Tactile Perceptions of Digital Textiles: A Design Research Approach

Douglas Atkinson[1], Pawel Orzechowski[3], Bruna Petreca[1], Nadia Bianchi-Berthouze[2], Penelope Watkins[1], Sharon Baurley[1]*, Stefano Padilla[3], Mike Chantler[3]

[1]Brunel University, Uxbridge
{douglas.atkinson,bruna.petreca
,sharon.baurley}@brunel.ac.uk,
penelopewatkins@aol.com,

[2] UCLIC, University College
London, Gower Street, London
n.berthouze@ucl.ac.uk

[3] Texture Lab, Heriot Watt
University,Edinburgh
{po38,s.padilla,
m.j.chantler}@hw.ac.uk

*corresponding author

ABSTRACT

Current interactive media presentations of textiles provide an impoverished communication of their 'textile hand', that is their weight, drape, how they feel to touch. These are complex properties experienced through the visual, tactile, auditory and proprioceptive senses and are currently lost when textile materials are presented in interactive video. This paper offers a new perspective from which the production of multi-touch interactive video representations of the tactile qualities of materials is considered. Through an understanding of hand properties of textiles and how people inherently touch and handle them, we are able to develop methods to animate and bring these properties alive using design methods. Observational studies were conducted, noting gestures consumers used to evaluate textile hand. Replicating the appropriate textile deformations for these gestures in interactive video was explored as a design problem. The resulting digital textile swatches and their interactive behavior were then evaluated for their ability to communicate tactile qualities similar to those of the real textiles.

Author Keywords

Design research; User interactions; Visualisation; Methodology; Design methods; Multimodal interfaces.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous – Design.

INTRODUCTION

This paper details the use of a design led process [8, 11, 33] to create content for the interactive video display interface 'iShoogle' and the study in which this content was used to explore and understand users' perceptions of the properties of textiles relating to textile 'hand' [5, 22]. We explore whether design led methods to manipulate textiles and presentation techniques suggested by textile experts can help untrained consumers to better perceive the hand of iShoogle interactive video textiles.

Different textiles behave differently when they are handled and there are common ways in which people handle textiles to perceive their qualities. In developing the interactions for iShoogle content, we examined these handling methods, exploring how to manually animate different textiles to communicate their diverse textile hand.

The uncovering and utilisation of people's tacit knowledge of textile hand and methods of interrogating it (as a result of their constant use of and engagement with textiles in daily life) is key to designing lifelike interactions with textiles in interactive video. Though much work has taken place to explore the creation of haptic feedback to appreciate the hand properties of textiles [7, 20], the gestures used to handle and interrogate the haptic qualities of textiles have been largely overlooked. The study described in [32] suggests that the gestural interaction with the digital textile may enhance the user experience and their emotional engagement. We hypothesise that an understanding of such gestures and the resulting visual information when deforming textiles are critical tools when designing textile swatches for interactive video. We have used design sensibilities to frame the development of content for the interactive video presentation of textiles in 'iShoogle': We have produced films of animated textiles, where the type of manipulation by hand, the preparation of the textile (pleating), and the lighting, all contribute to communicating the 'hand' of different types of textiles.

This paper first describes the software we used that allows interactive textile swatches to be created from video footage. Two important issues need to be addressed in the creation of the interactive video: the gesture to manipulate it and the way the textile behaves in response to the gesture. Hence, we explored the gestures non-expert consumers use to evaluate the 'hand' of textiles. First in a lab setting, and secondly in a retail environment where shoppers were observed evaluating garments and their gestures used to handle garments were noted. The re-creation of the gestures observed as interactions for iShoogle textile swatches forms the basis of a design problem. The research team attempted to address this problem through the practical and iterative

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design of a filming rig, and manipulation processes to capture and represent textile manipulations. This led to the creation of different conditions in interactive video textile swatches, which were tested to see if they helped untrained evaluators to more accurately rate the hand of the textiles.

CONTEXT & CONTRIBUTION

In e-retail, there is a need for tools that communicate the tactile or proprioceptive experience of products. Citrin *et al.* [6] have shown that online shoppers' ability to make purchasing decisions is hindered by the lack of tactile information about products available to them. Levin *et al.* [19] indicate that this 'see-touch-handle' factor is the most important element in the purchasing decisions of online shoppers, but crucially is missing from their e-retail experience. Schifferstein and Cleiren [24] also demonstrate that consumers acquire most information about products through vision and touch. Furthermore, Lee, *et al.* [18] report that the risk of online presentations of products not fully matching the actual item affects customers' enjoyment of e-retail. Peck and Wiggins [23] have shown that marketing communications incorporating tactile elements leads to an increased emotional response in consumers that may influence decision-making. Karana et al. '*assume that people commonly use certain sensorial properties as signs in order to ascribe meanings to materials and products'* [16]. These studies demonstrate that in online retail environments the touch senses are not fully catered for. It is therefore possible that a means by which to reliably understand and communicate textile hand may lead to more lifelike online experiences of textile products and thus greater satisfaction with e-retail purchases. This is one possible application for this research, however we believe that the contribution of this paper is more widely applicable due to the methodology proposed.

The study of multi-sensory interaction and substitution (e.g.[28]) in psychology and neuroscience is an exciting, growing area. These studies have led to designers exploiting these mechanisms in HCI [30, 3]: in particular in work on gesture for surface computing [31]. We contribute to this growing literature by proposing a methodology to create interactive material that exploits low cost prototyping. This is based on two parallel areas of investigation: 1) study of the language used to interact with items (which may also announce other sensory experience); and 2) an in depth study of the deformation of the item in response to the language of interaction, including how it can be captured. We do not look at how people interact with a touchscreen (cf.[31]), rather we look at how people use gesture to interact with real objects to perceive their tactile properties through the visual and proprioceptive senses. Thus it is essential to explore the affordances of real objects [13]. In this way our methodology compliments other studies, as once the real life interactions with an object or material have been explored they can be applied to interactions with various media or even to non-interactive media, improving its visual communication of tactile properties.

INTERACTIVE VIDEO PRESENTATION OF TEXTILES: ISHOOGLE INTERFACE

To present interactive video textile swatches the iShoogle iPad interface was utilised. iShoogle works in conjunction with ShoogleIt.com [21], an Adobe Flex based website. ShoogleIt.com allows digital video to be uploaded and split into individual frames, which can then be edited to produce basic interactive videos. The iShoogle interface for iOS (see Figure 1, left) allows the manipulation of these interactive videos to be triggered by a particular gesture. Different gestures, each with a corresponding interactive video, can be combined into one single iShoogle, giving the effect of a single interactive video with multiple interactions.

METHODOLOGY TO DEVELOP INTERACTIVE VIDEO PRESENTATIONS OF TEXTILES

Understanding how consumers handle textiles

During two prior studies, 30 participants aged between 18 and 25 (19 male, 11 female) were observed and filmed while handling a set of seven textile samples: Two types of wool of differing weights, viscose jersey, nylon tulle, cotton buckram, rubber coated polyester wadding and a wool-Lurex blend. These textiles were chosen for their diverse hand, in order to try to maximize the number of potential gestures participants might use to manipulate and interrogate them. The aim of this study was to discover which gestures untrained participants used most commonly to discern the hand of textiles.

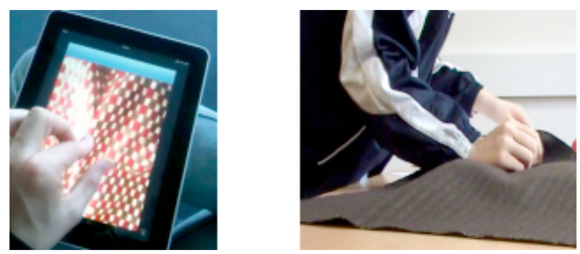

Figure 1 (left): The iShoogle interface. **(right):** Textile manipulation using the thumb and forefinger to rub the edge. The most commonly observed gesture

Common gestures observed included rubbing the edge of the textile between thumb and forefinger, rubbing the edge of the textile within a closed fist (see Figure 1, right), stroking the edge of a textile between thumb and forefinger, gathering a flat textile into a closed fist (scrunching) and stroking a flat textile with one or more fingers. Gesture usage by individual participants remained consistent throughout the duration of the study, some participants making use of a wide range of gestures and some using only one preferred gesture. There was no correlation between the type of gesture and the textile type.

A further study was then conducted in-situ in the London, Regent Street branch of a well known, mass market fashion retailer, to observe the particular gestures used by consumers when evaluating textile goods (clothing) for purchase. Two researchers moved about the shop floor making observations over the course of one afternoon. The initial gesture (the first gesture made when approaching and interacting with a garment displayed in the store) used by consumers to evaluate hanging garments was noted on a mobile phone note-taking App. The initial gestures of 50 male and 50 female participants, ages estimated to be between 18 and 40, were recorded. The gestures and their frequency of usage are detailed in Figure 2.

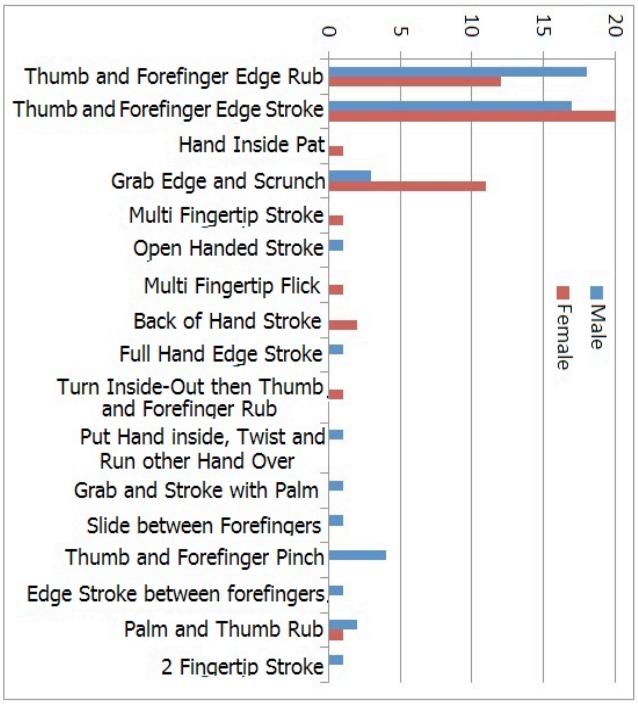

Figure 2: Textile evaluation gestures observed in a retail environment and their frequency of use, sorted by gender of shopper

The two most commonly observed gestures included using the thumb and forefinger to either rub or stroke the edge of the garment. There was a high incidence of the use of these gestures in male and female shoppers. The third most commonly observed gesture was more prevalent in females. This was grabbing the edge of a garment and scrunching it using the whole hand. It may be that this gesture gives a better idea of the hand of more unusual textiles used in womenswear. In menswear, textiles tend not to deviate from certain staples. It may be worth testing this hypothesis in future experiments.

More complex gestures were observed, e.g. putting the hand inside a garment and twisting, while running the other hand over it was carried out on a lightweight cotton (voile) dress, possibly to discern its degree of transparency.

It was also notable that the three most commonly used gestures all grasped or trapped the textile between the fingers. These gestures were concurrent with the findings of the initial lab based study. Such gestures are impossible to directly replicate using current touch-screen display technology. The gestures we focus on for the purpose of this study are described in the Methods section.

Designing textile manipulations and converting them into touch screen interactions

Building on this understanding of how people handle textiles, we went on to investigate methods to produce interactive content for iShoogles that would reflect the observed manipulations, and how the textiles responded to them. The research team attempted to re-create the observed gestural manipulations of textiles, initially as digital video for conversion to iShoogles to be displayed on a touch-screen device. It was desirable that the textiles move and deform as if they were responding to the gestures of the user, but hands or devices moving the textile should not be visible in the iShoogle. Schutz-Bosbach demonstrates that when visual presentation is synchronously coordinated with touch feedback the textural properties of a visually presented object are haptically perceived, even if the touch feedback is of an object of a different texture [26]. To this end it was necessary to design filming methodologies that would enable such manipulations to be captured. This became the initial 'design problem' in what Fallman refers to as the 'Conservative Account' of the design process [8], a linear, problem solving view of design. The researchers, aided by the suggestions of a group of textile experts attempted to address this problem through live design experiments to harness their tacit knowledge of textiles, thus moving into Fallman's 'Pragmatic Account' of design [8], engaging in a situated process of interpretation and creation of meaning from available materials and in response to their 'life world' (tacit knowledge and lived experience). The textile experts held a postgraduate degree in Fashion or Textile Design, or an undergraduate degree plus over 5 years experience in a related industry. The six-person panel (5 female, 1 male, age 25 to 60) included 3 members of the research team and 3 postgraduate students. Suggestions for textile manipulation methods, lighting conditions, and textile preparation were recorded during informal brainstorming sessions. Though the gender bias of the panel could be seen as a limitation, it is typical in the fashion and textile industries.

Design of Filming Rig

A rig was designed to facilitate the manipulation of textiles, which supported various backing plates and media on which textiles were placed (See Figure 3). These included a clear acrylic plate to allow textiles to be manipulated from above and filmed from below.

Methods of manipulating textiles

Using the clear acrylic plate it was possible to lay the textiles on top of it and film them from below, thus allowing the manipulation of textiles from the opposite face to that being filmed. It was possible to perform several gestures such as scrunching textiles in one hand – relating to the observed 'grab edge and scrunch' gesture, 'thumb and forefinger pinch' and also stroking a textile, allowing it to gather as the finger progressed across it. All of these interactions were matched to a native iOS gesture. This method produced extremely good results for opaque textiles, but the hands of the person manipulating transparent textiles showed through.

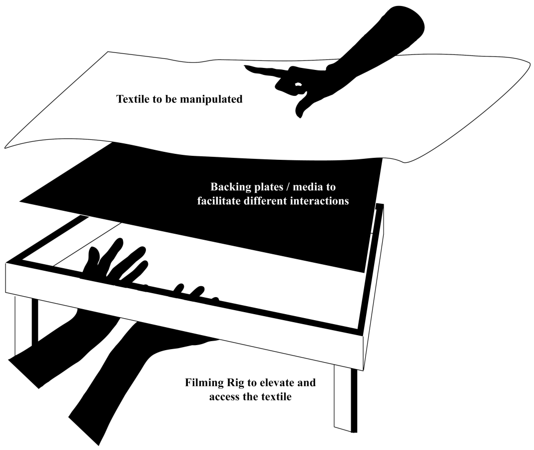

Figure 3: Diagram of the filming rig

This problem was solved by the interactivity creation functions of the ShoogleIt and iShoogle software, which allowed the textiles to be filmed in reverse, as the video content could be specified to play backwards or loop from a specified start frame, when interaction was added.

This reverse filming method was used for all of the textile manipulations with the clear acrylic plate. The gestures described above were implemented in the final iShoogle interface as they were iOS native and this filming technique gave the most lifelike results for a wide variety of textiles while concealing the method of their manipulation.

Further gestural manipulations discovered during our observations of textile handling were also explored as part of the ‘sketching’ and prototyping phase of the design process [8]. Using other backing plates on the filming rig they were iteratively realised and tested for their ability to solve the design problem. They were not used in our final study due to the difficulty in replicating the real life gestures Thumb and Forefinger Pinch, Multiple Fingertip Stroke, Flick, and Pat using iOS native gestural interactions.

Lighting of textiles for filming

Using Elinchrom D-Lite professional studio lights different lighting conditions were assessed by the textile experts to choose which would convey the most information on a textile’s structure and properties, whilst producing lifelike representations. Three light set-ups are generally regarded as giving the best impression of surface detail and relief on textured surfaces [29] while standard ambient light serves to flatten photographic images of texture.

The optimum combination of lighting sources and angles was iteratively tested. The camera was placed at a central point and the filming rig positioned with its corners at 0, 90, 180 and 270 degree points around the centre. Initially single light sources at 2 metre heights, and a distance of 1 metre, were tested at 22.5 degree increments through around the centre point. The lamp head was positioned at a 90 degree angle to the tripod.

Using a light source placed centrally beneath the filming rig (Figure 4, left) proved the most effective method to highlight gloss and surface details. However it was problematic due to the reflections on the clear acrylic sheet. The effect was slightly more prominent with no lighting above, though this second light source was useful for showing more structural detail.

Combining the central light source below the textile and the 2 metre high light source above the rig at 180 degrees created the effect that was most similar to the visual information which a participant would gather from examining a real textile in a well lit environment (see Figure 4, right).

Lighting textiles from above only (back lighting the textiles in the captured video) at a 90 degree angle to the camera highlights more of their woven structure and thickness due to variations in light transmission through the textile (See Figure 5). This was chosen by the textile experts as the lighting type which helped to convey most information about the textile structure.

Figure 4 (left): A single light source centrally located below the textile, mounted next to the camera. This caused unrealistic reflection of the lamp but was successful at highlighting gloss. **(right):** Lighting from both above at 180 degrees and centrally below with lamp moved outside the filmed area. Less successful at highlighting gloss surfaces

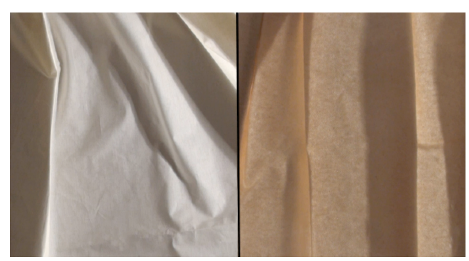

Figure 5: Textiles lit from above only at 90 degrees (backlit)

Textile Preparation Hypothesis’

During the design of the filming rig and lighting, the group of textile experts proposed the following hypothesis’:

H1. Pleating (a finishing method by which an accordion-like folded structure is heat set into a textile) may allow untrained participants to infer properties relating to the stiffness/flexibility of a textile from its ability to hold a pleated shape.

H2. When lit from behind, untrained participants may be able to better infer the properties of a textile related to its thickness and weave structure.

We tested these hypotheses with the following experiment.

EXPERIMENT TO DETERMINE PERCEPTION OF PROPERTIES OF TEXTILE HAND

Having designed methods to represent, capture and film realistic interactions with textiles for the iShoogle interface, and thus solving the initial design problem, a new design problem arose: To discover which design of presentation and preparation techniques for iShoogle display media would best convey the hand qualities of a textile. iShoogles of four textiles were used in a study to explore the perceptions of the textile hand of these textile samples in untrained consumers. In a sense this is a field-testing study for a designed artifact [11].

Aims/Objectives

This study aims to demonstrate that through the design of certain simple, inexpensive preparation techniques of textiles, a more accurate impression of their hand can be conveyed when they are filmed for presentation on digital display media. It is our goal to discover which textile preparation and which lighting condition will provide the most realistic impressions.

METHOD

A set of four textiles was chosen for the study. All were 100% cotton and believed to be familiar to participants due to their common applications: “Jersey”, a conventional T-Shirt textile; “Voile”, used in lightweight summer shirts, blouses and dresses; “Raised Cotton”, used in nightwear, coats and outerwear; “Buckram”, a stiffener used in hats and accessories.

Four bi-polar pairs of descriptive terms were used to select the cotton textile samples. These pairings of terms were: Rough-Smooth, Thick-Thin, Warm-Cool and Stiff-Flexible. The textiles represent each extreme and a neutral mid point on each bi-polar scale (see Table 1, below). The textiles were later rated on these scales.

ROUGH	**NEUTRAL**	**SMOOTH**
Buckram	Voile	Jersey
THICK	**NEUTRAL**	**THIN**
Raised Cotton	Jersey	Voile
WARM	**NEUTRAL**	**COOL**
Raised Cotton	Buckram	Voile
STIFF	**NEUTRAL**	**FLEXIBLE**
Buckram	Raised Cotton	Jersey

Table 1: Cotton textiles and their properties

Our choice of descriptive term pairs relates to the findings of Soufflet, Calonnier and Dacremont [27] who demonstrate that the most significant scales their participants used to rate the properties of textiles were Stiff-Flexible, Thick-Thin and Soft-Harsh. Soft-Harsh was translated from the French terms *Doux-Rêche* which are more correctly translated as Soft-Rough, thus we believe supporting our choice of the Rough-Smooth term pairing. Also, according to the literature [1, 9] some of the properties of textiles that can affect handle are:

- Physical: thickness, mass per unit area. Relating to Thick-Thin
- Mechanical: extensibility, bending properties, shear. Relating to Stiff-Flexible
- Surface: compression properties, friction, surface irregularity. Relating to Rough-Smooth
- Thermal: conductivity. Relating to Warm-Cool

The textiles were filmed and converted into interactive movies using the web tool ShoogleIt.com and the iShoogle interface for iPad. The selected gestures used in the iShoogle interface were:

- Pinch: horizontally and vertically (two fingers moving together and apart)
- Stroke: horizontally and vertically (one finger moving across the screen)
- Scrunch (three or more fingers converging on a central point)

These gestures were native to iOS, easy to replicate using the method of filming them from below a clear acrylic plate while manipulating them from above, and included the stroking and pinching elements observed during the retail study and prior filming of participants. Manipulations of textiles were filmed accordingly, to give the effect of the user manipulating the textile using each of the above gestures. No hand or device was visible manipulating them on the screen, thus making it appear that the user controlled their deformation with their own hand.

An iShoogle was created for each of the four textiles in each of the following conditions. Henceforth more realistic lighting, similar to ambient daylight (2 lights, one centrally below and one above at 180 degrees) shall be referred to as Lighting 1 (or L1), back lighting (one light above at 90 degrees) shall be referred to as Lighting 2 (or L2):

- **UL1:** Lighting 1, Unpleated
- **PL1:** Lighting 1, Pleated
- **UL2:** Lighting 2, Unpleated
- **PL2:** Lighting 2, Pleated

The only exception was the textile Buckram, which due to its end use as a stiffener in apparel could not be pleated. iShoogles were still created for unpleated Buckram using both lighting conditions, producing a total of 14 iShoogles, representing 4 unpleated textiles and 3 pleated textiles.

To determine which treatments would convey the most similar impression of the hand of the iShoogles when compared to the real textiles, the iShoogles and their associated textiles were rated on the four sets of bi-polar perceptual scales created by the above term pairs. Comparing the iShoogles and pleated and unpleated real textiles gave a total of 21 textile presentations to rate.

30 participants (14 females and 16 males between the ages of 18 and 40) took part in the study, conducted at University College London. The study was conducted in a quiet, neutral room with both fluorescent and natural light sources, the temperature was maintained at 22°C.

Participants were seated at a desk on which was placed an iPad with the iShoogle interface open and the response form for the study (see Figure 6). Each scale was presented as a 10cm tickless line; the rating was computed as the distance in millimeters to the mark placed by the participant, giving values of 0 to 100. The study procedure was explained to participants and they were asked to base their ratings of the iShoogle textile swatches on what they could infer from visual cues to their hand, as no haptic information was conveyed. They were then asked to rate the 21 different textile presentations in a randomized order, however the real textile swatches (both unpleated and pleated) were always presented after their iShoogle counterparts so that ratings of the digital presentations were not biased by prior experience.

Figure 6: The iShoogle interface & participant response form

Finally 10 participants (5 female and 5 male) were randomly selected to take part in a qualitative survey regarding their opinions and experiences of the gestures they used when interacting with the iShoogle textiles. They were asked which gesture seemed most engaging, most realistic and which they thought was the most helpful to understand the properties of the textiles.

RESULTS

Figure 7 shows the boxplots for the ratings for the real textiles and for UL1, UL2, PL1 and PL2. The ratings for the real textiles reflect the categorization of each type of textile provided in Table 1.

The ratings for UL1 and UL2 show a similar trend except for the Buckram ratings along the Warm/Cool dimension. Slightly more variability can be observed for PL1 and PL2. This is reflected by the Pearson's correlation values between the real textile (either pleated or unpleated) and their digital version created with two different lighting conditions (see Table 2). The correlation values for UL1 and UL2 are in fact overall higher than those for the pleated versions except for the Warm/Cool scale. In this case, a higher value is obtained between the Pleated real textile and PL1. For the Thick/Thin scale the highest values are obtained with both PL1 and UL1 conditions.

In order to check whether the type of preparation affected the participant's ratings a Repeated Measure Analysis of Variance (ANOVA) with Greenhouse-Geisser correction was applied.

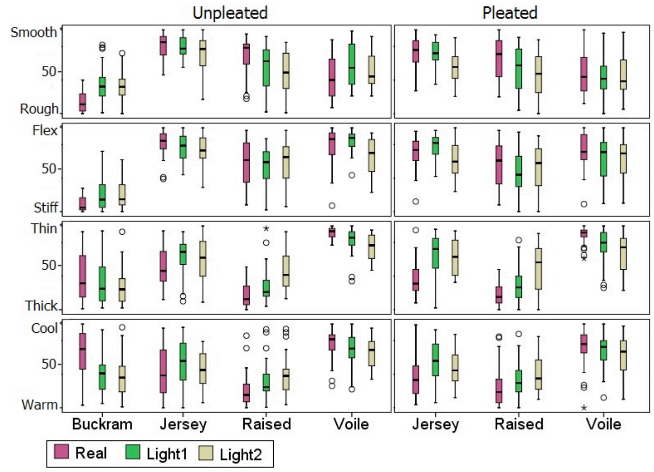

Figure 7: Boxplots of subjective ratings per textile type and preparation type. Real refers to the physical textile, Light 1 and Light2 refer to the unpleated and pleated iShoogles

	Unpleated		Pleated	
	RvsL1	RvsL2	RvsL1	RvsL2
Rough/Smooth	0.48	0.47	0.36	n.s.
Stiff/Flexible	0.72	0.69	n.s.	n.s.
Thin/Thick	0.63	0.54	0.62	0.32
Warm/Cool	0.51	0.41	0.60	0.44

Table 2: Pearsons' correlation values between the real textiles and the iShoogle (L1 or L2) for both unpleated and pleated treatments. All the correlation values reported are significant (p<.01)

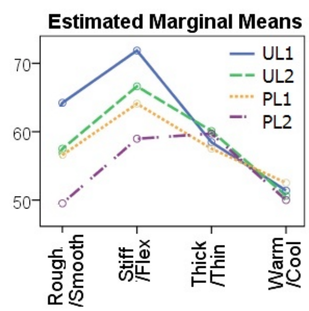

Figure 8: Estimated marginal means for the four digital textile conditions and the four term pair scales

Term	UL1 vs.UL2	PL1vs. PL2	UL1vs. PL1	UL2vs. PL2	UL1vs. PL2
Rough-Smooth	0.006	0.009	0.002	0.000	0.000
Stiff-Flex.	0.013	n.s.	0.003	0.004	0.000

Table 3: p-values for the Post Hoc Bonferroni tests. Only significant values are reported

The ratings collected for the four different conditions were the within-subject factors, and the four term pair scales were the between-subject factor. Greenhouse-Geisser correction was used, as the collected data violated the assumption of sphericity (Mauchly's Test of Sphericity: $p < 0.000$). The results show that there are statistically significant differences between the ratings of the different conditions ($F(2.812, 1251.555) = 5.371$, $P < 0.001$) and there is a statistically significant interaction between the term pair scales and the textile preparation. Post hoc tests using the Bonferroni corrections revealed that these differences are for the Rough/Smooth scale and Flexible/Stiff scale as reported in Table 3 and shown in Figure 8. The ratings for PL1 and UL1 are always higher than for PL2 and UL2 showing that Lighting 1 causes the textiles to be perceived as smoother. The same can be said for the ratings for Unpleated vs. Pleated conditions showing that the Pleated textile preparation decreases the feeling of roughness and stiffness. UL1 also gave a smoother and more flexible perception than PL2.

In order to quantify the perceptual distances between the real and the digital fabrics and to understand the criteria that explain such dissimilarities, we propose to use Multi-dimensional scaling (MDS). To apply MDS, for each participant and for each pair of texture descriptors (scales) a dissimilarity matrix was built. Each dissimilarity matrix was formed of 6 columns and 6 rows representing the 6 different textile conditions (the two real ones and the 4 treatments). Each entry of a participant' matrix represented the difference in ratings between each pairs of conditions (row and column) summed over the 4 textiles. This provided a set of estimated dissimilarity matrices, four for each participant (one for each pair of texture terms). The matrices for a given pair of textures terms were used as input to the Multidimensional Scale routine in the SPSS21 statistical analysis software: the INdividual Difference SCALing (INDSCAL) method. The INDSCAL results provided the coordinates for the stimuli in a perceptual space defined by the set of dimensions that account for most of the variance contained in the data.

The top-left corner of Figure 9 shows the screeplots for the 4 INDSCAL models. Only up to four dimensions were investigated given the small number of variables available. As the screplots in Figure 9 (top-left corner) show, for each texture dimension, an acceptable Kruskal's Stress measure according to Kruskal's rule of thumb [17] (excellent for Stress < .1; unacceptable for Stress > .15) is reached with 4 dimensions, therefore the 4D models were used for further analysis. The rest of Figure 9 and Table 4 provide measures of fitness for the 4D models presented in Figure 10.

The top-right corner of Figure 9 shows the participants' Weirdness measures for the 4D models. The boxplots show that for most participants the Weirdness measure is quite low suggesting an acceptable fit between the average model and most participants' models. These data are reflected in the scatterplots shown in Figure 9. Each point of a scatterplot represents a participant. We can see that in all the graphs, most participants lie on the diagonal, meaning that they equally use all four dimensions when they judge a hand characteristic of a fabric. However, a number of participants are shown to give different importance (weight) to each dimension. In particular, the Thick-Thin scatterplots show that a number of participants consider dimension 3 as not important (weight value = 0). This is also observable in Table 4 where the RSQ for D3 for the Thick-Thin model is lower than the RSQ for the other three dimensions. For the other texture-term models, D4 shows lower importance.

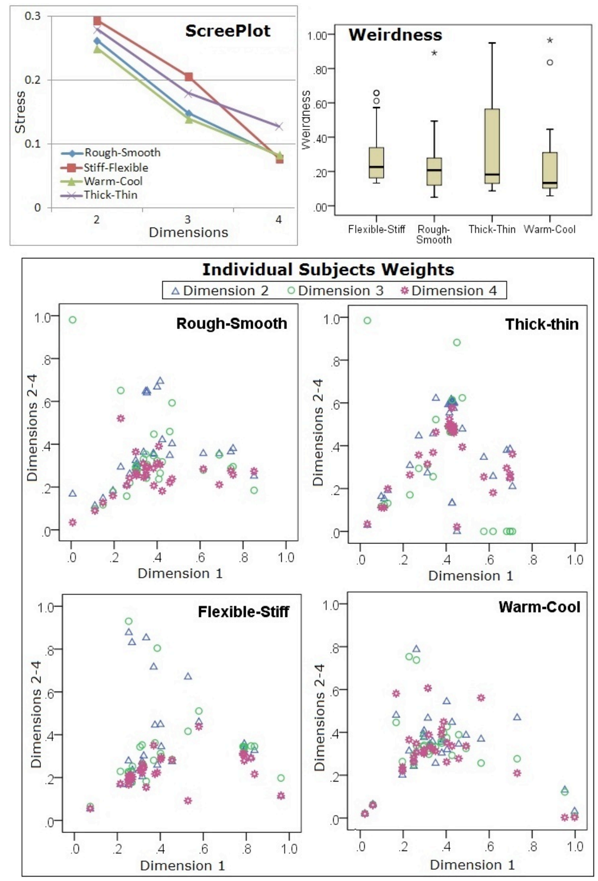

Figure 9: INDSCAL model measures of fitness. Top-left: ScreePlots. Top-right: Participants' Weirdness measures. Bottom: Participants' individual weights for the four 4D models.

Models	**Stress**	**RSQ**	**D1**	**D2**	**D3**	**D4**
Rough/Smooth	.08	.6	.18	17	.14	.07
Thick/Thin	.12	.82	.26	.17	.15	.24
Stiff/Flexible	.08	.62	.25	.18	.13	.06
Warm/Cool	.08	.56	.18	.14	.13	.12

Table 4: 4D INDSCAL Model fitness measures. The last five columns show the average RSQ and the RSQ for each dimension.

Figure 10 presents the Configuration Stimuli for the 4D models. Each of the six textile conditions (two real and four iShoogle) are represented by a symbol in the 2D plots. The distance between the symbols represents how differently the six textile conditions are perceived. We use the 2D plots to understand the perceptual criteria that may be used by the participants to describe the (dis)similarity between the unpleated real textiles and the four iShoogles. When possible, the dimensions of the plots were named as either *Level of Textural Detail* (highlighted in red) or *Amount of Structure* (highlighted in green). The *Level of Textural Detail* dimension separates the more *realistic* PL1 and UL1 from PL2 and UL2 providing more *textural* details. The *Amount of Structure* dimension separates the *structured* PL1 and PL2 from the *unstructured* UL1 and UL2.

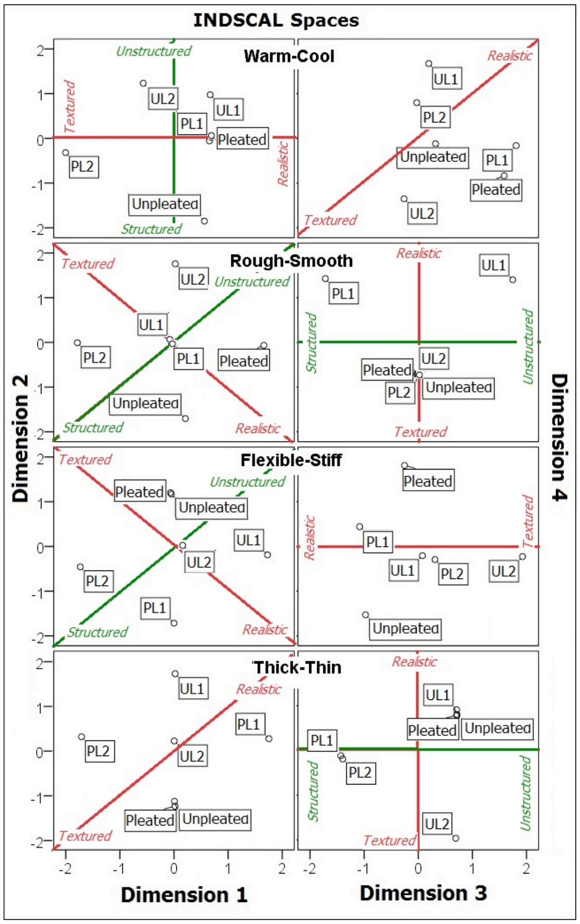

Figure 10: INDSCAL models showing the distances in perception between different textile presentations for the 4 texture-term pairs. The green dimension refers to the level of structure in the iShoogle, the red dimension represents the level of textural details.

Warm-Cool space: The first dimension (in red) separates the L1 and L2 iShoogles suggesting that this dimension may refer to the level of detail provided by the digital representation. Given that L1 iShoogles are closer to the real unpleated textile than L2 ones, we suggest that the level of detail provided by L2 was not the primary criterion for evaluating how warm the textile was. The second dimension (in green) separates unpleated from pleated treatments suggesting that the second dimension may refer to the level of structure presented by the digital representation. More structure seems to provide a better perceptual fit with the real unpleated textile. Whilst in the space D1D2 higher realism is used to judge the similarity, the red dimension in space D3D4 suggests that the textural details are used as secondary criteria.

Rough-Smooth space: The criteria underlying the ratings along the rough-smooth scales are similar to the warm-cool space in terms of distances between the iShoogle textiles and the unpleated real textiles. However, a rotation of 45 degrees of the D1D2 space facilitates the naming.

Thick-Thin space: Unlike the previous spaces, the level of detail appears to play a more important role, as originally suggested. In fact in D1D2 the L2 iShoogles are the closest to the unpleated real textile. The overall visual appearance (realism) is also used, as on the 4th dimension (the second in terms of RSQ as per Table 4) L1 is closest to the unpleated real textile. The level of structure is provided by the third dimension (green). In this case less structure seems to provide a better understanding of the textile.

Stiff-Flexible space: As for the Thick-Thin space, UL2 is the closest to the unpleated real textile in D1D2. Dimension 2 seems to be related to the amount of structure, in this case with less structure causing the iShoogle textile to be perceived as closer to the unpleated real textile. The third dimension relates to the overall visual appearance with the L1 iShoogle being closer to the unpleated real one.

Finally the results of the interviews were analysed. They indicate that the 'Scrunching' gesture was the most informative about the textiles and also the most engaging. The reasons given included the amount of visual information it provided. Participants elaborated by describing it as 'showing movement from all sides' (P# 6), 'easiest for me to see how the material moved and sprung back' (P# 5) and showing the 'greatest number of folds in the textile' (P# 3). Other reasons for engagement with the 'Scrunch' gesture included feelings of fulfillment and greater control. Studies of the design of full-body interactive technology [2] and touch-based technology [10] show that higher involvement of body movement and tactile behavior result in higher emotional engagement and, feeling of presence through proprioceptive feedback.

In terms of realism the 'Scrunching' gesture was chosen often, however various stroking gestures were also chosen with equal frequency. P# 1 and 4 stated that the scrunch was the most similar to the real gestures they would use to interact with textiles. P# 2 and 6 stated that the degree of correlation between their gestures and the interaction was key to their perception of the experience as realistic.

DISCUSSION

We believe that through the iterative design process and the use of design thinking we have been able to explore possibilities for creating interactive video in a cheap, accessible manner. Using the methodology described it is possible to produce interactive textile swatches without the need for the creation of 3D models. Though this is a highly advanced field, where research dates back to the early 1990s [4, 20], it requires specialist knowledge and time to create interactive simulations of textiles. Whilst we recognise the potential of an algorithmic approach, in this study we propose the possibility for everybody to create interactive representations of textiles at any time with no computational experience. This is important for designers during the creative process and for consumers in a blogging or crowd-sourcing context [12]. Our approach allows a designer or a consumer to quickly create an interactive representation of a textile, requiring only the skill of taking good video footage. Designers can produce such simulations and interact with consumers during the design process, shops (especially artisans) can upload interactive representations of their garments and consumers can add representations of their own garments to their blogs.

Using these techniques we have demonstrated the need for individual observation of each textile and for both lighting and manipulation techniques to be correctly designed for the textile in question to best communicate its properties.

The hypothesis (H2) of textile experts that L2 (back lighting, highlighting textile structure) would aid the communication of Thick/Thin, bringing the ratings of L2 iShoogle textile swatches closer to those of the real textile on this rating scale, has been demonstrated to be correct. Although L2 increases the communication of the properties Stiff/Flexible and Thick/Thin, it is not the most useful for communicating the other properties. L1 (more realistic lighting, similar to ambient daylight) best communicates Rough/Smooth and Warm/Cool.

Contrary to H1, L2 (back lighting) rather than pleating aided in the evaluation of Stiff/Flexible. It is possible that to untrained evaluators stiffness is more intrinsically linked to the perceived thickness of a textile than the textile experts had expected. This may also demonstrate that when untrained evaluators are given access to information on the structure of textiles (as highlighted by light transmission through the textile) they are very capable of discerning the relationship to its hand properties, particularly in the case of mechanical attributes such as stiffness/flexibility.

We have explored textile preparation methods suggested by textile experts, in this case pleating as a means to better communicate the hand of textiles. The INDSCAL models demonstrate that pleating mainly improved the accuracy of the rating of textiles on the Thick-Thin perceptual scale. Here pleating may have helped to demonstrate the thickness of a textile by showing the thickness of its folded edges as it was manipulated. The ANOVA shows that on the scales Rough-Smooth and Stiff-Flexible, PL1 and PL2 were perceived to be less stiff and smoother than UL1 and UL2. The ANOVA did not identify any difference between the different conditions for the scales Warm-Cool and for Thick-Thin. The Warm-Cool scale is complex to perceive when evaluating textiles especially for an untrained person.

In the case of Thick-Thin it is possible that a different type of gesture is necessary to improve its perception (e.g., grasping or stroking a textile with fingers on each side). Interestingly, when asked to suggest additional gestures that they would like to use to evaluate the iShoogle textiles, participants did not suggest any gestures in which the textiles were grasped between thumb and forefinger or in the whole hand (the most commonly used by shoppers). Instead they suggested stretching (Ps# 1, 3, 5 & 8) and stroking with the palm of the hand (P# 4). This suggests that users have an inherent expectation of how they will interact with a two-dimensional screen, limiting them to a different set of possibilities than afforded by a real textile.

LIMITATIONS & FUTURE WORK

It is important to acknowledge factors that may have influenced participants' perceptions of the textiles. Thermal preference and perceptions may have been affected by a significant difference in the ambient outdoor temperature on the days the study was conducted. Lighting may also have been an influencing factor as reflections on the iPad screen from natural light sources may have differed.

Playback speed of the iShoogles was set at realistic levels, however lags in response time and jumping of frames were experienced due to processor and RAM limitations on iPads and may have appeared to make the textiles deform in unrealistic ways. Ps# 2, 6, 8 & 9 observed the importance of the iShoogle textile correlating to user interaction in a way that they perceived was under their control.

Further areas of investigation have been exposed which we see as the next steps for our research. The methodology could be applied to other gestures and behaviours of the product (e.g. drape). For example using the accelerometer in iPads it would be easy to create drape behaviour that responds to the tilting of the device. Our methodology could be applied to deformable surfaces with sensors on both sides, to capture the grasping and two sided textile manipulations we identified. Deformable screens and e-textiles may facilitate a more embodied interaction [25] and result in a more realistic affordance [15] and also allow comparison of the effectiveness of 3D gestures to gestures transposed to a 2D surface. Future research could include the design of interactions that encourage the user to behave in a manner similar to those observed in our study of shoppers in retail environments. Qualitative interviews could concurrently be utilised to elicit users' opinions on whether 'shopping style' gestures feel more natural and help them to discern more of the characteristics of textiles.

We also acknowledge that there are more sensory modalities to explore in the communication of textile hand. Sound in particular is strongly related to tactile experience [14, 28]. Our focus on the visual and proprioceptive sensory modalities can be seen as a limitation, however we propose their relation to holistic 'hand' experience is an under-explored area to which this study significantly contribute.

Though we focus on textiles, our methodology is applicable to the representation of a wide variety of textural items. It may also inform in-store surface computing presentations or mobile swatch libraries for designers. It will enable direct communication of the properties of products from manufacturer/designer to consumer, opening up possibilities for co-design and co-creation [12] and removing the need for intermediaries in supply chains.

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