Do Colors Affect Our Recognition Memory for Haptic Rough Surfaces?

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Abstract. Haptic (tactile) interaction is a promising approach to be used for human computer interfaces. But how various kinds of haptic effects are learned and memorized, and what factors might influence user performance, remain unanswered. Little is known about the recognition memory for haptic information. The authors used a recognition memory paradigm to study the influence of color information on recognition memory for haptic rough surfaces. Participants' performance is less confident at exposure duration of 2s than at other three durations. The performance shows little difference as long as rough surfaces are presented and queried in the same color. However, Experiment 2 revealed that the influence of colors on haptic memory is sensitive to color presentation and query conditions. Our results can be used as guidelines for haptic interfaces for selecting colors.

1 Introduction

Current mainstream human-computer interaction (HCI) is visual-information-centered [1]: information displayed on computer screens accounts for an extremely large proportion of that available to users.

Among new interaction modes feasible from a technical perspective, haptic interaction (i.e., forces transmitted back to human hand or fingers in a way that mimics the sensation of touching real objects, using specialized systems) is a promising one. Compared with visual and auditory interaction, it has a unique bi-directional nature. As we touch and manipulate objects, we simultaneously change their state and receive information about them [2].

For more than 50 years, the influence of verbal (for example, spatial language) or visual (for example, color) information on memory performance has been studied. The effect of spatial language on recognition memory for spatial scenes was studied [3], finding that spatial language influences the encoding and memory of spatial relation presented visually in pictures. In another study, the color's contribution to recognition memory for natural scenes was investigated [4], finding that colors enhance an individual's visual recognition memory.

Most studies to date have been concentrated on memory for visual and/or verbal information ([5], [6]), using visual or verbal information as the to-be-remembered material in recognition memory tests, although there are few exceptions in olfactory ([7], [8]) and haptic memory ([9], [10]). But to our big surprise, less or little is known

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about the influence of colors on the recognition memory for haptic information (for example, roughness), considering that neural correlates of both encoding and retrieval vary with the to-be-remembered material ([11]).

On the other hand, how haptic effects are learned, memorized and later used for interaction with computers is a rather complex process. Identifying factors making significant contribution to the process is important. Through a haptic interface designed for virtual reality applications, such as remote surgery, users usually can both see and feel objects within a single workspace. In such cases, the color of objects may be changed from one view to another, as the operation procedure proceeds. Can we intentionally select certain color for the objects within each view in such a way that the user's performance can be strengthened, thus raising the efficiency of haptic interfaces and reducing the users' workload?

To answer this question, we conducted a series of recognition memory experiments in which participant's haptic recognition memory for rough surfaces was tested. In our experiment task, both the processing of colors and haptic memory systems of the brain are involved. Experimental apparatus, colors and computer-generated rough surfaces used for experiments are described in Section 2, followed by two experiments and a discussion of the results in Section 3. Finally, conclusions are drawn in Section 4.

2 General Method

2.1 Experiment Apparatus

The hardware setup, as shown in Figure 1, consists of a PHANToM (Model: Premium EW) from SenseAble Technologies, a dual Pentium III PC operating on the Windows 2000 Professional platform, and a wireless liquid crystal stereo shutter eyewear (Model: CrystalEye 3) from StereoGraphics. This model of PHANToM has a maximum stiffness of around 1100N s /m and a workspace of 19.5cm × 27.0cm × 37.5cm. The shutter eyewear was used to enable participants to see the 3D experimental environment.

Fig. 1. The hardware setup for experiments

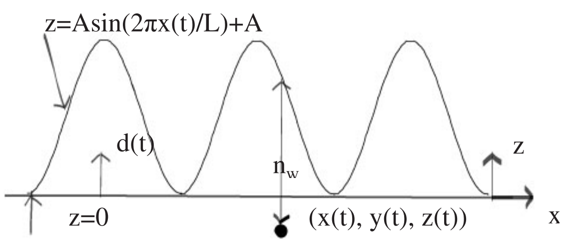


Fig. 2. An illustration of the textured surface and its associated variables

2.2 Stimuli

2.2.1 Colors

In order to investigate colors' influence on recognition memory for rough surfaces, we need to create a condition in which color information can be reduced to the minimum so that participants' performance in colored conditions can be compared with it. We use RGB values of (0.3, 0.3, 0.31) to paint all rough surfaces for this condition, considering the fact that RGB values of the default background of a scene created by Reachin API are RGB(0.3, 0.3, 0.3). The resultant visual effect is that surfaces almost integrate with the background of the experimental environment, with their profiles being marginally discernible. But the color information available is reduced to the minimum.

In addition to the (almost) gray values of RGB(0.3, 0.3,0.31) simulating Black and White (B&W) images being viewed in other studies, three types of colors are used as visual stimuli, and namely: RGB(1, 0, 0) for Red, RGB(1, 1, 0) for Yellow and RGB(0, 1, 0) for Green. The colors are fully (100%) saturated.

2.2.2 Haptic Rough (Textured) Surface

In order to create a touchable, rough surface, used is a one-dimensional sinusoidal grating superimposed on an underlying box. The sinusoidal grating is described by $z=A\sin(2\pi x(t)/L)+A$, where A and L are the amplitude and the spatial wavelength, respectively (see Figure 2).

We use the first method $F_1(t)$ in Choi' s study [12] for texture rendering. The force F(t) generated can be calculated as follows:

$$d(t) = \begin{cases} 0, & z(t)<0 \\ z(t) - A\sin(2\pi x(t)/L) - A, & z(t)\geq 0 \end{cases}$$

$$F(t) = Kd(t)n_w,$$

where K is the stiffness of the surface, n_w is the normal vector of the surface of the underlying box, (x(t), y(t), z(t)) are the coordinates of the stylus at time t, d(t) is the penetration depth of the stylus into the textured surface at time t.

For all the experiments described in this paper, amplitude A is fixed at 0.4mm. Since our PHANToM has a fairly larger value of stiffness K than that of Choi's [12], it is fixed at 450 Newton seconds/meter. To create six different levels of roughness in the query phase (described in Section 3), the six wavelengths Li (L1, L2, L3, L4, L5 and L6) used are 1.0, 2.0, 4.0, 8.0, 16.0 and 32.0mm, respectively. They are divided into two groups, and namely: L1, L2, L3 for one group, and L4, L5, L6 for the other group.

3 Experiments

In the experiments, there are two phases, and namely: presentation phase and query phase. In the presentation phase, participants are asked to explore three rough target surfaces (either L1, L2, L3 or L4, L5, L6, in randomized order) successively, with a 3-second interval between successive explorations. In the query phase immediately following it, the three rough target surfaces are randomly mixed with another three rough non-target surfaces (either L4, L5, L6 or L1, L2, L3). Participants are then asked to explore the resultant, randomly-positioned, six rough surfaces and give an answer as to whether they have explored each of them in the presentation phase, setting the push button to the right of each surface to either “Yes” or “No”.

Figure 3 shows the display layout for the presentation phase. In it there are one big box (rough surface) and seven push buttons. The surface is such that when it is explored continuously, three kinds of roughness can be felt successively, with each being presented for an exposure duration of 8 seconds, with a 3-second interval (changed from a rough surface to a smooth one) between the successive presentations. After three kinds of roughness are presented, the surface remains smooth forever, and the query phase will be entered.

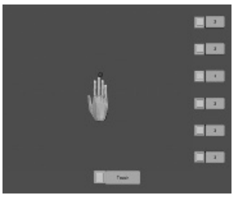


Fig. 3. Display layout for presentation phase

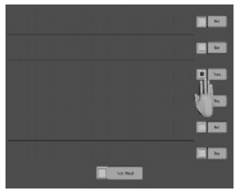


Fig. 4. Display layout for query phase

In query phase (see Figure 4 for the display layout), three target and three non-target surfaces are randomly mixed together. Participants are asked to explore each of the six surfaces and indicate whether he or she has explored it in the presentation phase by giving a “Yes” or “No” response. Twenty participants, 12 males and 8 females, aged from 18 to 38, took part in Experiments 1 and 2. All participants had normal or corrected-to-normal visual acuity and normal color vision.

3.1 Experiment 1: Exposure Duration

In Experiment 1, the rough surfaces are presented and queried in the same color condition, and namely: they are presented and queried in either (1) Gray (AA); (2) Green (GG); (3) Red (RR); or (4) Yellow (YY). Four experiments are conducted, each for one condition. Each of the three rough target surfaces (L1, L2, L3 or L4, L5, L6) is presented for either 2s, 4s, 8s, or 16s, with a 3-second interval between successive presentations. Twenty participants took part in Experiment 1, and they were randomly divided into two groups of 10 persons each to counterbalance the performance.

RESULTS: The results for Experiment 1 are shown in Figures 5 and 6.

The mean hit rate, and the mean value of the d’, averaged across 20 participants and the 4 conditions are plotted (y-axis) against exposure duration of the rough surfaces during the presentation phase (x-axis), respectively. Here, and in all the following data figures, the error bars plotted correspond to plus or minus one standard error.

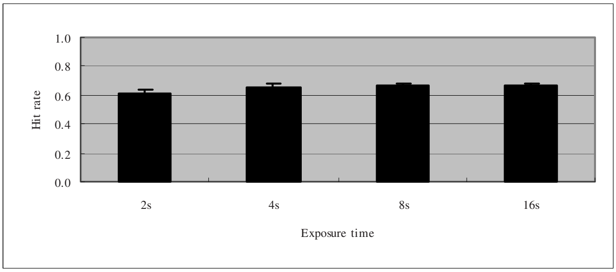


Fig. 5. Hit rate as a function of exposure duration of the surfaces in presentation phase

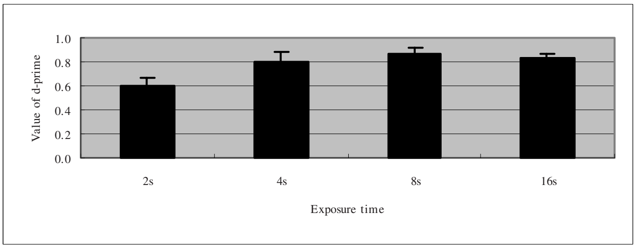


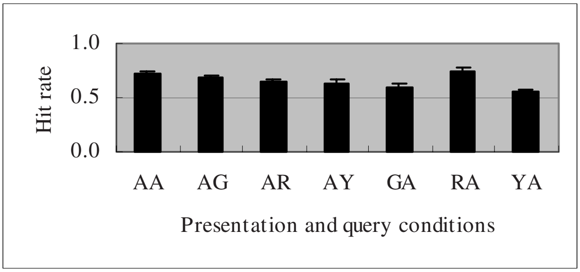
Fig. 6. Value of d' as a function of exposure duration in the presentation phase

DISCUSSION: As Figure 5 shows, the performance in terms of averaged hit rate did not change very much as the exposure duration is varied. The effect of exposure duration is typical for transfer to short-term memory: it appears to be relatively insensitive to speed of presentation [13]. Analysis of variance (ANOVA) in terms of hit rate did not show significant differences between exposure durations, between paired conditions (paired combination among AA, GG, RR and YY), or between GG, RR, YY combined and AA. In other words, the performance changes little as long as surfaces are presented and queried in the same color. Participants' performance is less confident at exposure duration of 2s than at 4s, 8s and 16s.

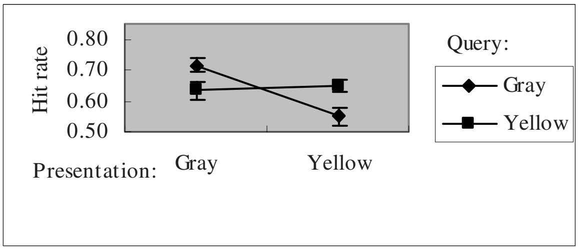
3.2 Experiment 2: Presentation and Query Conditions

The results of experiment 3 in [5] revealed that (recognition) performance for visual images worsened when they were presented in color and tested in black and white, or vice versa. Therefore, we set up the following six conditions in Experiment 2: (1) AG: rough surfaces presented in gray, but queried in Green; (2) AR: those presented in gray, but queried in Red; (3) AY: those presented in gray, but queried in Yellow; (4) GA: those presented in Green, but queried in gray; (5) RA: those presented in Red, but queried in gray; (4) YA: those presented in Yellow, but queried in gray. Exposure time for each of three rough surfaces in Experiment 2 is set as 8s. The same twenty participants took part in Experiment 2.

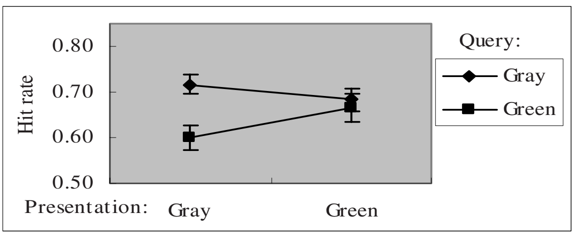
RESULTS: Analysis of data in Experiment 2 also included the data for AA condition at an exposure time of 8s in Experiment 1. Since there is no significant difference in false alarm rate between paired presentation and query conditions, only hit rate is analyzed. The results are shown in the (a), (b), (c) and (d) of Figure 7.



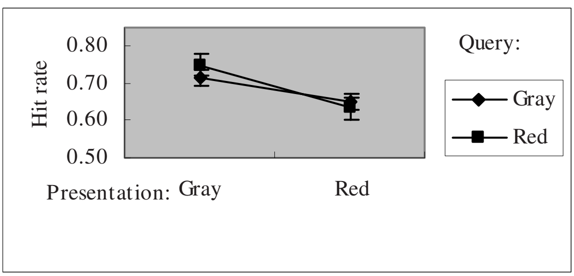
(a)



(b)



(c)



(d)

Fig. 7. Results of Experiment 2. (a) Hit rate for presentation and query conditions. (b), (c) and (d): the x-axis plots whether rough surfaces were presented in gray or colors (green, red or yellow); the y-axis plots the hit rate for surfaces queried in gray or colors (green, red or yellow).

DISCUSSION: Our experimental task involves two processes: a learning process in presentation process, and a retrieval process in the query process. We control the color available to learning and retrieval systems, because neuroimaging studies revealed a possible involvement of visual cortex in haptic processing ([14], [15]).

From Experiment 2, we found that participants' performance is worse for (1) rough surfaces presented in gray and queried in Yellow than those presented and queried in gray; and (2) those presented in Yellow and queried in gray than those presented and queried in Yellow, as shown in Figure 7(b). This finding is similar to that of the Experiment 3 in [4]. However, we found that participants' performance is slightly better for (3) rough surfaces presented in gray and queried in Red than for those presented and queried in gray, and (4) those presented in Red and queried in gray than those present and queried in Red, as shown in Figure 7(d).

The result for Green is different. When rough surfaces are presented in gray and queried in Green, or when they are presented and queried in Green, the performance is worse than when they are presented and queried in gray, than when they are presented in Green and queried in gray, respectively, as shown in Figure 7(c).

Our results are in part in line with one theory according to which the probability of recall of an item is a direct function of the similarity between the recall situation and the original learning environment [16], [17]. But the cases for RA, GR and YR color presentation and query conditions in our experiment did not result in lower hit rate.

The performance patterns are also what the encoding specificity principle predicts [18]. But colors' influence on haptic memory seems to be much more complex and versatile.

4 Conclusions

A recognition memory paradigm was used to study the influence of colors (Green, Yellow and Red) on recognition memory for haptic rough surfaces based on two experiments. Participants' performance is less confident at exposure duration of 2s than at other 3 durations. The performance shows little difference as long as rough surfaces are presented and queried in the same color.

Experiment 2 revealed that the influence of colors on haptic memory is sensitive to presentation and query conditions: RA condition results in significantly better performance than GA condition. The former could be used to improve user performance, whereas the latter should not be used in haptic interfaces whenever possible. Our results can be used as guidelines for haptic interface design for selecting colors.

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