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Exploring Frictional Surface Properties for Haptic-Based Online Shopping

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Abstract

The sense of touch is important in our everyday lives and its absence makes it difficult to explore and manipulate everyday objects. Existing online shopping practice lacks the opportunity for physical evaluation, that people often use and value when making product buying decisions. The work described here investigates differential thresholds for simulated frictional surfaces, an important haptic feature for product comparison. One aim is to gain insight into the design space for multiple comparisons of virtual surfaces as will be needed to support online shopping. A user study has been conducted to explore differential thresholds in stick-slip frictional force. The study demonstrates that, on average, a dynamic friction threshold of 14.1% is needed to differentiate between two frictional surfaces. Moreover, it has shown, for a Phantom Omni, that the maximum number of unique comparable dynamic coefficient of friction combinations available is twenty eight, at any given level of static coefficient of friction. The results are a step towards defining surface differential thresholds for online shopping and other haptic-based applications that require multiple surface comparisons.

Categories and Subject Descriptors (according to ACM CCS): H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities; H.5.2 [Information Interfaces and Presentation]: User Interfaces—Haptic I/O H.5.3 [Information Interfaces and Presentation]: Group and Organization Interfaces—Web-based interaction

1. Introduction

The sense of touch is essential in our everyday lives. A lack of such sensory feedback makes it hard to explore properties such as weight, texture, pressure and temperature of everyday objects. Existing online shopping does not give potential buyers access to these physical evaluative criteria that many people use when choosing products, such as clothes and electronics [SG11, BS10]. Hwang et al. [HJS06] note the need for physical contact with online products to enable shoppers to gain the sort of product information from first-hand knowledge often experienced in a conventional shopping environment. Reflecting on the experience of shopping online, Gleckman [Gle00] states “I still want to see and touch a product before I buy it. Web sites are pretty good for selling books and airplane tickets. But they don’t do feel.”

Despite its increasing use in various computer applications [BKHAK04, LD03], haptic feedback has received less attention in online shopping applications [EOES07]. There are five main barriers that limit haptic support for online shopping. Foremost is the need for specialised devices [BKHAK04,LD03]. Other barriers include difficulties in providing a standard haptic interaction platform that simplifies the integration of haptic properties with applications [CTB*05], providing a network environment that eliminates jitter and latency of the transmitted haptic data to achieve efficient haptic interaction [GJF*07], providing a fast and effective means of capturing complex haptic properties of real objects [AMLL06,CRKA05], and offering a wide range of simulated haptic properties, e.g., combinations of weight and/or surface texture [CKK03].

The availability of various haptic properties is important for modelling virtual products. For instance, while a hand-held massager may require modelling that shows how heavy it is to hold or how frictionless its massaging-head feels on skin, modelling a cuddly toy may require showing how soft or spongy it is. However, simulation of a wide range of realistic virtual object details may never be entirely achievable due to technology limitations [HMG03]. Object prop-

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erties simulation is a complex concept that involves many dimensions, such as weight [BS10], roughness and friction [LK09, HFRY93], which are likely to require a significant amount of time and effort to model efficiently [AL07,SP96]. However, it may be feasible to circumvent these difficulties by concentrating on providing an impression of the object in question that is sufficient to enable relative comparisons to be made. This might not be dissimilar to the sort of visual impressions available in online shopping. Despite obvious differences in the quality and availability of product images across e-commerce websites, they play an important role in catching the user's attention [LB03] and generating positive attitudes amongst users [HTT04].

The study of surface simulation has often been approached from two different perspectives. Firstly by modelling friction as lateral forces to the nominal surface in a direction opposite to the haptic device probe motion and secondly by modelling texture as both lateral and normal forces generated in any direction [SP96, BS02]. The sensation of texture results from the effects of both a complex combination of bumps and cavity details, and friction on surfaces [OAdW*98]. However, friction has been regarded as an important perceptual dimension of active touch [SS96]. Smooth materials such as glass, aluminium, plastic, nylon, Teflon or silicone, which can be viewed as the building blocks of skin frictional properties [SS96, ZM99], are often used to make products such as home furniture, accessories and clothing. In the context of the work described here, we will represent friction by a stick-slip force.

Notwithstanding the fact that people normally examine surfaces using their bare fingers, a probe examination proved to be effective in discriminating between different types of surfaces [KL99, TAT*06]. Probe friction is commonly modelled on stick-slip motion phenomenon. The "stick" state is due to higher static coefficient of friction (StaticCF) between surfaces, and the "slip" state due to lower dynamic coefficient of friction (DynamicCF) during the slip state itself [MKS04]. These coefficients allow any two surfaces to either stick to each other or slide over each other [MKS04]. Many commonly used friction models (e.g. Karnopp, Armstrong and Dahl) depend on this idea of stick-slip, while others use algebraic equations or hybrid models that include events to cater for the increasing demand for realistic frictional surfaces [OAdW*98].

Due to the importance of DynamicCF during active exploration, this paper describes an evaluation of frictional surface perception to guide future work in haptic based online shopping. It explores *Just Noticeable Differences* (JNDs) for DynamicCF force using a force feedback device to better understand the design space of an online shopping environment. The JND threshold is a measure of the minimum difference between two stimuli that is necessary for a difference to be perceived [Ges97]. Much prior research has focused on JNDs for friction in human subjects, but none, to our knowledge, has tailored findings to the online shopping domain. Provancher and Sylvester [PS09] report JND thresholds of 0.28% - 18% when examining virtual friction stimuli through finger exploration using a Phantom Premium 1.0 device, corresponding, respectively, to standard static coefficients for friction stimuli of 0.2 - 0.8. Biet et al. [BCGLS08] report a JND threshold as low as 9% using a friction based tactile display that stimulates frication by generating an air gap between the finger and a high frequency vibrating plate. In an experiment involving using bare index fingers to feel friction on a glass surface, Samur et al. [SCP09] report an 18% JND threshold. Hinterseer et al. [HKSC07] describe a haptic prediction model based on human perception falling within the JND thresholds of 5% and 15%.

However, these findings, while suggestive, cannot be incorporated into online shopping applications due to the constraints on the experimental setup and the suitability of technology. Motion constraints on the arm or fingers, as used by other friction experiments, do not realistically reflect shopping activity where surface exploration is experienced freely. Furthermore, high-end haptic technologies, such as those used by Provancher and Sylvester [PS09], may not be appropriate for online shopping due to the amount of space required to house such devices, while others, such as implemented by Biet et al. [BCGLS08], offer tactile feedback (e.g. to simulate textures) but do not provide kinaesthetic feedback (e.g. to simulate weights). For haptic-based online shopping, the use of general devices with various feedback cues will be required.

As a result, given these variations in JND thresholds using different experimental techniques and technologies, there is a need for further investigation to support haptic-based shopping applications. This study explores JND threshold for a Phantom Omni haptic device using free virtual surface exploration through a probe. Unlike other technologies, the Omni is relatively small in size and able to provide a variety of haptic interactions. If haptic-based shopping were to be adopted in the future, these advantages are likely to be among the characteristics of the ideal device.

2. Motivation and Aim

The interaction between customer and computer is an important factor of business effectiveness over the Internet. A key difference between traditional and virtual shopping is the ability to compare products by physical examination [SG11]. The rapid development of haptic technology in virtual environments has made physical interaction commercially available in many specialised applications (e.g., aviation and medical training). However, the recent emergence of relatively cheap high fidelity haptic devices such as the Phantom Omni (`www.sensable.com`) and the Novint Falcon (`www.novint.com`) has opened new potential opportunities. The JND study described here investigates the threshold for simulated frictional surfaces, while providing a better insight into the design space for multiple comparisons of virtual surfaces in online shopping applications. However, the results can be generalised to other applications where comparisons are favourable, such as in re-education of sensation in the hand after nerve injury and repair, or for providing navigational cues for blind people using the Web [EOES07].

An experiment was conducted that aimed to identify (*Aim 1*) the minimum JND of dynamic friction needed to distinguish between two simulated frictional surfaces across a range of different surfaces. This is important because identification of the JND threshold will determine (*Aim 2*) the maximum number of unique combinations available for relative comparisons of frictional surfaces, and the latter is necessary to support the use of haptic feedback to enable subjects to relatively compare a variety of different virtual surfaces. The stick-slip forces to represent friction in this study are enabled by the H3DAPI (`www.h3dapi.org`), an open source haptics software development platform.

3. Apparatus

A Phantom Omni force feedback device (SensAble Technologies) was used to render the frictional force. The device allows for virtual interactions in three-dimensional space with six degrees of freedom. The force feedback workspace is approximately 160mm (width) x 120mm (height) x 7.1mm (depth) and utilises configurable StaticCF and DynamicCF values ranging from 0 to 1 and these were used to create various frictions. Users interact with the device by holding a pen-like stylus attached to a solid base on the device (see Figure 1).

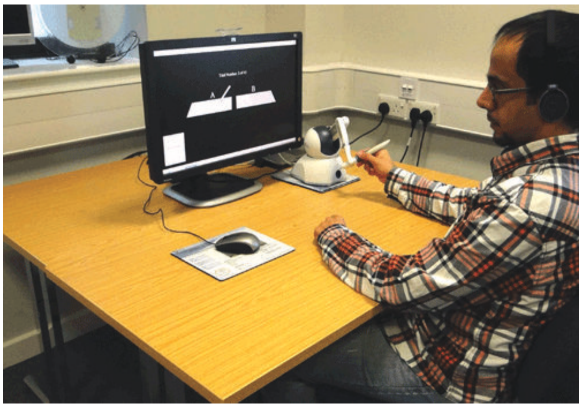
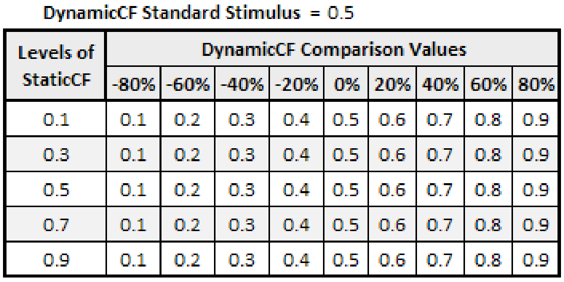


Figure 1: *Experiment setup*

To support the haptic interactions with the device, two virtual surfaces were developed (see Figure 2) using H3DAPI 2.0, an open source haptics software development platform that uses X3D with haptics, C++ and the scripting language Python in one unified scene graph to handle both graphics and haptics. Scenes and frictional forces were rendered on a laptop running Window XP on an Intel Core 2 Duo CPU at 1.66GHz with 504 MB of RAM, displayed on a 24-inch LCD monitor.

4. Experimental Setup

Surface friction texture was rendered by the Phantom Omni haptic device as stick-slip friction [MKS04] by changing the values of StaticCF and DynamicCF to switch between no relative motion and resisted relative motion. A method of transitions with three rating categories was employed to characterise accurately the friction thresholds [BSV09]. The method helps to negate the effects of adaptation, habituation and sensitisation [BSV09] caused by the high volume of trial repetitions when using the method of constant stimuli in its traditional form [Ges97]. Haptic surface frictions were evaluated based on a number of arbitrary StaticCF levels (i.e. 0.1, 0.3, 0.5, 0.7 and 0.9). On each StaticCF level, a DynamicCF standard stimulus of 0.5 was evaluated against nine DynamicCF comparison stimuli (i.e 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and 0.9) (see Table 1). The extreme high and low of StaticCF and DynamicCF were selected to fall between 0 and 1, which are the lowest and highest frictional force magnitudes the haptic device can simulate. Participants were asked to successively feel a pair of virtual surfaces and decide which was the stickier. Each surface pair was presented once only to each participant as described in the method of transitions [BSV09]. Surfaces were displayed on a computer screen, and participants could touch them via a haptic interface. Ethical approval was granted by the School of Engineering and Computing Sciences Ethics Committee at Durham University.



DynamicCF Standard Stimulus = 0.5

Levels of StaticCF	DynamicCF Comparison Values								
	-80%	-60%	-40%	-20%	0%	20%	40%	60%	80%
0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.3	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.5	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.7	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.9	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9

Table 1: *StaticCF and DynamicCF friction values*

4.1. Method

Participants were seated with their heads located approximately 60cm from the centre of the screen. The stylus tip of the Phantom Omni was positioned to match arm length, ensuring that participants were able to rest their elbows on the table. The device was manipulated with the dominant hand, while the other hand was used to enter answers on the screen using a regular PC mouse.

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Experiment Trials

Date: 03-05-10
Candidate ID: 19

Trial: 3 of 45

Which surface feels stickier?
○ Surface A is stickier.
○ Surface B is stickier.
● The are the SAME.

☑ Confirm your answer.

Figure 2: *Experiment visual output*

The visual output consisted of the haptic device pointer, two identical virtual surfaces, general trial information and a surface texture question-form (see Figure 2). Pink noise (from `www.simplynoise.com`) was applied to participants throughout the experiment using a set of headphones in order to mask any auditory cues from the environment or the haptic device. In addition, the haptic device was placed on a double layer of mouse pads to reduce vibration noise transmitted from the surface of the experiment desk. To feel the surfaces, participants had to move the haptic pointer on the screen until it touched the top side of each surface and then slowly move the pointer sideways while applying moderate pressure on the virtual surface. Participants were able to feel the surfaces as often as they liked, and were also able to switch between them as often as they liked to compare textures. Once satisfied, participants gave their answers using the form on the left side of the screen. Participants were always aware of the number of trials remaining, as this number was shown at the top of the screen.

All participants were given a training session to familiarise them with (i) the haptic device and (ii) the texture task and question form. The training session consisted of trials of six pairs of textures with extremely large differences in DynamicCF intensities using different StaticCF levels, that were repeated if necessary, to allow participants to become familiar with the interface and the device. Participants could use either hand to record results during training session. Subsequently, the participants performed 45 trials under experimental conditions. The complete session, including the training phase, lasted for 35-40 minutes.

4.2. Procedure

Twenty healthy male subjects, aged 18 to 39, participated in this experiment. All except one was right handed and they used their dominant hand with the haptic device. All were daily computer users.

Participants' perception of StaticCF and DynamicCF combinations were collected. DynamicCF comparison values were run nine times on each StaticCF level, which resulted in 45 experimental trials, i.e. 9 x 5 (see Table 1). Experimental trials were sequenced in a random order using a random number generator (from `www.stattrek.com/Tables/Random.aspx`) with the constant stimuli used first for half the trials and the comparison stimuli first for the other half to provide unbiased JND estimates [Ges97]. Each experimental condition was tested by all 20 participants, creating a total of 900 trials, i.e. 20 x 45. To the question "Which surface feels stickier?" (see Figure 2), they were offered three alternative answers:

- Surface A is stickier.
- Surface B is stickier.
- They are the SAME.

Stickiness was defined as "how hard it is to push the stylus sideways across the virtual surface". After they had confirmed their answer with a confirmation checkbox, they proceeded to the next trial until all the 45 trials were completed.

4.3. Results

All twenty participants successfully completed the experiment. The results for DynamicCF stimuli comparisons were computed separately, based on the level of StaticCF level, to establish the JND via the method of transition outlined by Burro et al. [BSV09]. The resulting graph represents the so-called psychometric function with the proportion of stickier responses (y-axis) starting from lowest to highest, plotted against values of the comparison stimuli (x-axis) are shown in Figures 3 - 7. The graphs display the proportion of times the standard DynamicCF stimulus paired with nine comparison DynamicCF stimuli were reported as having a greater stickiness at different levels of StaticCF. The comparative judgment yielded a sigmoid curve, as a function of the difference in contrast between two stimuli.

The proportion point of 0.50 on the psychometric function is known as the Point of Subjective Equality (PSE) [Ges97]. This point represents a complete lack of discrimination where the comparison DynamicCF stimulus is perceived subjectively as equal to the standard DynamicCF stimulus. The proportion points of 0.25 and 0.75 on the psychometric function were used to find the DynamicCF JND threshold for each level of StaticCF. The upper JND (JNDU) threshold is the stimulus ranging from PSE to the 0.75 proportion point, whereas the lower JND (JNDL) threshold is the stimulus ranging from PSE to the 0.25 proportion point. JNDU and JNDL were then averaged to give one JND threshold for the each StaticCF level [Ges97]. The JNDs and corresponding Weber Fractions are summarised in Table 2.

The results reveal a positive bias PSE of 0.538 from the psychometric function under level 0.1 of StaticCF while other levels of StaticCF show very close negative PSE bias ranging from 0.464 to 0.455. The results also indicate approximately constant average JND thresholds using DynamicCF at different levels of StaticCF. DynamicCF perception scored the highest average JND thresholds of 0.080 on StaticCF level 0.5 while the lowest average JND thresholds were

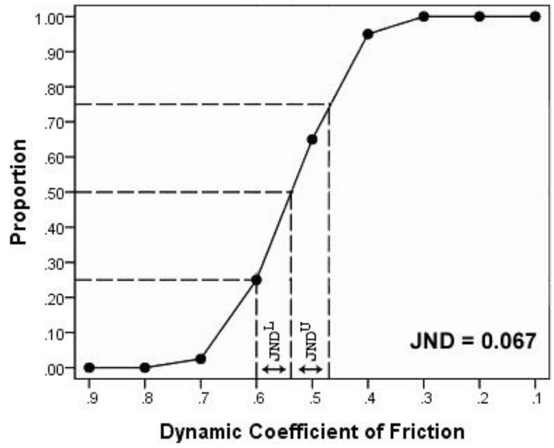

Figure 3: *Average JND results for stickiness discrimination based on the 0.5 standard DynamicCF at level 0.1 of StaticCF (summarised in Table 2).*

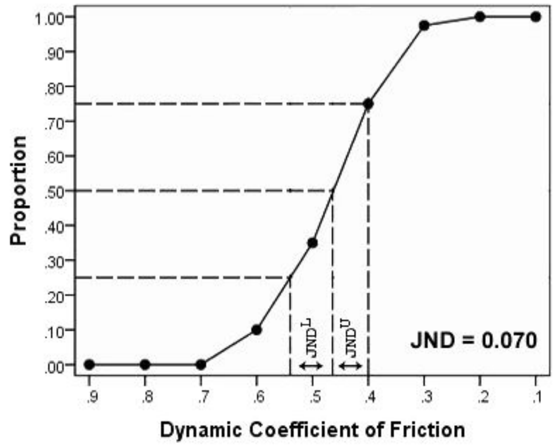

Figure 4: *Average JND results for stickiness discrimination based on the 0.5 standard DynamicCF at level 0.3 of StaticCF (summarised in Table 2).*

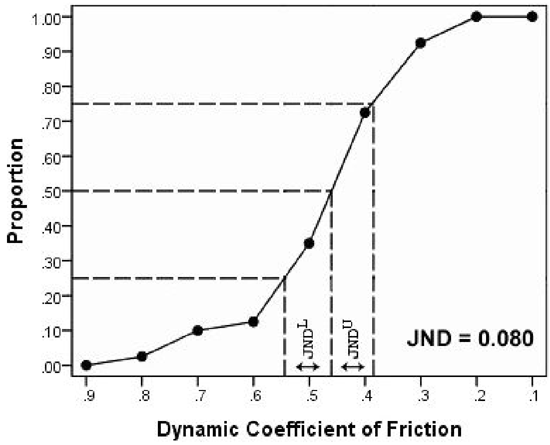

Figure 5: *Average JND results for stickiness discrimination based on the 0.5 standard DynamicCF at level 0.5 of StaticCF (summarised in Table 2).*

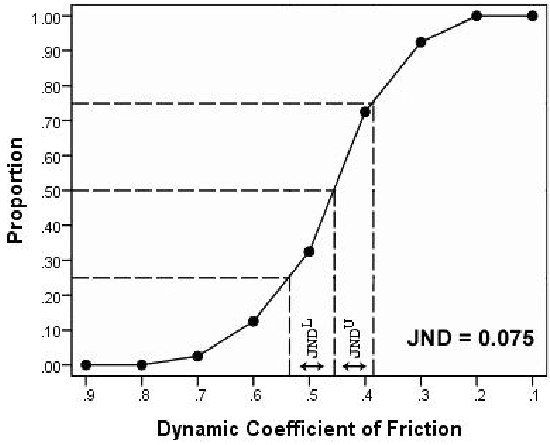

Figure 6: *Average JND results for stickiness discrimination based on the 0.5 standard DynamicCF at level 0.7 of StaticCF (summarised in Table 2).*

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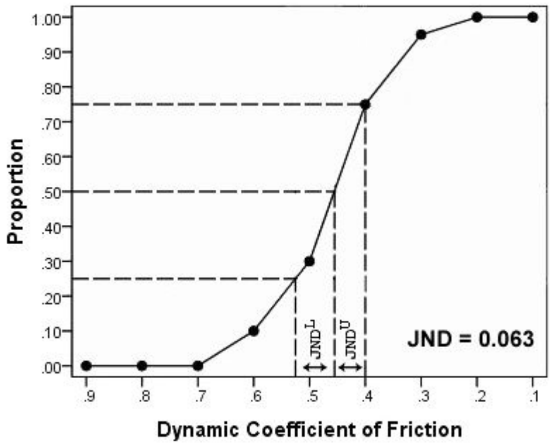


Figure 7: *Average JND results for stickiness discrimination based on the 0.5 standard DynamicCF at level 0.9 of StaticCF (summarised in Table 2).*

scored on the extreme ends of the StaticCF levels (i.e. 0.1 and 0.9). The average DynamicCF Weber Fractions for the the five StaticCF levels is 14.1%.

StaticCF levels	PSE	SE	JND^L	JND^U	Average JND	Weber Fraction
0.1	0.538	± 0.018	0.062	0.071	0.067	13.3%
0.3	0.464	± 0.021	0.076	0.064	0.070	14.0%
0.5	0.460	± 0.030	0.084	0.075	0.080	15.9%
0.7	0.455	± 0.025	0.080	0.070	0.075	15.0%
0.9	0.455	± 0.022	0.070	0.055	0.063	12.5%
	Average Weber Fraction for DynamicCF				=	14.1%

Table 2: *Results of virtual stickiness perception experiments in the form of JNDs and Weber Fractions for the 0.5 standard DynamicCF across all StaticCF levels.*

5. Discussion

A biased PSE was found at all considered levels. Participants tended to underestimate the standard DynamicCF stimuli intensity under level 0.1 of StaticCF. However, the DynamicCF stimuli magnitude is overestimated under all other StaticCF levels. Biased PSE of this magnitude is considered common in psychophysical experiments [Ges97].

This study's investigation of the threshold required for dynamic friction perception (*Aim 1*), has demonstrated that, using 0.5 standard DynamicCF, the required JND at any level of StaticCF is, on average, 14.1% (see Table 2). It should be noted that the small variations of DynamicCF Weber Fractions on different levels of StaticCF is to be expected since many human perception abilities follow this type of behaviour at different intensities [Ges97]. Although this study adopted free virtual surface exploration through a Phantom Omni haptic device probe, the study outcome is consistent with those of Hinterseer et al. [HKSC07], who found the haptic prediction model, based on human perception, to be in the 5% to 15% range. It is also in a similar range to those of Samur et al. [SCP09] and Biet et al. [BCGLS08]. However, it accords to those of Provancher and Sylvester [PS09] only when the coefficients for friction stimuli are above 0.6N. This is an important validation of difference thresholds in a free movement environment.

The estimated JND threshold was used to calculate the 0.13 increment factor based on the highest DynamicCF comparison stimulus (i.e. 0.9 x 0.141 = 0.13 increment factor) which was used to identify eight different DynamicCF stimulus points for relative surfaces comparisons (see Table 3). Despite the fact that using a lower increment factor based on a lower DynamicCF comparison stimulus results in more DynamicCF stimulus points for relative surfaces comparisons, a lower increment factor will make higher DynamicCF stimuli difficult to compare. Hence, it is essential that the increment factor be calculated based on the highest DynamicCF comparison stimulus.

Unique Stimulus (increment factor = 0.13)			
0.00	0.13	0.26	0.39
0.52	0.65	0.78	0.91

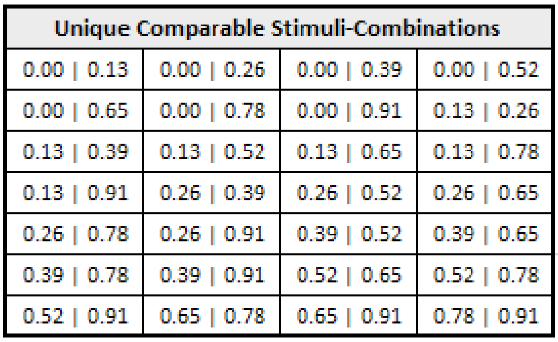
Table 3: *Unique stimulus points for relative surface comparisons*

In order to find the maximum number of unique comparable combinations (*Aim 2*), this equation was applied:

```
nCr = ( n! ) / (r! (n-r)! )
```

where *"n"* is the total number of stimuli, *"r"* is the number of stimuli in combination, *"nCr"* is the number of ways that the stimuli can be arranged without repetition, and the exclamation mark *"!"* indicates factorial function [LR03]. The maximum number of unique comparable combinations available is 8C2 = 28 different combinations, which are shown in Table 4. Since it was revealed that changing StaticCF has little or no effect on DynamicCF JND perception, these unique combinations are applicable at any given StaticCF intensity. However, in doing so, we need to address an issue that emerges. Although we can compare the DynamicCF combinations, changing the StaticCF at close intervals may not affect the perception unless the StaticCF JND threshold is known. However, since the focus here is on active exploration represented by DynamicCF, the StaticCF is beyond the scope of this paper.

Generalisation beyond the present study is limited by (i)



Unique Comparable Stimuli-Combinations			
0.00 | 0.13	0.00 | 0.26	0.00 | 0.39	0.00 | 0.52
0.00 | 0.65	0.00 | 0.78	0.00 | 0.91	0.13 | 0.26
0.13 | 0.39	0.13 | 0.52	0.13 | 0.65	0.13 | 0.78
0.13 | 0.91	0.26 | 0.39	0.26 | 0.52	0.26 | 0.65
0.26 | 0.78	0.26 | 0.91	0.39 | 0.52	0.39 | 0.65
0.39 | 0.78	0.39 | 0.91	0.52 | 0.65	0.52 | 0.78
0.52 | 0.91	0.65 | 0.78	0.65 | 0.91	0.78 | 0.91

Table 4: *Twenty eight unique comparable combinations.*

the sample population (ii) the capabilities of the haptic device used and (iii) the use of simple frictional forces to simulate various surfaces. Firstly, participants of our experiment were male students and staff from Durham University aged 18-39. Although this sample is a significant proportion of the online shopping demographic, if haptic online shopping is to be commonplace in the future, it would be helpful to consider a wider population range of participants, including females, children and older adults. This would enable either general guidelines to be built or dynamic threshold calibration based on the current user to be supported. Secondly, the device used in this study, a Phantom Omni, has a friction force limitation of 1.0N. Depending on the context of use, examination of the different thresholds at greater friction forces may be necessary. This will be important when comparing a number of objects. For instance, if three different surfaces are to be compared at one time, would one high friction surface influence the perception of the two lighter friction surfaces? Thirdly, surface damping and stiffness were held, respectively, at constant values of 0 and 0.5 throughout the experiment. An examination of variations of damping and stiffness values may be necessary to observe their influence on the perception of DynamicCF during active exploration.

6. Conclusion and Future Work

Twenty healthy male subjects participated in a haptic surface perception experiment. The experiment consisted of 45 trials in which participants were encouraged to feel two virtual surfaces and decide which was stickier. Discrimination perceptions were collected based on a number of arbitrary StaticCF levels (i.e. 0.1, 0.3, 0.5, 0.7 and 0.9). On each StaticCF level, a standard DynamicCF stimulus of 0.5 was evaluated against nine DynamicCF stimuli (i.e 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and 0.9).

This study demonstrated that, on average, the dynamic friction threshold is 14.1% (*Aim 1*). Using free virtual surface exploration of a general haptic device, the study showed consistent findings to previous studies with constrained environments. The estimated JND threshold was used to calculate the 0.13 increment factor based on the highest DynamicCF comparison stimulus, which, in turn, was used to identify eight DynamicCF stimulus points for relative surface comparisons. Twenty eight unique comparable combinations were identified using the eight DynamicCF stimulus points (*Aim 2*).

The identification of the maximum number of unique comparable combinations of frictional surfaces is necessary to support the use of haptic feedback to compare different products when shopping online. The intention of this study is not to create virtual surfaces that match the real world, which is likely to require significant time and effort to model efficiently [AL07, SP96], but to convey appropriate relative friction perceptions, while allowing for comparisons across many surfaces.

Real world surface comparisons are one of many important aspects that help shoppers choose one product rather than others; yet, this aspect is absent when shopping electronically. This work is a step towards the development of online shopping that support haptic evaluation with multiple comparisons. This will also be applicable to other haptic applications that require multiple comparisons.

Online shopping has a visual component and haptic interaction can be used to complement visual representations of products. Future work will consider how visual and haptic (weight and texture) can be used to support product selection in online shopping applications. This work is ongoing.

7. Acknowledgements

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