Abstract—This study verified that the transition of the interval in perceptional alternation has a chaotic rhythm, but only in some cases. A wave was constructed by plotting observational data with spline interpolation and examined by nonlinear analysis. An attractor was modeled by constructing the wave, and the Lyapunov exponent and fractal dimension were calculated. These were analyzed using the random-shuffle method, a surrogate data method. The examination confirmed that some data have a chaotic rhythm, while others do not. Therefore, it cannot be stated unequivocally whether the transition of the interval in perceptional alternation has a chaotic rhythm. However, a new mechanism in perceptional alternation may be found by referring to the difference between chaotic and random data.

I. INTRODUCTION

This thesis sought to demonstrate that the transition of the interval in perceptional alternation has a chaotic rhythm. Chaotic phenomena seem to change at random, but actually obey a deterministic rule. Examples include the change in the weather, the flow of smoke, and the movement of a leaf. In addition to natural phenomena, chaotic rhythms can be found in humans, such as brain waves.

The examination of visual consciousness is one way to study chaos in humans. Although something is actually in sight, one cannot perceive the whole. One perceives some parts, but not others. In order to study “consciousness,” which is not observable, it is efficient to study the difference between what one can and cannot perceive.

Perceptual alternation in ambiguous figure perception and binocular rivalry does not occur at a constant interval, but at variable intervals. This study examined whether the transition in the interval obeys a rule involving a chaotic rhythm, or at random. If a chaotic rhythm were observed, one could conclude that perceptional alternation happens not at random, but via a deterministic rule.

Many studies have examined the transition of the interval in perceptional alternation [1–3], resulting in conflicting conclusions. However, the amount of raw data on the interval was so small that the phenomenon has not been examined using nonlinear analysis. To overcome this fault, spline interpolation was applied and a wave was modeled that consisted of sufficient plots so that it could be examined via nonlinear analysis.

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II. PROCEDURE

A Necker cube was used as the stimulus and presented continuously for 900 s in the first experiment and for 3600 s in the second experiment. The subjects pushed a button only when the perception of the Necker cube switched (Fig. 1). Different subjects participated in the two experiments.

Fig. 1. Necker cube (above) and an illustration of perceptional alternation (below).

The times were plotted at 0.2-s intervals using the spline interpolation method and a model of the wave. Figure 1 presents the Necker cube and Fig. 2 shows how a wave is constructed using the spline interpolation method.
Using interpolation, the wave consisted of almost 4500 points in the first experiment and almost 18,000 points in the second. They were analyzed by computing the self-correlative describing attractor using Takens’ embedding theorem [4] (Fig. 3) and verified to show a chaotic rhythm. An example of an attractor is shown in Fig. 4.

The Lyapunov exponent was calculated using the Sano–Sawada method [5] and the fractal dimension using the Grassberger–Procaccia method [6]. The fractal dimension indicates the degree of nonlinearity. The data were examined using the random-shuffle method, a surrogate data method [7]. In brief, 40 waves were modeled by shuffling the plots of raw data and testing the plots using the spline interpolation method, as with the observed data. Then, the differences in the Lyapunov exponents were examined and fractal dimensions between the waves were made from the observed data and the surrogate data.

In order to judge that data has a chaotic rhythm, it is necessary two conditions that the fractal dimension of the attractor is not integer and the largest Lyapunov exponent is positive. However, only in two conditions, it isn’t enough to judge data to be a chaos. In case of the random data, too, two conditions sometimes apply. Therefore, we should use surrogate data method to decide that the data has a chaotic rhythm.

### III. RESULTS

#### A. Raw data

The two experiments differed markedly in the number of alternations and standard deviations, and the maximum and minimum numbers of perceptional alternation, as shown in Table 1. This results indicate that the number of perceptional alternation are much different each subject.

<table>
<thead>
<tr>
<th></th>
<th>First experiment</th>
<th>Second experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>average</td>
<td>212.5</td>
<td>1228.5</td>
</tr>
<tr>
<td>SD</td>
<td>106.72</td>
<td>842.43</td>
</tr>
<tr>
<td>Maximum</td>
<td>411</td>
<td>2110</td>
</tr>
<tr>
<td>Minimum</td>
<td>59</td>
<td>436</td>
</tr>
</tbody>
</table>

#### B. Fractal dimension

The fractal dimensions calculated from these two experiments are not integers. Many of the fractal dimensions of the surrogate data were not saturated and the asymptote of the correlation dimension could not be obtained, as shown in Fig. 5. By comparison, one can easily obtain the asymptote of the correlation dimension for the observed data.

After examining the data using the random-shuffle method, in the first experiment, the waves in 3 of the 16 subjects had chaotic rhythms, while in the second experiment, the waves in 3 of the 4 subjects had chaotic rhythms, as shown in Fig. 6.
Fig. 5. Correlation and embedding dimension. This shows the most correct embedding dimension obtained with saturation, which is the fractal dimension. The figure for the surrogate data (above) is not saturated, while that for the observed data is saturated.

Fig. 6. Fractal dimensions in the first (above) and second (below) experiments. “×” indicates the results for the observed data and “・” denotes those for the 40 surrogate datasets.

C. Lyapunov exponents

The number of Lyapunov exponents varies with data because the dimensions of attractor are not same. Therefore, we gave the official approval to the largest Lyapunov exponent.

The largest Lyapunov exponents of all the data were positive. After examining the data using the random-shuffle method, in the first experiment, the waves in 6 of the 16 subjects had chaotic rhythms, while in the second experiment, the waves in 2 of the 4 subjects had chaotic rhythms, as shown in Fig. 7.
Fig. 7. The largest Lyapunov exponents in the first (above) and second (below) experiments. “×” indicates the results for the observed data and “・” denotes those for the 40 surrogate datasets.

D. Summary of the results

Overall, the data proved to have chaotic rhythms in 2 of the 16 subjects in the first experiment and in 2 of the 4 subjects in the second experiment.

IV. CONSIDERATION

The difference in the proportion of subjects with chaotic rhythms in the two experiments likely resulted from the difference in the amounts of observed data. Since the second experiment was four times longer than the first, much more observations were made in the second experiment. This may have caused the interpolated data to maintain the correct rhythm of the observed data more correctly. In addition, the stable Lyapunov exponents and fractal dimensions from more raw data could not be calculated in order to obtain more reliable results. In particular, the Lyapunov exponents differed markedly between the first and second experiments, as shown in Fig. 8.

Fig. 8. The Lyapunov exponent in the second experiment is constant (top), while it is not in the first experiment (bottom).

Therefore, the results from the second experiment are believed to be more valid than those from the first, and the longer the observations were, the more the subject data were judged to have chaotic rhythms.

V. CONCLUSION

That perceptional alternation in the Necker cube has a chaotic rhythm cannot be definitely concluded, but three possibilities can be suggested. First, although perceptional alternation may essentially happen at random, errors that have a chaotic rhythm occur. Alternatively, while perceptional alternation may essentially have a chaotic rhythm, errors happen at random. Finally, whether perceptional alternation has a chaotic rhythm depends on the performance of each subject. The final suggestion is that various factors influence perceptional alternation to different degrees (fatigue, sleepiness, and weariness). Therefore, some data have chaotic rhythms, and others do not.

No definite conclusion as to which alternative holds can be drawn from the results of the present experiments. However, by determining the differences between data that have a chaotic rhythm and those that do not, a new mechanism in perceptional alternation may be developed.

REFERENCES
