

Roughness and spatial density judgments on visual and haptic textures using virtual reality

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Abstract. The purpose of this study is to investigate multimodal visual-haptic texture perception for which we used virtual reality techniques. Participants judged a broad range of textures according to their roughness and their spatial density under visual, haptic and visual-haptic exploration conditions. Participants were well able to differentiate between the different textures both by using the roughness and the spatial density judgment. When provided with visual-haptic textures, subjects performance increased (for both judgments) indicating sensory combination of visual and haptic texture information. Most interestingly, performance for density and roughness judgments did not differ significantly, indicating that these estimates are highly correlated. This may be due to the fact that our textures were generated in virtual reality using a haptic point-force display (PHANToM). In conclusion, it seems that the roughness and spatial density estimate were based on the same physical parameters given the display technology used.

1 Introduction

Surface texture is a multidimensional and multimodally perceived property. However neither the interplay between different textural dimensions nor the contribution of different modalities is well understood as yet. When the same set of textures was presented visually, haptically and visuo-haptically, participants could differentiate either texture roughness or element density well by either touch or vision unimodally. In the bimodal conditions, density judgments were more strongly influenced by vision than by haptics, whereas roughness judgments were more strongly influenced by haptics [1]. According to a “modality appropriateness” interpretation, the bimodal estimates may have been influenced differently by the different *visual and haptic on-*

line reliabilities for judging spatial density and roughness [1, 2], and/or by *biases* due to the *long-term experience* with the relative effectiveness of these modalities [1].

The present study extends the topic of multidimensional textural perception to virtual reality. Using magnitude estimation [3], we explored the dependency of roughness and spatial density judgments on modality by presenting a broad range of textures. We expected that judgments would differ between vision and haptics, and that in the bimodal display the more appropriate modality would influence the judgments to a greater extent.

2 Methods

A total of 16 persons participated for pay. The participant sat in front of a visuo-haptic workbench comprising a PHANToM 1.5 haptic force-feedback device and a 21"-computer screen (Fig. 1a). The right index finger was connected to the PHANToM. Simultaneously, the participants looked via a mirror at the screen. The mirror aligned the visual and haptic stimuli and prevented the participant from seeing his or her hand.

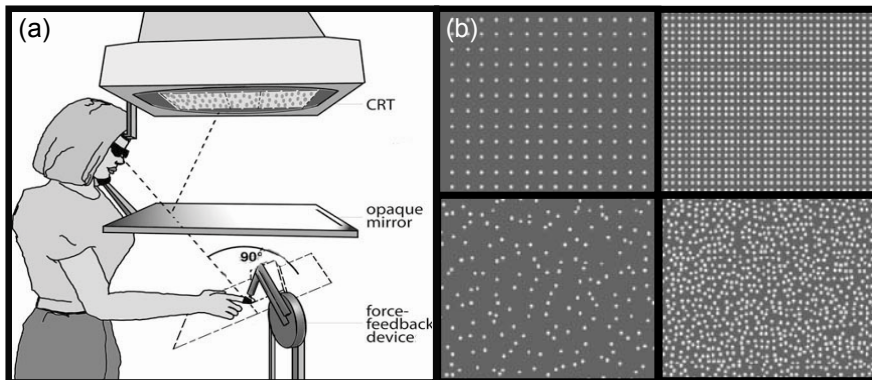


Fig. 1. (a) Visuo-haptic workbench and (b) sections of textures with lowest and highest density (left and right) and lowest and highest jitter (upper and lower; reduced).

Our stimuli were raised-dot patterns (Fig. 1b). Haptically, dot shape was defined by radial sine-functions on an otherwise planar surface (amplitude 0.5 mm, radius 1 mm). Visually, height values of the dots were converted into luminance values (between 5 [surface] and 61 cd/m^2 [0.5mm]). Each texture was defined in terms of the average number of dots/ cm^2 and “dot jitter”: we started with a regular dot matrix (0 % jitter); each dot was then randomly “jittered” within a circular area (radius was defined as percentage of average dot distance).

We used a four-variable, mixed design with three within-participant variables: *dot density* [5, 10, 15, 20, and 25 dots/ cm^2], *dot jitter* [0, 25, 50, and 75%] and *display mode* [haptic, visual, visuo-haptic]. Between participants we varied the *judged texture dimension* [spatial density vs. roughness]. During each trial, a texture was displayed

for 5 seconds coupled with white noise on the headphones. In the visual-display mode, participants held their index finger still, while in the other two modes they moved it across the texture. Then, they used a calculator-like numerical pad to enter an estimate for the magnitude of the targeted texture dimension. The experiment consisted of a practice phase and an experimental phase, which included 3 repetitions per condition.

3 Results and Discussion

Each estimate was standardized by dividing it by the individual’s overall mean. Individual means and – as a measure of judgment reliability – individual standard deviations per condition were entered into two separate four-variable ANOVAs.

The means differed between dot densities, $F(4,56)=44.8$, $p<.001$ ¹, confirming that in virtual reality as well participants can judge textural dimensions (Fig. 2 a,b). A significant effect of display mode, $F(2,28)=4.9$, $p<.05$ indicated slightly higher estimates for both visual and visuo-haptic modes as compared to the haptic mode (Fig. 2a). Furthermore, there was an interaction, jitter X density, $F(12,168)=2.6$, $p<.01$, indicating a small effect of jitter (cf. Fig 2b). “Reliability” differed between display modes, $F(2,28)=4.9$, $p<.01$ (Fig 2c), with the visuo-haptic mode being most and the haptic mode least reliable. There was no other significant effect.

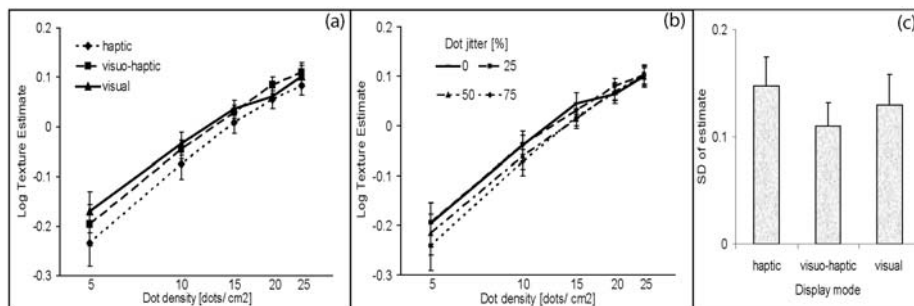


Fig. 2. Logarithms of average texture estimates under each (a) dot density X display mode, (b) dot density X dot jitter (log scale) and (c) average estimate “reliability” under different display modes

Most importantly, we did not find any difference between the roughness and spatial density estimates. Further, we found judged roughness to increase with increasing dot density, whereas in the previous study [1] it has been – both visually and haptically – reported to decrease with element density. The present result, however, is consistent with findings on roughness perception with a probe [5]. There, perceived roughness increased with spatial density as long as the probe dropped between texture elements, but, thereafter, decreased again. The PHANToM simulates a point-contact

¹ If necessary all p -values were corrected according to Huynh and Feldt [4]

to the surface – resembling an infinitesimal small probe – and so our finding is consistent with the literature.

Taken together, these results tend to indicate that the restricted sensory inputs in this point contact haptic interface (i.e., kinesthetic, but no cutaneous cues, and a symbolic visual display) lacked sufficient information to perceptually differentiate the two dimensions of spatial density and roughness – in contrast to the previous study which used the bare fingertips and the actual raised textured surfaces [1].

If this is the case, particularly the lack of a dimension effect under visuo-haptic display implies that there was no long-term bias towards the “appropriate” modality in judging the two dimensions. However, in qualitative accordance with models of optimal cue integration [2], judgments for the visuo-haptic display resembled more those for the more reliable, namely the visual as compared to the haptic modality, and, in terms of reliability the system profited from the integration. Thus, we found some evidence for reliability-dependent weighting of perceptual information [cf. 2].

Overall, the findings suggest that we managed to create haptic and visual textures that conveyed sufficient perceptual information for texture discrimination and inter-modal integration. However, differences to real textures point to the necessity of further research– particularly on the cues differentiating between the textural dimensions of roughness and spatial density in the different sensory modalities.

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