The 'Chopstick' Illusion: A Simply Demonstrated Tactile Illusion

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Abstract

This paper introduces and analyzes a simply demonstrated tactile illusion. The tactile illusion described here is named the "chopstick" illusion since it can be easily demonstrated using a pair of wooden chopsticks. This illusion is demonstrated by moving one's fingers up a broken-off wooden chopstick with the fingertips of the thumb and index finger. As two chopsticks are separated, an angled edge is often created at the chopstick head as one tears away a piece of the other. This edge has a gradual constant increase in the surface dimension. A tactile illusion is experienced by moving the midpoints of the fingertips of the thumb and index finger along the flat portion of the chopstick. The observer of the illusion feels as if the thickness of the material at the edge of the chopstick increases in the form of a bump, but in reality does not and the stick is only getting wider. To investigate this illusion, two experiments were conducted: One with commercially available broken-off wooden chopsticks and one with fabricated plastic chopsticks. The first experiment showed that the chopstick illusion was perceived 72% of the time, while the second experiment showed a 63% perception rate. It was also found that the chopstick groove, which initially separates the two chopsticks played a key role in perceiving this tactile illusion.

Index Terms: Haptic Illusion, Tactile Illusion, Haptic Perception, Tactile Perception, Chopsticks

1 Introduction

In our exploration of the physical world, tactile illusions arise in everyday life, usually undetected. The concept of tactile illusions has been known for a long time [11] and can sometimes be demonstrated with simple things found in our everyday lives [4]. The notion of a tactile illusion can be both interesting and useful in rendering haptic environments.

The aim of this paper is to present a newly found tactile illusion: the "chopstick" illusion. The chopstick illusion can be easily demonstrated at an extremely low cost and convenience using conventional wooden chopsticks that are joined together at one end (as frequently found in many restaurants). When the chopsticks are torn apart, one chopstick will often tear a part of the other chopstick, creating a slight and constant increase in width, as shown in Figure 1.

The chopstick illusion is felt by sliding the tip of the thumb over the center of the chopstick while simultaneously supporting the surface from the other side with the middle part of the index fingertip. As depicted in Figure 2, moving the fingers along the broken-off chopstick ($+X$ direction) with the increasing width (Y direction) will result in a perception that thickness (Z direction) of the chopstick is changing, which is felt as a bump. Looking away from the chopstick and increasing the speed of the movement can also enhance the perception of this tactile illusion. We will refer to the total chopstick width at the top of the chopstick (ΔY) as *width*, the distance from the top chopstick tip to the beginning of the angled edge (torn edge; ΔX) as *height*, and the angle that width and height make, as *angle*.

The sliding motion over this change in width creates a tactile sensation of increasing thickness (ΔZ) of the surface slanted in the Y direction, while in actuality that angled surface is a constant thickness throughout the whole length of the chopstick (Figure 2). It is stressed that the absence of vision and a faster fingertip motion accentuate the effectiveness of the illusion. To maximize the effectiveness, it is also important that the motion along the chopstick is applied with the correct technique, which is discussed further in Section 3.

Figure 1: Example of the wooden chopsticks used to generate the tactile illusion. When separated, one chopstick often tears a piece of the other chopstick, creating an angled edge.

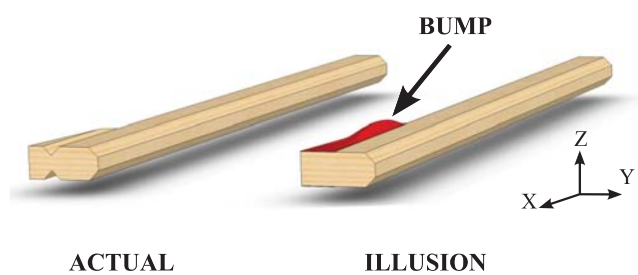

Figure 2: Chopstick tactile illusion. A person running their thumb and index finger along a broken-off chopstick ($+X$ direction) with increasing width (ΔY) will perceive a sense of increasing thickness (ΔZ), or a bump, on the chopstick.

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2 Background

The concept of tactile illusions can be traced back as far as the ancient Greek empire, where Aristotle demonstrated the so-called "reverse Aristotle tactile illusion" [11]. In this tactile illusion, Aristotle demonstrated that when an individual crosses their index and middle finger while touching two objects at the same time, the individual perceives as if they are touching only one object with their index and middle finger. Although the concept of tactile illusions is well known, the fundamental and neurological cause of many are still unidentified.

To describe and better understand tactile illusions, it is useful to compare them to optical illusions. In an optical illusion, the image perceived by the brain through eyesight differs from what the image actually and physically is. Figure 3 demonstrates a simple optical illusion (Hermann grid illusion), in which gray dots randomly appear at the intersections of the white lines. Although physically there are no gray dots at the intersections, the brain is tricked into seeing them.

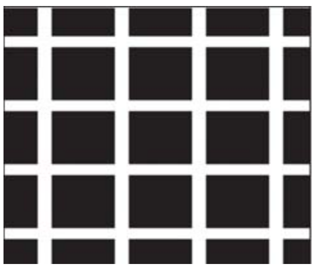

Figure 3: Hermann Grid Optical Illusion. The eye sees gray dots on the white intersection although there are none.

Tactile illusions work similarly with the sense of touch, however, they are much harder to find and communicate [4]. Compared to tactile illusions, many optical illusions are easy to demonstrate and access with the help of images in books or images on internet websites. Making an easily portable and demonstrable tactile illusion is, thus, more special in the sense that many individuals cannot otherwise perceive them [4]. Some literature has also shown how similar optical and tactile illusions can be psychophysically related [1].

Since, in essence, optical illusions are the basis for all visual technology seen in screen displays [3] and magnification/mirror technology [2], tactile illusions can play a great role in haptic interfaces. By manipulating the sensation of touch, it can be possible to alter the haptic interface display or simplify haptic designs [9, 6, 10].

Hayward [4] summarizes a series of simply demonstrated tactile illusions and discusses several of their aspects. According to the classification in the Hayward paper, the tactile chopstick illusion presented in this paper is best described in the category of shape from distributed cutaneous deformation of the skin and is related to the perception of the world outside the body. Similar tactile illusions in the same category include the "comb" tactile illusion [5] and some Braille display systems [6, 10].

Similar in the sense of the misconception of world outside the body is the interesting "fishbone" illusion [7]. The fishbone illusion is experienced when an individual rubs their fingertips across a surface with alternating strips of smooth and textured surface. This contrast in surface texture is perceived as bumps at the rougher parts of the surface. Nakatani et al. hypothesizes two causes for the perception of the the fishbone illusion: Mechanical skin deformation (surface skin and inner tissue deformation) and tactile signal processing (neural encoding and signal processing). It is also postulated the the strained skin mimics that of depressed skin, creating similar neural signals to the brain [8, 4, 6]. Similar mechanisms are likely responsible for the chopstick illusion presented here.

3 Illusion Description

The wooden chopsticks that are considered for this tactile illusion have a flat surface on the top and bottom and are joined together at the base of the chopstick pair (Figure 1). At its thickest point, the chopstick set used for the chopstick illusion has a cross section thickness (Z) and width (Y) of approximately 4.00mm and 12.40mm, respectively. The chopstick illusion only consists of the broken-off chopstick that, when torn from its counterpart, obtains more width (Y) in the form of an angled edge. An illustration of this broken-off chopstick is shown in Figure 5.

In order to perceive this tactile illusion, it is important to correctly understand and execute the following steps. Note that as tactile illusions are not absolute perceptions, it is helpful to vary speed and handling parameters during the execution of these steps in order to increase the likelihood of perceiving the illusion.

The perceiver should hold the end of the chopstick furthest from the broken off edge in the non-dominant hand and let the angled edge point away from the dominant hand as shown in Figure 4. Next, using the dominant hand, form an "O" with the thumb and index finger while slightly holding the chopstick between the two fingers. Note that the chopstick should be held without much effort. A good reference on how hard the chopstick should be held is the whitening of the top of the fingernail; if there is any whitening, too much force is used holding the chopstick.

To feel the illusion, align the thumb and index fingertips to the center of the chopstick in a fashion shown in Figure 4, and move the fingers from the middle of the chopstick to the top ($+X$) without running off the top edge, slightly touching the angled edge that is protruding out. While moving, the fingertips should always follow the chopstick center. This movement direction can also be seen in Figure 4. While moving the fingers *up* the chopstick, an illusion of increasing thickness (ΔZ), or a bump at the beginning of the angled edge, is experienced as shown in Figure 2. It has been reported that a moderate movement speed along the chopstick produces an increased illusion sensation.

Figure 4: Effective right hand grip and movement direction.

4 Fabrication and Material

Two experiments were carried out to investigate the depths of the chopstick tactile illusion. The first experiment used actual broken-off wooden chopsticks, while the second experiment used laser-cut fabricated acrylic chopsticks.

4.1 First Experiment Chopsticks

As explained in Section 3, the wooden chopsticks used had a constant thickness (Z) of 4.00mm and were flat on top and bottom. With the exception of the base chopstick, which had no protruded angled edge, the remaining ten chopsticks were broken-off with different width (Y) dimensions.

The base chopstick that had no change in width was expected to have no illusion effect and was included as a control. This base stick was 6.35mm in width throughout the whole stick length. As shown in Table 1, the ten angled chopsticks had various changes in total width at the tip of the chopstick, ranging from 7.62mm to 10.72mm at an average of 0.36mm between steps. Considering that the JND (Just Noticeable Difference) for a fingertip is 0.254mm [12], this segmentation in total width is appropriate for this experiment.

Table 1: Experiment 1: wooden broken-off chopstick dimensions

Stick Number	Height (X-Dir) (mm)	Width (Y-Dir) (mm)	Angle (Deg.)
1	25.40	10.72	22.9
2	25.40	10.16	21.8
3	25.40	9.40	20.3
4	25.40	9.14	19.8
5	25.40	8.89	19.3
6	25.40	8.64	18.8
7	25.40	8.38	18.3
8	25.40	8.15	17.8
9	25.40	8.08	17.6
10	25.40	7.62	16.7
Base	N/A	6.35	N/A

The chopstick widths could not be precisely made at regular width intervals due to the wooden chopsticks breaking off randomly at various widths. The widths could also not be adjusted (sanded, cut, etc.) to a certain size or smoothness because doing so would blunt the edges and possibly thwart the tactile illusion. Since an aspect of this study was to research an easily demonstrated and inexpensive tactile illusion, all characteristics of a freshly separated chopstick had to be preserved. Also, due to the nature of how they were joined before breaking, the protruded edges always started 25.40mm from the chopstick top.

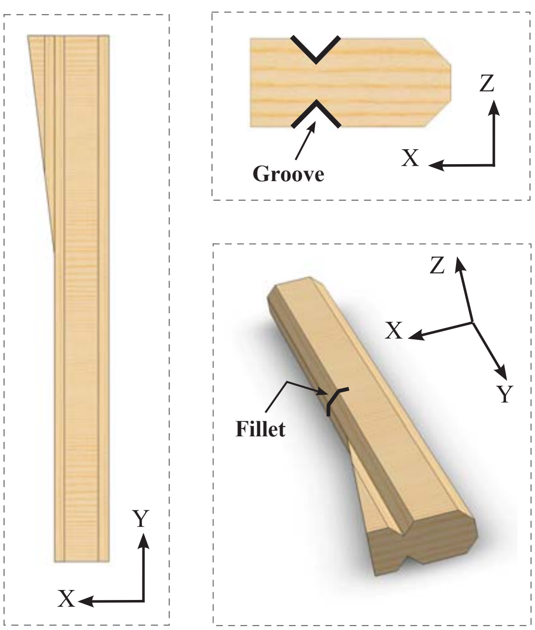

Figure 5: Illustration of the broken-off chopstick used for this tactile illusion. Note that we refer to the rounded edge leading up the chopstick head as the fillet and the slotted area that initially divided two chopsticks as the groove.

4.2 Second Experiment Chopsticks

To further explore the key aspects of the chopstick tactile illusion and to see if this illusion can be artificially recreated, a second experiment was performed. This second experiment utilized fabricated plastic models of the chopsticks.

Using a 60W laser cutter (Universal Laser Systems VLS4.60), these chopstick models were cut out of a 2.19mm smooth and clear acrylic. Because the laser cutter could only cut a groove on one side, two mirrored pieces were firmly glued together using acrylic adhesive forming a whole chopstick that is 4.38mm in thickness, which was similar to the model shown in Figure 5. To reduce the discrepancy between the actual wooden sticks and fabricated sticks, the flat top and bottom smooth acrylic plastic surfaces were lightly and carefully sanded to match wood texture. Careful consideration was put forth not to blunt any edges. The finished fabricated chopsticks are shown in Figure 6. Although this fabricated model was close to the actual wooden chopstick counterpart, it is difficult to exactly mimic the sharp and fine broken-off wooden edges.

Nineteen plastic chopsticks were fabricated in total. Sixteen of these chopsticks all had the same features that the wooden chopsticks had. These sixteen chopsticks (stick numbers 1 through 16) varied in angled edge height (X) from 11.01mm to 38.10mm, width (Y) from 8.47mm to 15.24mm, and angle from 14.9° to 42.7°.

To investigate key features that contribute to the perception of the chopstick illusion, two additional chopsticks were fabricated. One chopstick was fabricated so that the groove between the angled edge and the main part of the chopstick was omitted. The other was made so that the fillet leading up to the angled edge was omitted. These special sticks are referred to as "no groove" (NG) and "no fillet" (NF) as seen in Figure 6. As in the first experiment, a base chopstick that did not have an angled edge was fabricated as a control. The dimensions for all fabricated chopsticks are shown in Table 2.

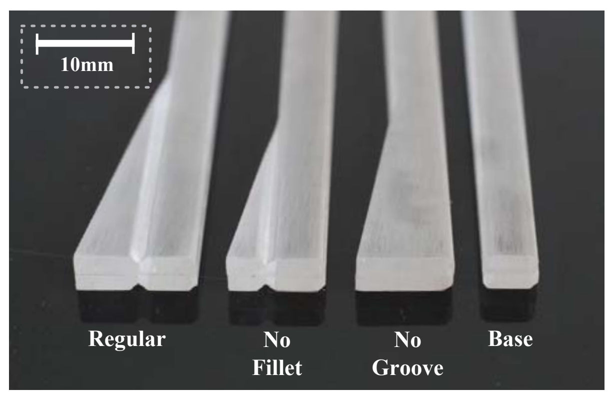

Figure 6: In the second experiment, the chopsticks were fabricated with surface sanded acrylic plastic. To investigate key illusion triggers, one stick had no corner fillet leading up to the slanted edge while one stick had no groove.

5 Experimental Procedure

Two different experimental setups were used to test different aspects of the chopstick tactile illusion. The first experiment focused on finding a realistic effective chopstick width using actual wooden chopsticks, whereas the second experiment was fine tuned to analyze the effect of changing the height, width, and angle of the angled edge while also exploring the effects of omitting key features of the chopstick. Before each experiment, all individuals read and signed a consent form approved by the University of South Florida's Institutional Review Board.

Table 2: Experiment 2: Fabricated plastic chopstick dimensions

Stick Number	Height (X-Dir) (mm)	Width (Y-Dir) (mm)	Angle (Deg.)	Stick Number	Height (X-Dir) (mm)	Width (Y-Dir) (mm)	Angle (Deg.)
1	38.10	*10.16*	14.9	**11**	38.10	13.87	*20.0*
2	31.33	*10.16*	18.0	**12**	34.71	12.63	*20.0*
3	24.55	*10.16*	22.5	**13**	31.33	11.40	*20.0*
4	17.78	*10.16*	29.7	**14**	27.94	10.17	*20.0*
5	11.01	*10.16*	42.7	**15**	24.55	8.94	*20.0*
6	*25.40*	15.24	31.0	**16**	21.17	7.70	*20.0*
7	*25.40*	13.55	28.1	***NG***	25.40	10.16	21.8
8	*25.40*	11.85	25.0	***NF***	25.40	10.16	21.8
9	*25.40*	10.16	21.8				
10	*25.40*	8.47	18.4	***Base***	25.40	6.35	0.0

5.1 First Experiment Procedure

Fourteen healthy individuals, 7 males and 7 females, aged 23.4 ± 3.1, participated in the first experiment. None of the participants had any significant fingertip calluses. Before the experiment, each participant was introduced to the chopstick illusion and trained to accurately perform the correct movement to perceive the illusion. Participants were informed that there is no wrong answer and that some, all, or none of the chopsticks may produce the tactile illusion.

The participants were presented with one individual wooden chopstick at a time and given as much time as they needed per stick. The presented chopstick was selected at random. Each chopstick was tested once per person. After each chopstick was presented, each participant was asked *"Does the chopstick feel like it has a change in thickness dimension, or a bump, anywhere as you move up the chopstick?"* A "yes" response was recorded as "1", while a "no" response was recorded as a "0" for each chopstick.

5.2 Second Experiment Procedure

For the second experiment, the objective was to analyze the effects of changing chopstick dimensions on the effectiveness of the tactile illusion and to investigate the key triggers of the illusion.

Twenty healthy individuals, 11 males and 9 females, aged 25.3 ± 6.2, participated in the second experiment. No participants of the first experiment participated in the second experiment. None of the participants had any significant fingertip calluses. In this experiment, individuals were presented with a total of nineteen fabricated plastic chopsticks, which are described in Section 4.2. All pre-experimental procedures were identical to the first experiment. Each participant was asked the same question and the data was recorded in the same fashion as in the first experiment.

6 Results

All statistical analysis was performed using MATLAB®. Both experiments were analyzed using an analysis of variances (ANOVA) with post-hoc analyses performed using a Tukey's honestly significant difference criterion based on the studentized range distribution.

6.1 First Experiment Results

The actual wooden broken-off chopsticks yielded a statistically significant difference $(F(10,130) = 6.06, p < 0.001)$. Post-hoc testing shows that the baseline chopstick (with no angled edge) was statistically significantly different than chopsticks 1 through 7 (with angled edge). No individual perceived the tactile illusion on stick 10 or the baseline stick. The results are summarized in Figure 7.

Individuals successfully felt a distinct tactile illusion on wooden chopstick 1 through 7. Between these chopsticks, the mean illusion perception rate was 72% with maximum perception rate at chopstick 1, 2, 5 and 6 at 77%, while no sticks had perfect perception. All chopsticks that were not statistically significantly different than the baseline stick had an angled edge height of 25.4mm and an angled edge width less than 8.15mm. This suggests there is a threshold dimensions of the chopstick's protruded angled edge. The perception of the tactile illusion starts being statistically significantly different from the base stick for an angled edge width of 8.38mm and higher. However, considering the JND, this threshold is ± 0.254mm. The data shows that once the illusion threshold is reached, there is no clear pattern of perception rate.

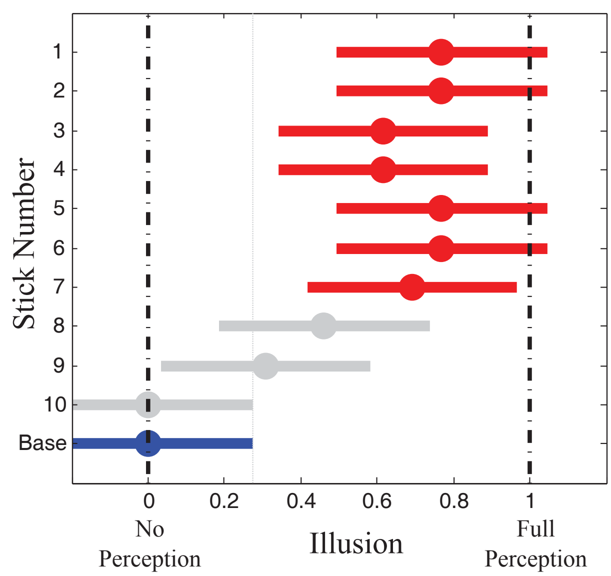

Figure 7: ANOVA statistical test result for wooden broken-off chopsticks shows that participants in the first experiment significantly experienced the chopstick tactile illusion in chopsticks 1 through 7 compared to the base stick. Bars represent the 95% confidence interval.

6.2 Second Experiment Results

An ANOVA and post-hoc test showed that 15 out of 18 fabricated plastic chopsticks were statistically significantly different from the baseline stick in the tactile illusion perception $(F(18,366) = 3.25, p < 0.001)$. This comparison is shown in Figure 8. No participants observed the illusion on the baseline stick. The mean illusion perception rate between statistically effective chopsticks was 63%, with the lowest perception rate in stick 13 at 48% and the highest perception rate on stick 14 at 72%. The only regular plastic chopstick that did not display the illusion was chopstick number 16. This agrees with the results from the first experiment as the width of stick 16 was under the threshold needed to experience the illusion. Between all the other plastic chopsticks that did meet the width threshold dimensions, the chopstick illusion was perceived. However, as in the first experiment, of those sticks that were successful, there was no clear pattern in perception rate among them.

The chopstick that had no edge fillet leading up the chopstick head (NF) was statistically different in illusion perception from the baseline stick, which suggests that this feature is not essential in the effectiveness of the chopstick illusion and could be excluded. However, omitting the the chopstick groove (NG) led to participants not being able to detect this tactile illusion, suggesting that the groove is a key component to the chopstick tactile illusion.

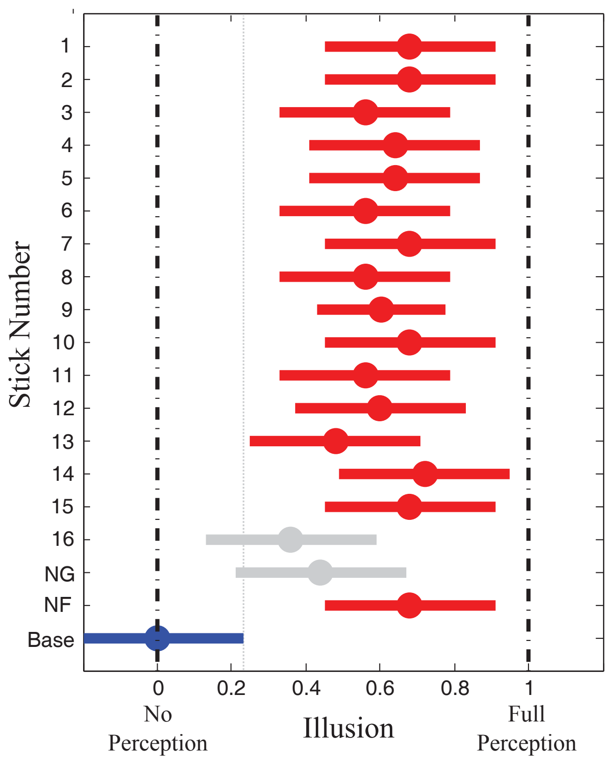

Figure 8: ANOVA statistical test result for fabricated plastic chopsticks shows that participants in the second experiment significantly experienced the chopstick tactile illusion in chopsticks 1 through 15 compared to the base stick. No tactile illusion was felt on the stick that did not have a groove, while omitting the fillet did not make a difference.

7 Conclusion

We have introduced and demonstrated a newly found, low-cost, and easily communicable tactile illusion, the "chopstick" illusion. The chopstick illusion creates a sensation of a change in dimension, or a bump, on a broken-off chopstick, when actually no dimension change occurs. This tactile illusion was successfully recreated using fabricated plastic chopsticks. While the first experiment with wooden chopsticks yielded a 72% mean illusion perception rate, the second experiment with fabricated acrylic chopsticks provided a lower 63% mean illusion perception rate. This drop in perception rate between successful sticks could be explained by the difference in material and fabrication, as broken-off wooden edges in an actual chopstick are much sharper and can interact with skin differently. No clear pattern was observed between any of the chopsticks that successfully demonstrated the tactile illusion. However, from the acquired data set, there seems to be an illusion threshold in chopstick width of 8.15mm; any sticks below this dimension did not display the tactile illusion. Considering the JND this threshold is $\pm$0.254mm. It is still uncertain of what the bandwidth of the effective chopstick dimensions is and further pending experimentation is necessary to quantify the exact threshold for this tactile illusion.

It was demonstrated that the chopstick groove, which initially divides the two chopsticks, plays a key role in the perception of the chopstick tactile illusion, while the fillet on the edge leading up the chopstick had no impact. This finding that the groove is a key feature can lead us to conclude that the abrupt change in skin deformation sends neurological signals which are interpreted as depressed skin, rendering a bump, which is not observed when the groove is omitted. This conclusion can be used to create or observe similar tactile illusions, which in turn can be utilized for haptic rendering purposes such as in communication for the visually impaired (braille). The "chopstick" tactile illusion in itself is a great low-cost method to demonstrate and educate individuals on the concept of tactile illusions.

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