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WHAT DETERMINES TACTILE ILLUSION OF A ROTATED DISK

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Eighteen undergraduates experienced Cormack's tactile illusion of a rotated disk. The subjects were tested on the magnitude of this illusion every 5 seconds while continuing to rotate a disk using the forefinger and thumb of both hands. The subjects were given 60 seconds for adaptation prior to the test under each of the following conditions: adapting both hands (BH), adapting the holding hand (HH), or adapting the rotating hand (RH). A control (C) with no adaptation was also prepared. The effect of adaptation decreased in strength in the order: BH, HH, RH, and C. The difference was significant between each pair of the four conditions. The results indicate that the illusion is produced mainly by holding hand adaptation but that rotating hand adaptation also contributes.

Key words: tactile perception, Cormack's illusion, duration, adaptation

When holding a disk between the forefinger and thumb of the left hand and rotating it using those of the right hand, we feel the shape of the disk elongate in the direction of the rotating hand and then change into a flat ellipse. Cormack (1972) introduced this illusion and performed a few experiments on it. He found that the illusion magnitude increases sharply for the first 30 seconds and then more gradually throughout the 60-second duration. The illusion disappears when we look at the disk or stop rotating it. The illusion increases with the size of the disk and the rotating speed, and decreases with the thickness of the disk. It was also found that the pausing during rotation decreases the illusion, while the effect of the pause depends on the duration of rotation (Cormack, 1972; Watanabe, 1980, 1995).

Cormack tried to explain the illusion in terms of the adaptation of the fingers, since the temporal growth curve of the illusion was similar to those of visual aftereffect and kinesthetic aftereffect (Hammer, 1949; Singer & Day, 1965). Cormack proposed two hypotheses to explain the illusion. One hypothesis ascribes the illusion to the adaptation of the holding hand. Here it is thought that rotating the disk allows the fingers of the holding hand adaptation as they twist the edge of the disk, resulting in a reduction of the vertical axis of the disk. Concomitantly, rotation allows limited adaptation in the fingers of the rotating hand. Thus the fingers of the rotating hand are affected little by adaptation. The difference in adaptations between the hands produces the illusion.

The other hypothesis ascribes the illusion to the adaptation of the rotating hand. Here it is thought that rotating the disk allows the fingers of the rotating hand to adapt

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to the average of the thickness and the diameter of the disk, while the holding hand adapts constantly to the diameter of the disk between the fingers. Thus it is thought that the difference in adaptation between the two hands produces the illusion.

Cormack tried to single out one of the two above-noted hypotheses as the most plausible explanation of the illusion. However, he was unable to do so. Watanabe (1980) measured illusion magnitudes using stimuli controlled for the adaptative abilities of the holding hand and the rotating hand. Based on the results, he concluded that the illusion should be ascribed mainly to adaptation of the holding hand rather than that of the rotating hand. He however paid little attention to the role played by the rotating hand.

Can holding hand adaptation be the sole source of the illusion? If rotating hand adaptation is a partial source of the illusion, how exactly does the hand produce the illusion? The purpose of this study is thus to reexamine the determinants of Cormack's illusion using a method of allowing adaptation to occur prior to the test. Using this method, we tested subjects as to illusion magnitude when prior adaptation was allowed in both hands (BH), the holding hand (HH), the rotating hand (RH), and when not allowed, namely, the control (C).

The rationale for this experimental paradigm is as follows. If the illusion should be ascribed solely to holding hand adaptation, the illusion magnitude for HH will be the largest of all the conditions and equal to that for BH. If the illusion should be ascribed solely to rotating hand adaptation, the magnitude for RH will be the largest of all the conditions and equal to that for BH. Thirdly, if the illusion should be ascribed to the adaptation of both hands, the magnitude for BH will be the largest and that for C the smallest of all the conditions. In addition, following this paradigm, the magnitude for HH and RH should be somewhere between those for BH and C, depending on the contribution of the holding hand and the rotating hand to the illusion.

Method

Subjects:

The subjects were 18 male undergraduates from Kinki University in Kyushu. Two of them were unfamiliar with the experiment, and the rest had experienced a similar experiment before.

Apparatus and stimuli:

A tape recorder was used to provide a timing cue to the subjects for each trial. A click sound was recorded on the tape every second against a continuous sinusoidal tone of 295.4 Hz in frequency for a 60-second adaptation. Following a 2-second silent period after the adaptation, a starting signal was given followed by a click recorded every 5 seconds for the 60-second test period.

A brass disk was used as the stimulus. It was 30 mm in diameter and 2 mm in thickness. A comparison stimulus was prepared to give the subjects a standard for estimating the illusion magnitude that they felt between their fingers. The comparison stimulus consisted of a circle 30 mm in diameter and twelve ellipses varying in horizontal axis by 3 mm increments from 33 mm to 66 mm with the vertical axis constantly 30 mm. The ellipses were made from two half circles and had a rectangle connecting them. The circle and ellipses were arranged in order of horizontal axis lengths on a white cardboard 38 cm in width and 26 cm in height and then numbered from 1 (circle) to 13 (the ellipse with the largest horizontal axis).

Procedure:

The subjects sat at a table with their hands placed upon it. They also sat across from an experimenter. The table was illuminated in a dark room. The comparison stimulus was placed at a 60-degree angle from the table so that the subjects could see the stimulus perpendicularly. With their eyes closed, they rotated a disk using the forefinger and thumb of the right hand while holding the disk between those of the left hand. After a 30-second period, the subjects were asked what they felt between their fingers. If they did not notice Cormack's tactile illusion, they were informed of the illusion and then required to rotate the disk for another 30-second period and were required to rotate the disk at the same speed as during the previous 30-second period.

The subjects were given four trials, one for each of the four conditions of adaptation: BH, HH, RH, and C. In the BH condition, the subjects rotated a disk using both hands during a 60-second adaptation. In the HH condition, they only held a disk using their left hand while an experimenter rotated it during the adaptation. For the RH condition, a specifically prepared disk, which was fixed on a rotation axis, was used. In this case, the subjects only rotated the disk using their right hand during the adaptation. In the C condition, they were tested without any adaptation.

During the adaptation, the subjects only rotated and/or held a disk. Using the previously recorded tape for timing, they were required to give the disk a half turn every click. In this way, the rotating speed was controlled at 30 rpm during the adaptation. During the test, they reported the number of the figure which best matched the shape that they felt between their fingers, while continuing to rotate the disk. They were prevented from looking at the disk in their hands during the test. Since smoothness of transfer from adaptation to test tends to depend on the condition of adaptation, two seconds were inserted between the adaptation and the test so that the transition would be equally smooth in all the conditions.

The subjects were given enough time to practice rotating a disk for each condition of adaptation before starting the experiment. A 3-minute rest was given between the trials, and the order of the four conditions was counterbalanced across the subjects.

Results

We calculated the magnitude of the illusion in a percentage ratio by multiplying by 10 the number obtained after subtracting 1 from the number that the subjects reported from the comparison stimulus. Fig. 1 shows the magnitudes averaged for 18 subjects for each condition of adaptation. As seen in the figure, the magnitude is the largest for BH, and decreases in the order of HH, RH and C throughout the durations. The differences among the four conditions decrease gradually from 5- through 60-second durations.

The magnitude data were examined using a two-way analysis of variance. The main effects of adaptation and duration were significant ($F(3, 51)=109.59$, $p<.01$; $F(11, 187)=225.09$, $p<.01$, respectively). The interaction effect between adaptation and duration was significant ($F(33, 561)=2.99$, $p<.01$). Since the relation of the magnitude among the conditions of adaptation changes little depending on the duration, the lower test was performed only at the 5-second and 60-second duration. The data from the 5-second duration were examined using a one-way analysis of variance for adaptation. The main effect of adaptation was significant ($F(3, 51)=82.10$, $p<.01$). The subordinate test showed that the illusion for BH was significantly larger than for HH ($t(17)=4.09$, $p<.01$), that for HH larger than for RH ($t(17)=6.43$, $p<.01$), and that for RH larger than for C ($t(17)=3.80$, $p<.01$). The data from the 60-second duration were examined using a one-way analysis of variance for adaptation. The main effect of adaptation was significant ($F(3, 51)=21.89$,

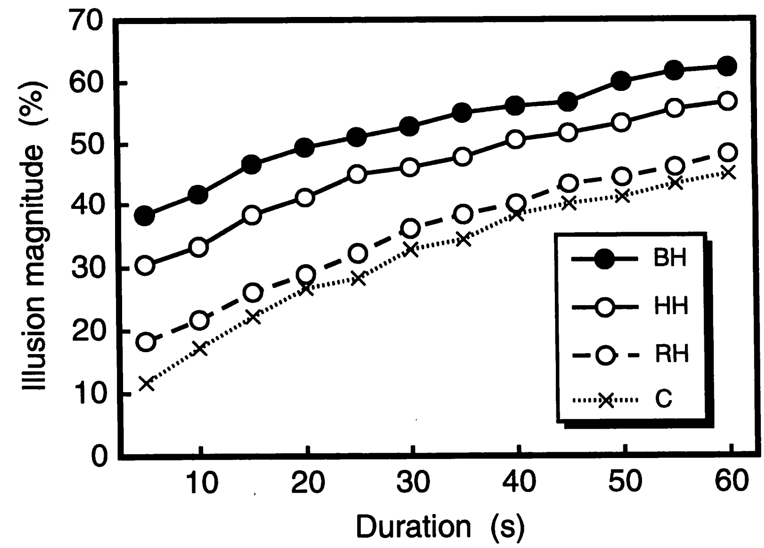

Fig. 1. The illusion magnitude as a function of rotating duration when prior adaptation was allowed in both hands (BH), the holding hand (HH), the rotating hand (RH), and when not allowed, namely, the control (C).

$p<.01$). The subordinate test showed that the illusion for BH was significantly larger than for HH ($t(17)=2.51$, $p<.05$), that for HH larger than for RH ($t(17)=3.42$, $p<.01$). There was no significant difference between RH and C ($t(17)=1.37$, *NS*).

The data from each condition of adaptation were also examined using a one-way analysis of variance for duration. The main effect of duration was significant for all conditions: BH, HH, RH, and C ($F(11, 187)=62.13$, $p<.01$; $F(11, 187)=76.63$, $p<.01$; $F(11, 187)=86.10$, $p<.01$; $F(11, 187)=111.86$, $p<.01$, respectively). We then calculated the difference by subtracting the magnitude of the 5-second duration from that of the 60-second duration. The data of the difference averaged for 18 subjects were 2.44, 2.61, 3.0, and 3.39, respectively, for BH, HH, RH, and C. The data were then examined using a one-way analysis of variance, which showed that the main effect of adaptation was significant ($F(3, 51)=10.28$, $p<.01$). The least significant difference test showed that the magnitude of RH was significantly larger than that of BB and HH, and that of C larger than that of RH ($LSD=0.50$, $p<.01$). No difference was found between BB and HH ($LSD=0.31$, *NS*).

Discussion

This study was intended to definitively determine the cause of Cormack's tactile illusion. Cormack (1972) propounded two hypotheses to explain the illusion. One hypothesis ascribes the illusion to the adaptation of the fingers holding a disk, while the other to that of the fingers rotating the disk. In short, Cormack's hypotheses ascribes the illusion to either the adaptation of the hand holding the disk or to that of the hand rotating it.

Watanabe (1980) concluded that the illusion can be explained from the effect of the holding hand on the basis of results from an experiment which used stimuli varying in function for the holding and rotating hands. In order to explain how both hands produce the illusion in more detail, the present study directly controlled the adaptation given to either hand prior to the test. If adaptation determines the illusion, the illusion magnitude should change, depending on which hand is allowed to adapt prior to the test.

We measured the illusion magnitude in four conditions: BH, HH, RH, and C. We obtained the largest illusion magnitude when a 60-second adaptation was provided to the both hands (BH). The following are the results we obtained at the 5-second duration. The magnitude obtained when allowing only the holding hand to adapt (HH) was smaller than that in the BH condition. The magnitude obtained when allowing only the rotating hand to adapt (RH) was smaller than that in the HH condition. The magnitude obtained when neither hands was allowed to adapt (C) was smaller than that in the RH condition. The results indicate that the holding hand contributes to the illusion more than the rotating hand because the magnitude was larger for HH than for RH. The rotating hand also contributes to the illusion because the magnitude was larger for RH than for C. This notion acquires further support from the result indicating that the magnitude was larger for BH than for HH.

These obtained results provide a new explanation of the mechanism of the illusion. The adaptation of the holding hand plays an important role in producing the illusion, but cannot be the sole source of the total illusory effect. The adaptation of the rotating hand also plays a role in producing the illusion. In other words, both hands contribute to give the imaginary shape to the disk felt between the fingers, though the main effect is produced in the fingers of the holding hand. We obtained other evidence to support the idea. The difference between the illusion magnitudes of RH and C is clear, especially early in the test. This means that touching the disk with the rotating hand during adaptation, in collaboration with touching the disk with the holding hand as soon as the subject begins to rotate the disk, is what produces the imaginary shape, and thus, both hands contribute to the production of the illusion.

We also found that the differences in the magnitudes among the conditions were remarkable for short durations, but decreased gradually as the 60-second duration was reached. This can be explained by the fact that the illusion magnitude increases sharply for the first 30 seconds and then more gradually thereafter. When the test starts, adaptation has been taking place for 60 seconds in the fingers for BH. Therefore, the magnitude increase in BH is more gradual than in any other condition. Concomitantly, the magnitude increase for C is the most sharp because adaptation begins simultaneously with the test's starting point. This idea is supported by difference in magnitudes for the 5-second and 60-second durations. The difference was the smallest for BH and HH and the largest for C of all conditions. After all, the temporal growth curve is similar to that of visual aftereffect and kinesthetic aftereffect (Hammer, 1949; Singer & Day, 1965). This result, therefore, also supports the notion that the illusion is actually produced by the tactile adaptation. However, it is possible to explain in even greater detail how adaptation affects this illusion, and for this further experimental study is needed.

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