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Effects of temporal frequency towards visual roughness perception by drifted grating stimulation

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M U Syafiq S Sadiah[2], A Z Shaameri[2], F M Sakri[3], M A Azizan[3], M F Haniff[1]

[1]Quality Engineering Section, Universiti Kuala Lumpur Malaysian Institute of Industrial Technology (UniKL MITEC), Bandar Seri Alam, 81750 Masai, Johor, Malaysia
[2]School of Electrical Engineering, University of Technology Malaysia, 81310 Skudai Johor, Malaysia
[3]Department of Aerospace, Universiti Kuala Lumpur Malaysia Institute of Aviation Technology (UniKL MIAT), Jalan Jenderam Hulu, Kampung Jenderam Hulu, 43900 Sepang, Selangor, Malaysia
[4]Electrical, Electronics and Automation Section, Universiti Kuala Lumpur Malaysia Spanish Institute (UniKL MSI), Kulim Hi-Tech Park, 09000 Kulim, Kedah, Malaysia

E-mail: usairy@unikl.edu.my

Abstract. Previous studies proved that in addition to spatial characteristics function in extracting roughness information, there is potential roughness dependability across changes in the temporal mechanisms of textured surfaces. In the present study, we created temporal coding mechanism by converting fine spatial structure surface into a temporal drifting pattern. We proposed that regular spatial structure of gratings with variation of temporal mechanism have different influence toward roughness perception. Results showed massive individual differences of roughness perception between subjects, suggesting that a combination of spatial and temporal mechanisms accounts for perceptual judgments of roughness. We suggest that visual roughness judgment was determined by spatial in grating stimulation, and improvement is needed in spatial components before temporal coding of visual roughness can be declared.

1. Introduction

Humans perceive they are real-world by visual examination and manual exploration of the objects around them [1]. Shape elements serve as significant cues for object perception, but material properties (such as surface texture, roughness, stickiness, and compliance) also provide additional information that can facilitate recognition [2] and other various cognitive functions including selective attention, learning[3], and cross-modal integration[4][5].

In tactile texture perception, roughness is one of the most important characteristics of a textured surface and it is evident that, at least for fine surfaces, spatial characteristics play an important role in extracting roughness information from textured surfaces [6][7]. The tactile perception of surface roughness can be estimated by skin vibrations generated during a fingertip stroking of a surface instead of being maintained in a static position [8]. It has been found that the reference frame in which spatial information is represented is strongly dependent on stimulus modality in vision and audition [9][10][11]

Recently, movement of textures against the fingertip was added to the horizontal sliding movement such as to generate a periodic modulation of the fine mechanical vibrations generated by the texture fingertip interactions [12]. Haptic perception of roughness textures is evidently affected by changes by spatial mechanism conditions [13][14] and , if visual perception of the roughness of textures were well-calibrated to a haptic perception of the same textures [15], it is expected to assume roughness dependability across changes in the temporal mechanisms of visual textures.

Although the behavioral and neural correlates of multisensory shape perception have received detailed investigation, little is known whether the surface texture is represented similarly, especially in vision and touch [2][4]. Crossmodal interplay has been shown as a broad range of cognitive processes [16]. Congruent visual-tactile stimulation led to improved behavioral performance in a crossmodal detection task [4][5]. The effects that occur with traditional visual-only and tactile-only tasks [9][10] may suggest the significance of these modalities in surface recognition.

The analysis and examination of the characteristics of visual information are largely been discussed due to its contribution to traffic safety and virtual reality technology. In this study, we focused on behavioral visual perception to clarify the temporal element in roughness perception. By roughness discrimination tasks using computer-generated grating stimulation, our goal is to investigate whether temporal frequency factors affect subject's judgment with controlled spatial conditions. We compare the result with normal speed judgment task to evaluate our novel grating stimulation.

2. Subjects

Ten right-handed, healthy volunteers (all males, mean age of 21.4±0.3 years old) participated in this experiment. All subjects had no remarkable injuries to the hands or fingers, normal visions, and given written informed consent for participation. The current study is focusing on healthy young participants below 24 years old with normal vision. Based on previous study [7], after eliminating outliers, the amount of useful information obtained from ten participants can be considered sufficient for the discussion.

3. Stimuli

The experimental stimulation was written in the numerical computing programming language MATLAB R2015b (The Mathworks, Inc.) with interfaces of Psychophysics Toolbox Version 3 (PTB-3). The parameters of the grating including pixels per cycle, spatial frequency, and visible size were calculated and one single static black and white grating image was generated. The actual sine grating and drift speed (in cycles per second) were then computed and the number of pixels to be shifted is specified to perform a movement perception of black and white gratings.

In this study, we set the temporal frequency by controlling seven types of drift speed as target stimuli; which are 0.1, 0.5, 2, 4, 6, 10, and 20 cycles/second. All the drift speed was tested by several pilot tests to measure the speed of drifting black and white gratings. Three of them (2, 4, 6 cycles/second) were used as standard stimuli for the subjects' reference during each trial. All seven speeds were used as target stimuli, pairing with those three speeds of reference.

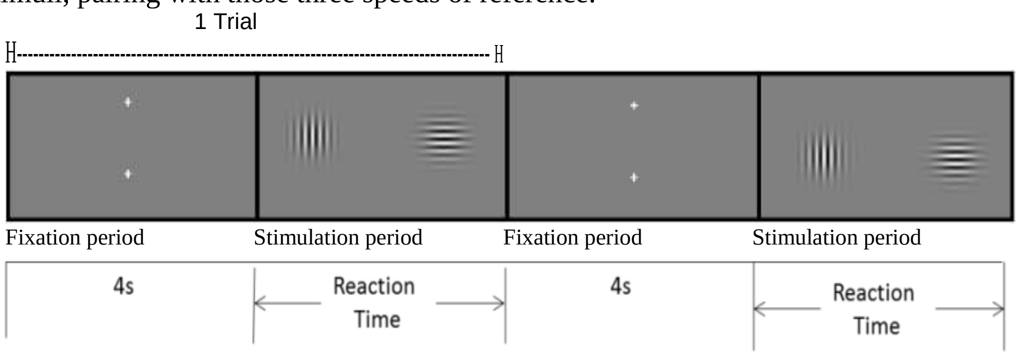

Figure 1.: Trial sequence. Reaction time was calculated between the start of gratings presentation and subject response and no time limit was appointed.

The equivalent speed of reference stimuli and target stimuli were also involved. Subjects assessed the same pair of reference and target ten times, totaling of 210 trials per subject.4 minutes of dark adaptation. Inside the experiment room, subject will sit on a chair with their right hand placed on the computer numeric keyboard for task's response. The keyboard size was 15mm long and 8mm width; fitting subject’s finger. A chin rest was provided fixed to the table to prevent subject's fatigue during the experiment and secondly for limiting subject's eye distance to be approximately 2.5 meters from the computer display. The experimenter was always outside the room to control the computing programming and to be on guard for subjects from sleeping during adaptation or experiment. The experimenter's voice can always be heard from inside the room.

Figure 1 illustrates the trial sequence. In the fixation period, subjects were not given any directions, but they need to be ready with incoming stimulation. Subjects will feedback all their responses in the stimulation period by the computer numeric keyboard with only three buttons horizontally arranged. In the speed cognition task, subjects need to judge whether target stimulus on the right was “faster” than reference stimulus on the left side. During task description before the experiment starts, subjects were asked to press right button if stimulus on the right side was faster or left button for the opposite. In case subjects could not decide which stimulus was faster between those two, they were asked to press the third button which was placed in the middle. In the roughness cognition task, subjects needed to select stimulus which was “rougher” between two presented on the left and right at the screen. Similar to speed cognition task, subjects were asked to press left button if stimulus on the left side was rougher, right button if stimulus on the right side was rougher and middle button if they could not conclude any of them.

4. Data processing and analysis

Each participant’s response was analyzed to remove outliers and separate incorrect or double click responses. Response distributions for each of the tasks were calculated for each subject. All the analyses were performed using RStudio Desktop version 1.0.136 (RStudio, Inc.) and SPSS version 17.0 (SPSS, Tokyo, Japan)

5. Results

We were interested to explore the mechanism inside tactile, visual and the interaction between them in the perception of roughness using fine textures. By designing two unimodal tasks and four bimodal tasks accompanying both modalities, we expected to understand more about how humans perceive roughness in the behavioral level of tactile and visual. We collected the subject’s response and only examined the “rougher” target response by subjects. The third-choice response (if the subjects could not decide which stimulus was faster/ rougher) were divided and inserted equally into another two responses. Results were plotted as the distribution of “faster” or “rougher” response when subjects perceived the target stimuli and compared with the reference stimuli on the left.

Mean of 10 subjects for “faster” response in speed cognition task are shown in figure 2. Three vertical lines are the three-reference stimulus speed (2, 4, and 6 cycles/s). In speed cognition task, all subjects have the same trend. They accurately perceived the speed of target stimulus; “faster” responses increased when the drifted speed of target stimulus increased. This result was expected and showed that subjects did not have any difficulties to percept and recognize each of grating stimuli. The error bar represents the standard deviation. The chance level for “faster” response was 33.33% since there were three types of responses. Pro-portion during the same drift speed between reference and target showed that subjects were around the chance level in 4 and 6 cycle/deg, but less in 2 cycle/deg. The proportion of “faster” response of target stimulus 20 cycle/deg was almost 100% for each comparison to reference stimuli and proportion of “faster” response of target stimulus 0.1 cycle/deg was almost zero.

In the roughness cognition task, inconsistent results between ten subjects were earned. Numerous possibilities can be seen for roughness perception of grating stimuli. We divided the result into three types, according to their cognitive characteristics. Individual results were separated and “rougher” response in roughness cognition task is shown in Figure 3. The results of roughness cognition tasks can be divided into three groups. In group (a), subject tends to feel rougher when the target stimulus was faster but dropped slightly after 10 cycles/s. Proportion during the same drift speed between reference and target showed that subjects were around the chance level in 4 and 6 cycle/deg, but less in 2 cycle/deg.

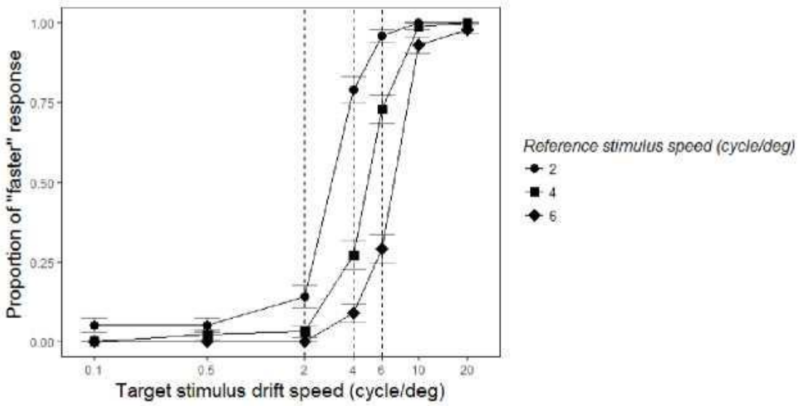

Figure 2. Results of 10 subjects for speed cognition task. All subjects have the same trend; they accurately perceive the speed of the target stimulus.

The proportion of "rougher" response of target stimulus 20 cycle/deg was slightly dropped for each comparison to reference stimuli and proportion of "rougher" response of target stimulus 0.1 cycle/degree was near to zero. In group (b), subjects primarily felt smoother when the target stimulus is faster. Proportion during the same drift speed between reference and target showed that subjects were high above the chance level in 4 and 6 cycle/deg. The proportion of "rougher" response of target stimulus 20 cycle/degree was almost 10% for each comparison to reference stimuli and proportion of "faster" response of target stimulus 0.1 cycle/deg was almost 100%. The results were relative with group (a), logically proposing same tendency of fast speed of drift stimuli. However, no slight increase in the "rougher" proportion between 10 and 20 cycles/degree. In group (c), constant "rougher" proportion was detected as the drift speed of target stimulus increased. The proportion was around 40% to 60 % which was above the chance level. Accordingly, subjects can sense the "roughness" inside the grating stimulation but could not discriminate against the difference of roughness at different speeds.

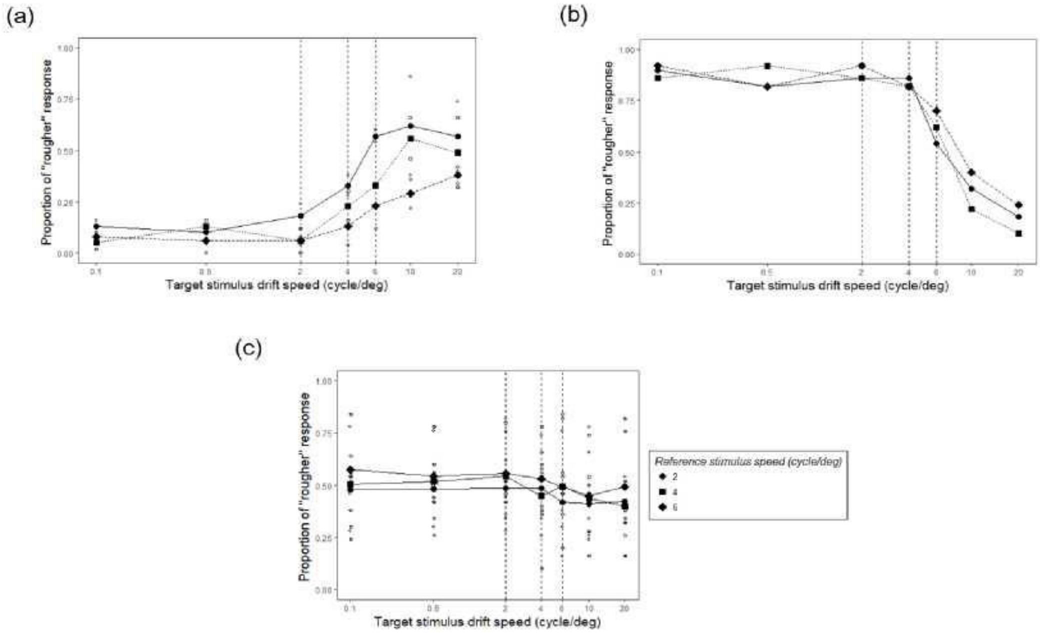

Figure 3. Results of roughness response. Roughness percentage of target stimulus was plotted for each reference stimulus speed. Generally, results can be divided into three types of roughness responses. In (a), subject tends to feel rougher when target stimulus was faster but dropped slightly after 10 cycles/s. In (b), subjects primarily felt smoother when target stimulus is faster. In (c), constant roughness was detected as the drift speed of target stimulus increased

6. Discussion

Our previous study suggested that in bimodal sensory tasks, both visual and tactile tasks roughness perception was influenced, although in different volumes. Visual sensory receive a big impact when cross-modality occurred from tactile information, more than tactile sensory received. This can be explained by behavioral evidence at [7] that indicated surface roughness is particularly salient to the tactile sense. On the contrary, we suggest that tactile sensory receiving little effects from visual information when two sensories are working. This may suggest that information encoded across vision and touch may not transfer efficiently across modalities, but tactile might do the "job" better than vision does.The fact that the subject's maximum roughness proportion was during target stimulus 10 cycle/degree in group (a) was rather interesting, suggesting drift speed around 20 cycle/degree contribute to weaker roughness properties of visual textures compared to 10 cycle/degree. The ceiling of roughness perception might closely relate with drifting speed under certain conditions, but the characteristics transformed after certain degree of velocity or acceleration of temporal frequencies. Additional tests with more subjects are necessary to prove the hypothesis.

Interestingly, certain subjects were also not consistent for the duration of five attempts of roughness cognition tasks. As an example, a subject performed one session of the task once every week for five weeks. In the first attempt, subject's proportion of "rougher" response increased when the drift speed of target stimulus increased. However, the range of minimum and maximum value of the proportion was decreased since the third attempt. From the fourth attempt, the increase pattern of the graph cannot be seen any longer. In another subject, during the second attempt of the experiment, subject conformed type (b) of the result in Figure 3. Three weeks later, the opposite result appeared. In the roughness cognition task, we carefully controlled the experimental spatial parameter and environment to be consistent in every task and every subject over the five attempts, thus it is unreasonable to conclude that the parameters influence the inconsistency among subjects. The fact that subject did not respond consistently throughout five weeks may suggest that extremely uncluttered spatial mechanisms in our grating stimuli carried less consequence for roughness perception in visual tasks. We expect to extend these preliminary studies to control different spatial character to expose subjects for more temporal judgment in roughness discrimination.

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