Human Evaluation of Visual and Haptic Interaction

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Abstract. This paper describes psychophysical experiments which were conducted to evaluate the influence of haptic information on visual perception of three-dimensional (3D) interpretation of an object's shape in virtual environment. In particular, we investigated whether haptic information provided by a force-feedback device contributes to 3D interpretation of ambiguous visual patterns, which causes spontaneous alternations of bi-stable 3D percepts. The subjects' task was to report by pressing a key which 3D shape was perceived when they were touching the virtual haptic cube along a pre-defined trajectory on the cubic surface. To examine haptic influence on the bi-stable percepts, the duration of each percept was recorded. The results indicate that haptic information of the surface shape can impose a dynamic constraint on visual computation of 3D shapes. The evaluation methods and results could be used for developing human-machine interfaces that provide more natural and realistic sensation of 3D objects in the future.

Keywords: Human perception, Psychophysical experiments, Visual-haptic interaction, Virtual Environment.

1 Introduction

Vision and touch are fundamental sensory modalities for understanding three-dimensional (3D) shapes of objects. In our daily life, we often experience realistic sensation of 3D objects when we see, touch and manipulate them. To develop natural man-machine interfaces, there have been considerable efforts to develop virtual reality systems which produce pseudo-visual and pseudo-haptic sensation of 3D objects, including binocular stereo vision systems with polarized or liquid-crystal shutter glasses, and various types of force-feedback devices.

Nonetheless, it is not well known how humans perceive 3D objects through vision and touch. Does the human sensory system interpret visual and haptic information of 3D objects separately? Or, does the visual sensation enhance the haptic sensation, and vice versa? If there is an interaction between vision and touch, what are the amount and the way of interaction between them? Is there any method for objective measurement of such an interaction?

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If we can quantitatively evaluate the effect of interactions between touch and vision, the evaluated data could be used to develop better human interface systems. For instance, if visual information can enhance haptic perception of 3D shapes at certain spatial and temporal conditions, we could use the knowledge to develop a system which may reduce the complexity of haptic devices. If we find conditions where we obtain more natural sensation of 3D objects by adding haptic information to visual information, we could develop a more user-friendly interface by making use of such conditions.

The present study aims at proposing psychophysical methods to evaluate visual and haptic interactions. In particular, we investigated whether haptic information contributes to 3D interpretation of ambiguous visual patterns. The use of ambiguous visual patterns is a key idea for evaluating haptic influence on visual perception, since it seems much harder to make an empirical measurement of haptic influence on unambiguous visual patterns. The Necker cube is a well known example of ambiguous visual patterns, which causes spontaneous alternations of bi-stable 3D percepts [1]. To measure the amount of haptic influence on the perception of the Necker cube, a force-feedback device was used to generate a virtual haptic cube, which is consistent with either of the two visual interpretations. The subjects' task was to report by pressing a key which 3D shape was perceived while they were touching the virtual haptic cube along a pre-defined trajectory on the cubic surface. To examine haptic influence on the bi-stable percepts, the duration of each percept was recorded. We found that the duration of the visual percept consistent with the haptic information was much longer than that in the inconsistent case. We confirm that haptic information of the surface shape influences visual depth reversal of the Necker cube. The evaluation methods and results could be used for developing human-machine interfaces that provide more natural and realistic sensation of 3D objects in the future.

2 Psychophysical Experiments

The purpose of the psychophysical experiment was to examine whether haptic information interacts with visual information. If the haptic information does influence the visual information processing, we wished to quantitatively measure an amount of influence that the haptic information makes.

Visual and Haptic Stimuli

For visual stimulus, we used the Necker cube which causes spontaneous alternations of bi-stable 3D percepts, as shown in Fig. 1 (a).

To test haptic influence on the Necker cube perception, a force-feedback device, Phantom ™ [2] was used to generate a virtual haptic cube. The haptic cube was consistent with either of the two visual percepts, as shown in Fig. 1 (b). The main idea is that if the haptic information influences visual perception, we expect that subjects should more frequently perceive one of the two visual percepts, which is consistent with the haptic cube. To generate visual and haptic stimuli, we used Reachin API ™ software [3]. Human subjects monocularly observed the visual pattern on the CRT monitor through a half mirror, as shown in Fig. 2. Thus, the subjects felt as if they touched the visual pattern with the stylus of the force-feedback device.

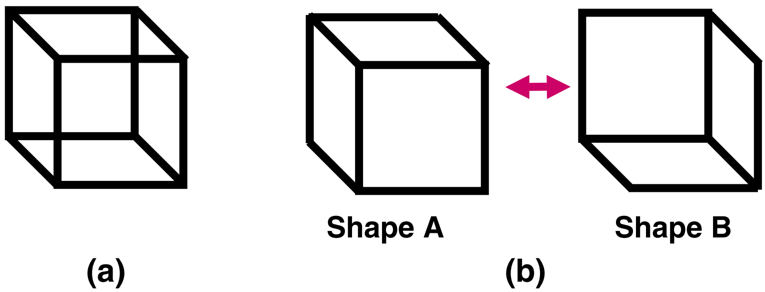

Fig. 1. (a) The Necker cube, (b) Bi-stable visual percepts; Shape A and Shape B

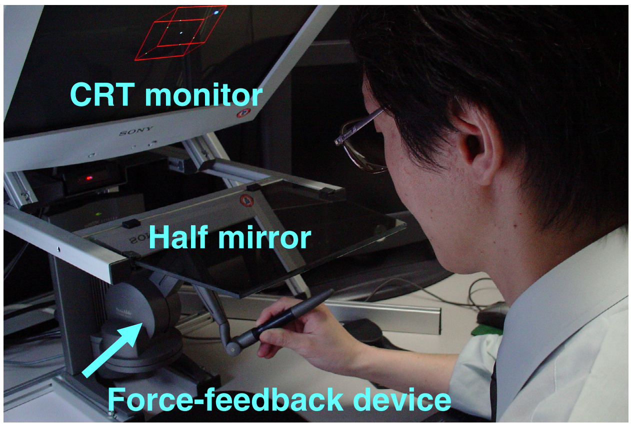

Fig. 2. Experimental apparatus: CRT monitor, a half mirror, and the force-feedback device, Phantom ™

Task

The subjects' task was to report by pressing a key which 3D shape was perceived while they were touching the virtual haptic cube along a pre-defined trajectory on the cubic surface, as shown in Fig. 3. While the subject perceived Shape A, he/she kept pressing a key for Shape A. When the percept changed to Shape B, he/she switched to press a key for Shape B. We allowed the subject to keep pressing another key, while he/she perceived an ambiguous pattern which could not be decided as Shape A or B. The subjects were instructed to use their right hand for touching the cube and to use their left hand for pressing the keys. The observation duration was 60 sec per condition. To examine the amount of haptic influence on the bi-stable visual percepts, the duration of each key press was recorded.

Human Subjects

10 Subjects participated in this experiment. All subjects have normal or corrected visual acuity. The subjects were instructed on the experimental procedures before starting the experiment. Each experiment took about one hour, including a few minutes of practice session.

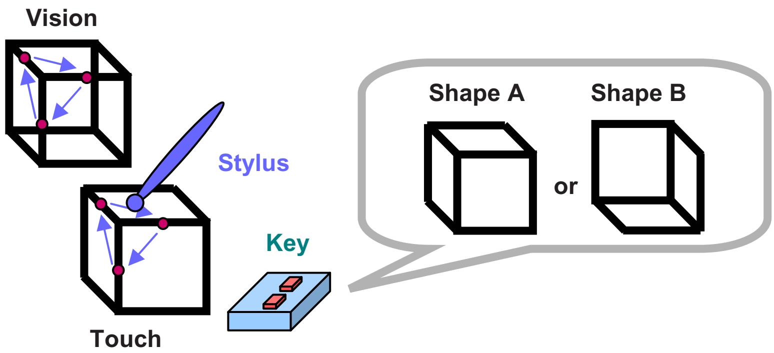

Fig. 3 The task, which required the subject to report whether he/she was perceiving Shape A or B by pressing a key while touching the virtual haptic cube

Conditions

We set following seven experimental conditions:

(1) FN (Fixation/ None) Condition

In this condition, the subjects fixated the eyes on a fixation point which was located in the middle of the Necker cube. No haptic feedback was provided to the subjects. Because this is the normal Necker cube condition, we expected spontaneous visual depth reversals during the observation of the ambiguous pattern.

(2) LA (Left/ Shape A) Condition

In this condition, the subjects touched a virtual haptic cube which was consistent with **Shape A** during the observation of the Necker cube. The subjects grabbed the stylus of the force-feedback device and moved it on the surface of the haptic cube along the pre-defined trajectory around the upper-**left** vertex inside the cube as shown in Fig. 3. A red dot was visually shown on the center of one side of the Necker cube for one second, and sequentially moved to the centers of two other sides. The subjects moved the stylus on the surface as the red dot visually moved. The tip of the stylus was visually shown with the Necker cube when the subjects performed the task.

(3) LB (Left / Shape B) Condition

In this condition, the subjects touched a virtual haptic cube which was consistent with **Shape B** and moved the stylus on the surface of the haptic cube along the pre-defined trajectory around the upper-**left** vertex inside the Necker cube. Because the location of the upper-left vertex of the Necker cube is not a vertex in Shape B, the haptic information provides the sensation of a flat surface. Subjects' task was the same as that of the LA condition.

(4) LN (Left / None) Condition

This is the control condition for the LA condition. When we pay visual attention to a vertex inside the Necker cube, it tends to be perceived in front. Because the subjects pay attention to the area around the upper-**left** vertex of the cube in the LA condition, even if they tend to perceive Shape A, the results could be attributed to the visual attention effect rather than the haptic effect. Therefore, we set the LN condition where the subjects move their eyes while observing the Necker cube as in the LA condition, but do **not** touch any haptic cube. The results of this condition thus show purely the effect of visual attention accompanied by the eye movement but not the effect of haptic information.

(5) RA (Right/ Shape A) Condition
In this condition, the subjects touched a virtual haptic cube which was consistent with **Shape A** and moved the stylus on the surface of the haptic cube along the pre-defined trajectory around the lower-**right** vertex inside the Necker cube. Because the location of the lower-right vertex of the Necker cube is not a vertex in Shape A, the haptic information provides the sensation of a flat surface.

(6) RB (Right / Shape B) Condition
In this condition, the subjects touched a virtual haptic cube which was consistent with **Shape B** and moved the stylus on the surface of the haptic cube along the pre-defined trajectory around the lower-**right** vertex inside the Necker cube. In this case, the haptic information provides the sensation of a protruded vertex.

(7) RN (Right / None) Condition
This is the control condition for the RB condition. In this condition, the subjects moved their eyes around the lower-**right** vertex of the Necker cube as in the RB condition, but did **not** touch any haptic cube. The results of this condition thus show purely the effect of visual attention accompanied by the eye movement but not the effect of haptic information, as in the LN condition.

3 Results

The main results are summarized in Fig.4. This figure shows the mean total duration of each percept (Shape A or B) for different conditions. The total duration of FN (Fixation) condition indicates that without haptic information the total duration of the visual percept A was about the same as that of the percept B. The duration of the percept A was slightly longer than that of the percept B since the viewpoint of Shape A may be more natural than that of Shape B.

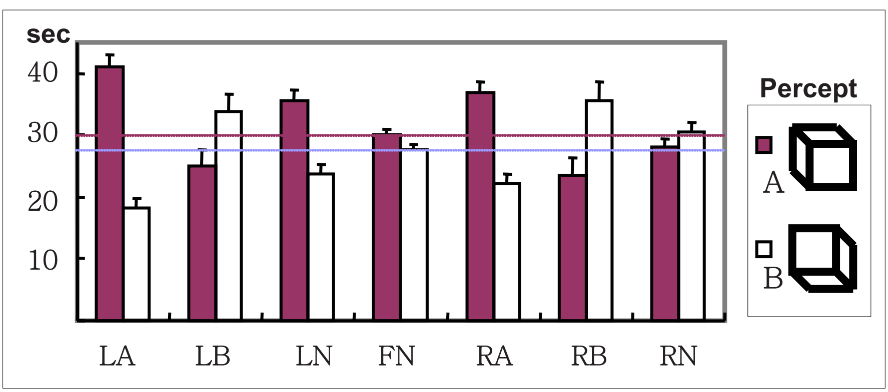

Fig. 4. The mean total duration of the percept A or B for different conditions

However, the total duration of the percept A was different from that of the percept B when the haptic information was added to the visual information. The duration of the visual percept consistent with the haptic information (i.e., the percept A in LA and RA conditions; the percept B in LB and RB conditions) was much longer than that in the inconsistent case (the percept B in LA and RA conditions; the percept A in LB and RB conditions).

The difference in perceptual duration found in LA and RB conditions may be attributed to visual attention accompanied by eye movements, since a corner of the Necker cube tends to be perceived in front when we pay attention to it. Nevertheless, the duration difference described above cannot be explained only by this visual attention effect, since the results of the control conditions (LN and RN) showed that the eye movement alone did not have as much effect. In the case of LN condition, for instance, the difference between the total duration of the percept A and that of the percept B is slightly over 10 seconds, whereas in the case of LA condition, the difference is nearly 25 seconds. Therefore, the difference between LA and LN conditions may indicate pure haptic influence on visual interpretation of the ambiguous pattern.

Furthermore, the data of LB and RA conditions also indicates that the eye movement cannot account for the duration difference, because the visual attention effect suggests that the duration of the percept A would be longer for LB condition and that the duration of the percept B would be longer for RA condition. The data shows the results contrary to the visual attention effect.

Therefore, the experimental data shown in Fig 4 suggests that the haptic information of the surface shape influences visual depth reversal of the Necker cube. The haptic influence, however, was not strong enough to totally suppress the visual percept which is inconsistent with the haptic cube.

Computational Analysis

To better understand the computational mechanisms of the visual and haptic interaction, we analyzed the distribution of the raw duration data. It is known that the duration data obtained by observing ambiguous visual figures can be well-fitted with the gamma distribution function [4]. The probability density function of the gamma function can be written as

$$P(t) = \frac{(t/\beta)^{\alpha} e^{-t/\beta}}{t\Gamma(\alpha)} \tag{1}$$

where (α,β) are the parameters that define the shape of the function, and the gamma function is given by

$$\Gamma(\alpha) = \int_0^t s^{\alpha-1} e^{-s} ds \tag{2}$$

Fig. 5 (a), (b) and (c) show the distributions of the duration data fitted by probability density function of the gamma function (1) in the case of the FN, LB, and LA conditions, respectively. In the FN condition where no haptic information was given to the subjects, the distribution function of the percept A is about the same as

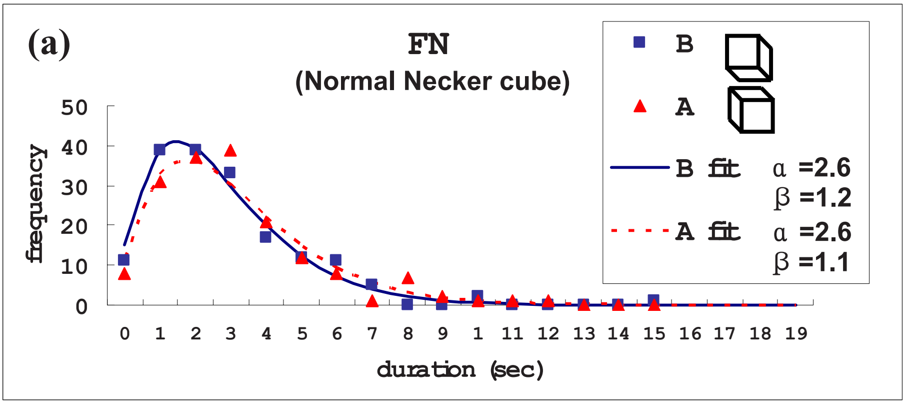

Fig. 5(a). The duration distribution of the FN condition fitted by the gamma probability function

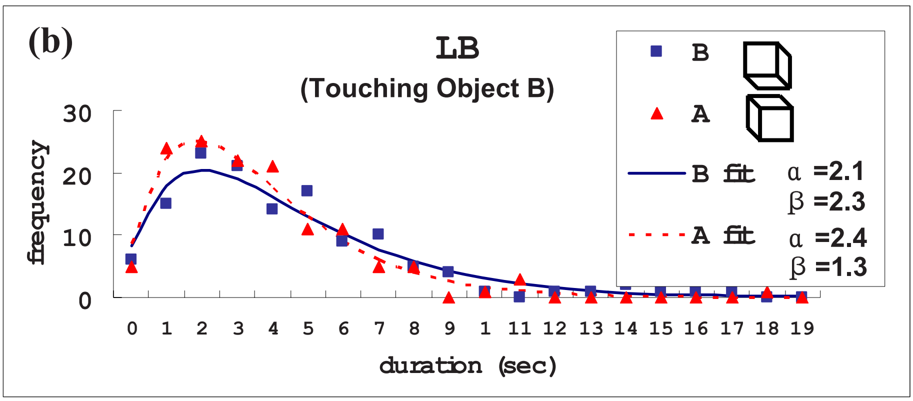

Fig. 5(b). The duration distribution of the LB condition fitted by the gamma probability function

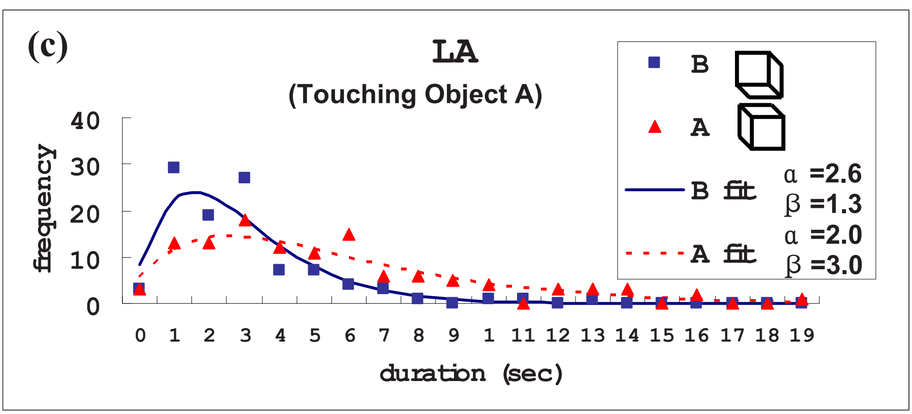

Fig. 5(c). The duration distribution of the LA condition fitted by the gamma probability function that of the percept B. On the other hand, in the case of LB and LA conditions where the subjects obtained haptic information by touching virtual cubes, the distribution functions shift in the positive direction when their visual percepts were consistent with the 3D shapes they touched. These positive shifts in the duration distributions suggest that the haptic information can influence the visual interpretation of ambiguous patterns.

We further analyzed how different conditions affect the parameters (α,β) estimated by fitting the gamma distribution function (1). Fig .6 (a) and (b) show the estimated α and β for all conditions. As shown in the graphs, the parameter β varied significantly among different conditions, whereas α did not.

If α is an integer, the gamma distribution is derived from a Poisson process, where a random event occurs α times with an interval β. Because touching virtual objects appears to affect only β, haptic information may increase the temporal interval, but not the required number of neural events which cause perceptual alternation. This result suggests that the occurrence of depth alternation is visual per se and cannot be

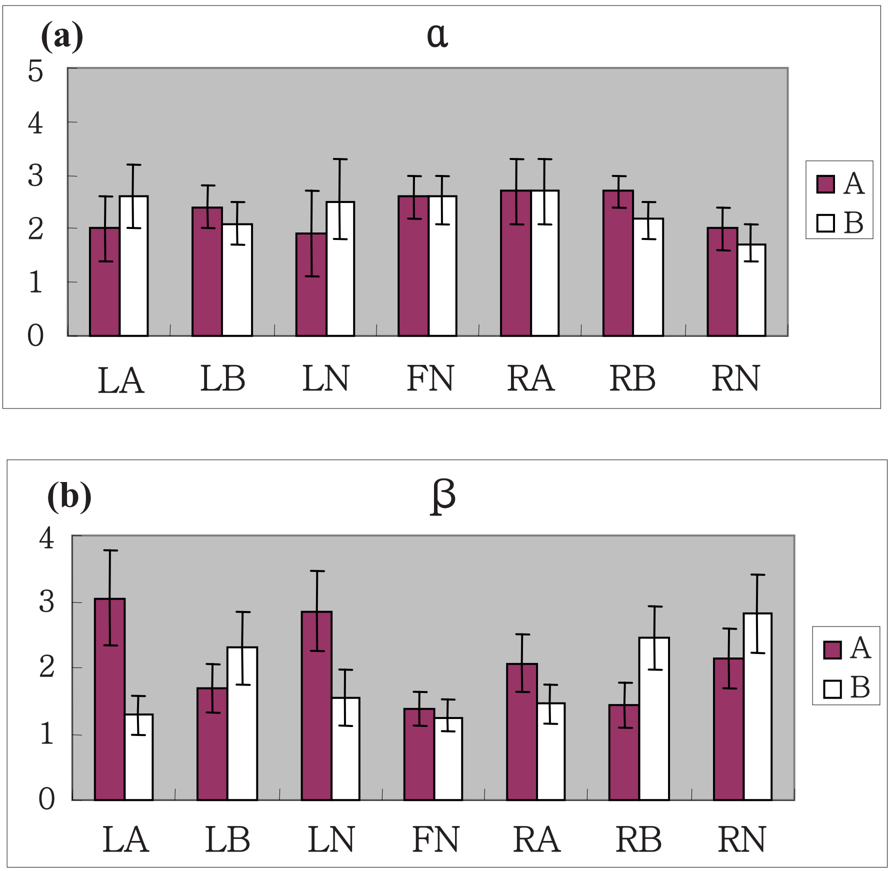

Fig. 6. The estimated parameters of the gamma probability density function for different experimental conditions: (a) the parameter α, (b) the parameter β

eliminated by the haptic information, but that the duration between the alternations could be controlled by the haptic information.

Furthermore, the graphs show that the estimated β of the LA, LB, RA, and RB conditions are all above the estimated β of the FN condition. This indicates that the interval between the perceptual alternations does not decrease even if the visual and haptic signals are inconsistent, whereas the consistency between the haptic and visual signals increases perceptual stability.

4 Discussion and Conclusions

In this paper, we evaluated visual and haptic interactions by human psychophysics using a visual display and a force-feedback device. We investigated whether haptic information contributes to 3D interpretation of an ambiguous visual pattern, the Necker cube. To measure the amount of haptic influence on the perception of the Necker cube, we generated a virtual haptic cube, which is consistent with either of the two visual interpretations. To examine haptic influence on the bi-stable percepts, the duration of each percept was recorded. We found that the duration of the visual percept consistent with the haptic information was much longer than that in the inconsistent case. This duration difference is not explained by visual attention, since the results of the control task showed that the eye movement alone did not have as much effect. We therefore confirm that haptic information of the surface shape influences visual depth reversal of the Necker cube.

Analysis of the duration data using the Gamma distribution indicates that consistency of visual and haptic signals may increase the temporal interval of neural events which cause perceptual alternation. The results suggest that haptic information can impose a dynamic constraint on visual computation of 3D shapes.

Since the psychophysical data shows empirical evidence for the interactions between touch and vision, the importance of multi-sensory integration increases when designing human-machine interfaces that provide more natural and realistic sensation of 3D objects. Furthermore, the evaluation methods proposed in this paper could be used for finding system requirements for developing effective human-machine interfaces. Because the duration of one of the bi-stable visual percepts which is consistent with haptic information provides a quantitative measure for the strength of visual and haptic interaction, we could use this measure to find optimal spatio-temporal conditions for integrating visual and haptic information. In our future work, we are planning to investigate such conditions for more effective and user-friendly multi-sensory interfaces based on the evaluation methods proposed in this paper.

References

1. Necker, L.A.: Observations on some remarkable phenomena seen in Switzerland; and an optical phenomenon which occurs on viewing of a crystal or geometric solid. Philosophy Magazine. 3, 329–337 (1932)
2. http://www.sensable.com/
3. http://www.reachin.se/
4. Borsellino, A., et al.: Reversal Time distribution in the perception of visual ambiguous stimuli. Kybernetik 10(3), 139–144 (1972)