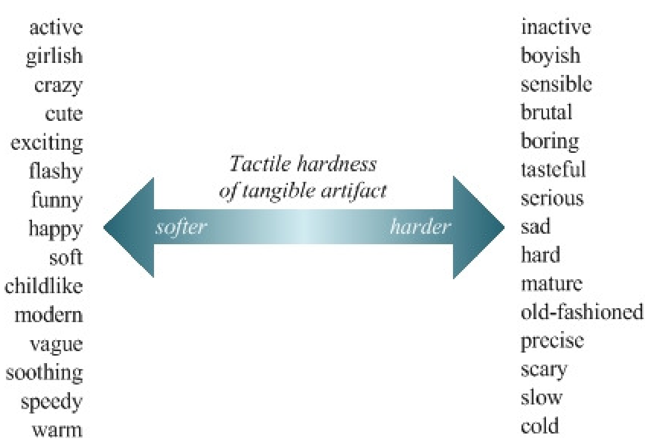

Figure 7. Some adjectives are evoked more when haptically exploring the softer artifacts, while their antonyms are evoked more in case the artifact becomes harder.

6.2 Experimental Setup

All 30 participants were children aged 10 to 13. In preparation of this experiment, some pilot tests took place which were run with adult participants. Informal observations gave the impression that children are much capable of answering questions regarding the tactile experience of object hardness. Answers by the children were given faster, almost immediate, and with much more certainty. Adults tended to think much longer and indicated that they tried to rationalize their answers. As is stated by Sonneveld

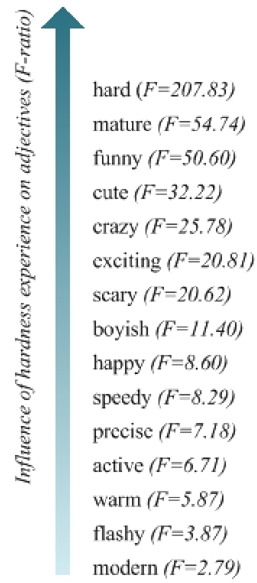

Figure 8. The relation between the tactile pairs of ajdectives (represented by one adjective) and the participants' experiences of the artifact's hardness. The tactile adjectives with higher F-ratio show a stronger response to artifacts' hardnesses than the ones with lower F-ratio.

[17], a part of the user's evaluation of tactile experience can be described as the dreamy and emotional experience stage. It involves associations with similar experiences and emotions connected to them. The noticed difference in evaluation capabilities by children and parents can possibly be caused by the fact that adults have more foreknowledge and more tactile experiences from the past that are taken into account; they want to make well-considered choices. Children, on the other hand, seemed very open-minded.

Another notable fact during the experiment were the differences in identifying hardness through touch compared to vision. During the experiment the artifacts were placed inside the blind box. Thus, while the participants explored the tangible artifacts haptically these were excluded from vision. Nearly all children were capable of identifying the series of hardness (29 out of 30 participants); they could put the objects in order from soft to hard, based on what they felt. After completing the study, all four artifacts were shown to the participants. When the children were asked informally to identify hardness based on what they saw, they made many misjudgements. It seemed as if no visual cues could be perceived, which is in agreement with [9].

6.3 Experimental Results

The results of the experiment showed that five of the tactile adjective pairs were not influenced by artifacts' hardnesses. (*adventurous-timid, natural-artificial, refined-coarse, simple-complicated, sporty-unathletic*). This conclusion could be a point of discussion. A question that might rise is whether the children do understand the meaning of all the adjectives used. It could be that the 10 to 13 year olds were unknown to some of the words, and therefore unable to connect it to the artifacts' hardnesses. Attention was paid to the understandability of the words during the study and explained whenever needed, but we can never be totally sure that the children really understood all of these adjectives.

6.4 Coming Full Circle

The results of this experiment are hard to translate back to our original game Flourishing Future. This is mainly because we wanted to focus on general knowledge of the haptic experiences and hardness. This knowledge could then inform the design of physical artifacts.

We decided to use as a starting point an existing validated list of adjectives [5]. For future work this could be repeated with adjectives targeted to specific designs.

7. CONCLUSIONS

The focus of this study was to investigate the role of material hardness in children's haptic experiences of tangible artifacts.

The experiment showed that the experiences of 15 out of the 20 selected tactile adjectives were influenced by hardness. For those 15 pairs of antonym adjectives, significant differences were found in the experience between the artifacts varying in hardness.

No evidence was found that multiple factors influenced the variability in the data. Therefore the course of the curves for all of the 15 pairs of adjectives might be considered the same.

The softer the artifact, the more *active, girlish, crazy, cute, exciting, flashy, funny, happy, soft, childlike, modern, vague, soothing, speedy* and *warm* it is experienced by the participants. Their anonym adjectives get stronger evoked if the artifact becomes harder (*inactive, boyish, sensible, brutal, boring, tasteful, serious, sad, hard, mature, old-fashioned, precise, scary, slow,* and *cold*).

Furthermore, it turned out that the hardness effects some adjectives stronger than others. It would be interesting to implement the outcomes of this study in tangible user interfaces, such as digital tabletop games, in order to find out what the effect of hardness is on the experience when engaging with a real application.

8. ACKNOWLEDGEMENTS

The authors want to thank Ali Mazalek and all the people from the Synaesthetic Media Lab at the Georgia Institute of Technology for helping us with our project. Thanks to STEMCELL for their cooperation and enthusiasm and Jean-Bernard Martens for his help with analyzing the results. Also thanks to our visiting colleagues Kim Böhre, Marigo Heijboer, Imke Schouten and Manon Spermon.

9. REFERENCES

[1] Ackerman, D. 1990. A natural history of the senses. Clays Ltd, England.

[2] Ashby, M.F. and Johnson, K. 2002. Materials and Design: The Art and Science of Material Selection in Product Design. Elsevier Butterworth-Heinemann publication.. 48-84.

[3] Bakker, S., Vorstenbosch, D., Hoven, E. v.d., Hollemans, G. and Bergman, T. 2007. Tangible Interaction in Tabletop games: Studying iconic and symbolic play pieces. In Proceedings of the International Conference on Advances in Computer Entertainment Technology (Salzburg, Austria). ACE'07. 163-170.

[4] Bohn, J. 2004. The Smart Jigsaw Puzzle Assistant: Using RFID Technology for Building Augmented Real-World Games. Workshop on Gaming Applications in Pervasive Computing Environments at Pervasive 2004 (Vienna, Austria).

[5] Choi, K. and Jun, C. 2007. A systematic approach to the Kansei factors of tactile sense regarding the surface roughness. In Applied Ergonomics,Vol. 38 (1). 53-63.

[6] Hornecker, E. and Buur, J. 2006. Getting a Grip on Tangible Interaction: A Framework on Physical Space and Social Interactions. In Proceedings of SIGCHI conference on Human Factors in Computing Systems (Montreal, Canada). CHI'06. 437-446.

[7] Kaltenbrunner, M. and Bencina, R. 2007. ReacTIVision: a computer-vision framework for table-based tangible interaction. In Proceedings of the 1st international conference on Tangible and embedded interaction (Baton Rouge, USA). TEI'07. 69-74.

[8] Kaye, J. and Brown, L. M. 2008. An eggs-ploration of the influence of material properties on haptic experience. Last accessed 17 Apr 2008, from: http://www.chi2008.org/altchisystem/dev/submissions/submission_jofish_1.pdf

[9] Klatzky, R.L., Lederman, S.J. and Reed, C. 1987. There's more to touch than meets the eye: The salience of object attributes for haptics with and without vision. In Journal of Experimental Psychology, Vol. 166 (4), 356-369.

[10] Lederman, S. J. and Klatzky, R. L. 1987. Hand movements: A window into haptic object recognition. In Cognitive Psychology 19, 1987, 342-368

[11] Magerkurth, C., Engelke T. and Memisoglu, M. 2004. Augmenting the virtual domain with physical and social elements. In Proceedings of the International Conference on Advancements in Computer Entertainment Technology. Singapore, June 3-5, 2004. ACM Press, NY, 163-172.

[12] Magerkurth, C., Memisoglu, H., Engelke, T. and Streitz, N. 2004. Towards the Next Generation of Tabletop Gaming Experiences. In Proceedings of Graphics Interface (London (Ontario), Canada). GI'04. 73-80.

[13] Mandryk, R.L., Maranon, D.S. and Inkpen, K.H. 2002. False Prophets: Exploring Hybrid Board/Video Games. In extended abstracts of SIGCHI conference on Human Factors in Computing Systems (Minneapolis, USA). CHI'02. 640-641.

[14] Pape, S., Dietz, L. and Tandler, P. 2004. Single display gaming: Examining collaborative games for multiuser tabletops. In Workshop on Gaming Applications in Pervasive Computing Environments at Pervasive 2004.

[15] Patomäki, S., Raisamo, R., Salo, J., Pasto, V. and Hippula, A. 2004. Experiences on Haptic Interfaces for Visually Impaired Young Children. International Conference on Multimodal Interfaces (Pennsylvania, USA). ICMI'04. 281-288.

[16] Prytherch, D. and McLundie, M. 2002. So What is Haptics Anyway? An Introduction to Psychological Studies of Touch and the Implications for and Understanding of Astists' Making and Thinking processes. Research Training Initiative. ISSN 1474-2365. Issue 2, Spring 2002.

[17] Sonneveld, M.H. 2004. Dreamy hands: Exploring tactile aesthetics in design. In McDonagh, D., Hekkert, P., Erp, J. van and Gyi, D. (Ed.), Design and emotion: the experience of everyday things. Taylor & Francis, London. 228-232.

[18] Ullmer, B. and Ishii, H. 2000. Emergent frameworks for tangible user interfaces. IBM Systems Journal, Vol. 39 (3-4), July 2000. 915-931.

[19] Vavik, T. and Kourennayia, D. 2006. Exploring and teaching tactility in design. Working paper of Nordecode Oslo, May 2006. Last accessed 17 Apr 2008, from: http://nordcode.tkk.fi/oslopapers/Tom_Vavik.pdf