Summary.—Faces and written words are two of the most familiar types of visual patterns with the brain’s selective response of N170 component in early perception. Using ERP adaptation paradigms, studies have found the N170 response is reduced when there is repeated presentation of upright faces relative to a control condition. In contrast to these well-established features of the face-related N170 adaptation effect, the characteristics of the N170 adaptation effect for printed words are less clear. The goal was to investigate the ERP adaptation effects of printed language (English words and Chinese characters) in a short ISI (200 msec.) adaptation paradigm. The present study showed that both alphabetic words and non-alphabetic words could produce a rapid N170 adaptation effect. Objects of expertise (e.g. words and faces) can produce a rapid N170 adaptation effect but other objects (e.g., houses) cannot, indicating that the specific stimuli have some specific mechanisms for the rapid N170 adaptation.

Faces and written language are two of the most familiar types of visual patterns. Several ERP (event-related potential) studies have demonstrated that both faces and words evoke a much stronger N170 response than other object categories in perception (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Eimer, 2000; Rossion, Joyce, Cottrell, & Tarr, 2003; Itier, Latinus, & Taylor, 2006). For example, the majority of ERP studies have found that the N170 amplitude elicited by faces as compared with objects that are not faces is typically much stronger and the topography of N170 responses to faces is more right-lateralized (Bentin, et al., 1996; Eimer, 2000; Itier & Taylor, 2004; Rossion & Jacques, 2008). In addition to the clear differences observed between faces and non-face objects, most of the studies have found that the N170 component evoked by printed words or characters is also much stronger than that elicited by other stimuli, such as consonant strings (Bentin, Mouchetant-Rostaing, Giard, Echallier, & Pernier, 1999; Maurer, Brem, Bucher, & Brandeis, 2005) or line drawings (Cao, Li, Zhao, Lin, & Weng, 2011; Cao & Zhang, 2011; Lin, Chen, Zhao, Li, 2014)
He, & Weng, 2011; Yum, Holcomb, & Grainger, 2011; Zhao, Li, Lin, Cao, He, & Weng, 2012), and are more pronounced in the left hemisphere.

Due to the brain’s selective response of N170 component to faces and words in early perception, many researchers have showed great interest in revealing them using many different paradigms. Recently, many studies have focused on investigating category-specific neural activity using a novel ERP adaptation paradigm. The particularly robust adaptation phenomenon is that cortical dynamics reduces neural activity when stimuli are repeated (Desimone, 1996). Initially, the adaptation paradigm was mostly used in fMRI studies to probe the brain’s representation of faces (Gilaie-Dotan & Malach, 2007; Avidan & Behrmann, 2009). Adaptation-reduced neural response following repeated presentation of a stimulus is also a well-known electrophysiological phenomenon (Desimone, 1996; Brown & Xiang, 1998). Recently, many studies have used neural adaptation procedures to identify the mechanisms that are responsible for category-specific ERP components such as the N170 (Kovács, Zimmer, Banko, Harza, Antai, & Vidnyanszky, 2006; Eimer, Kiss, & Nicholas, 2010; Nemrodov & Itier, 2011). This paradigm presents adaptor and test stimuli in rapid succession and can be employed to investigate the properties of the category-sensitive N170 component. Using ERP adaptation paradigms, studies have found that the N170 response is reduced when there is repeated presentation of upright faces relative to a control condition. Namely, the N170 amplitude triggered by face test stimuli was generally smaller on trials with face adaptors relative to the control trials where non-face stimuli (e.g., houses) were used as adaptors (Kovács, et al., 2006; Jacques, d’Arripe-Loiseau, & Rossion, 2007; Eimer, et al., 2010; Eimer, Gosling, Nicholas, & Kiss, 2011; Nemrodov & Itier, 2011, 2012), which has been referred to as a face-related N170 adaptation effect (Grill-Spector, Henson, & Martin, 2006).

In contrast to these well-established features of the face-related N170 adaptation effect, the characteristics of the N170 adaptation effect for printed words are less clear. Recently, a few studies began to investigate the word-related N170 adaptation effect (Maurer, Rossion, & McCandliss, 2008; Mercure, Cohen Kadosh, & Johnson, 2011; Fu, Feng, Guo, Luo, & Parasuraman, 2012). Both Maurer, et al. (2008) and Mercure, et al. (2011) showed that there was a category-level N170 adaptation effect for faces but not for alphabetic words. In Fu, et al. (2012), both faces and Chinese characters induced an adaptation effect on N170 amplitude but adaptation was more pronounced for faces. Taken together, the results of the above studies show a consistent face-related N170 adaptation effect, but the word-related N170 adaptation effect is not consistent. The inconsistency of word-related N170 adaptation in previous studies may be attributed to the different interstimulus intervals (ISI) that were used: 650, 1000, 1300, or 1500 msec. Maurer, et al. (2008) investigated the word-related...
N170 adaptation effect using an ISI of 1500 msec. (jittered between 1250 and 1750 msec.), and the ISI in Mercure, et al. (2011) was 1000 msec. In Fu, et al.’s study (2012), the word-related N170 adaptation effect was obtained using an ISI of 650 msec. (jittered between 500 and 800 msec.). Many studies have suggested that the duration of ISI has a large effect on N170 adaptation properties (Martens, Schweinberger, Kiefer, & Burton, 2006; Banko & Vidnyanszky, 2010; Kuehl, Brandt, Hahn, Dettling, & Neuhaus, 2013). Kuehl, et al. (2013) investigated the effect of ISI on N170 adaptation by five levels of ISI (400, 800, 1200, 1600, or 2000 msec.). They found that the N170 adaptation in a paired stimulus protocol critically depends on short ISIs. Specifically, strong adaptation effects were only found for an ISI of 400 msec., but not for ISIs of 800 msec. or longer; almost complete signal recovery was observed after an ISI of 1600 msec. (Kuehl, et al., 2013). Using magnetoencephalography (MEG), Harris and Nakayama (2007) also found the face-related adaptation effects for short ISIs (100, 200, or 300 msec.), but not for an ISI of 500 msec.

So it may be that variable ISI is the reason for the inconsistent word-related N170 adaptation effects. The above studies suggest that an ISI of 400 msec. or shorter may be more appropriate for obtaining a robust word-related N170 adaptation effect. More importantly, all of the previous studies on face representation that employ very short ISI (e.g. 200 msec.), have found a stable and classical face-related N170 adaptation effect (Eimer, et al., 2010, 2011). However, it is still unknown whether the word-related N170 adaptation effect can also be observed using a short ISI condition. The present study investigated the ERP adaptation effects of English words and Chinese characters using a short ISI adaptation paradigm.

**Hypothesis.** Printed words/characters could elicit a N170 adaptation effect with a short ISI.

**Method**

**Participants**

Twenty bilingual subjects (10 men) were recruited from local universities and paid for their participation ($M_{age}=22.3\ yr.,\ range=19–28$). All participants were right-handed, with normal or corrected-to-normal vision. The study was approved by the ethical committee of Zhejiang Normal University and written consent was obtained from all participants.

**Stimuli**

Grayscale pictures of faces, English words, Chinese characters, and houses were used for this experiment. Faces were images of 72 individuals (36 male and 36 female) selected from a standard set of faces from the authors’ laboratory, displaying neutral facial expression. They were cropped to remove external features (hair, ears, and jaw line) and replaced with the
same oval contour using Adobe Photoshop CS5, consistent with Eimer, et al. (2010). Seventy-two Chinese characters with a left-right configuration were chosen from the Modern Chinese frequency dictionary (1986), with the number of the strokes varying from 7 to 14, and were presented in Song font. All 72 English words, which are composed of four letters (e.g., worm), were presented in Times New Roman font. In addition, 72 gray-scale images of cartoon houses were used. The face stimuli were 180 × 276 pixels, subtending an angle of 4.0° × 6.2° from a viewing distance of 90 cm. The Chinese character, English word, and house stimuli were 198 × 198 pixels, subtending an angle of 4.5° × 4.5° from a viewing distance of 90 cm.

Procedure

The participants were asked to sit on a chair 90 cm away from the 17” CRT monitor (1024 × 768 pixel resolution) on which all stimuli were presented against a dark grey background. E-Prime 2.0 software was used for stimulus presentation and behavioral response collection (Psychology Software Tools, Pittsburgh, PA).

Participants were tested in a dimly lit room. In each trial, an adaptor stimulus and a test stimulus were presented sequentially for 200 msec. each with an ISI of 200 msec. and followed by a 1500 msec. intertrial interval, consistent with Eimer, et al. (2010). There were four possible test stimuli; faces (F), Chinese characters (C), English words (W), or houses (H). Each test stimulus was preceded by one of two possible adaptor stimuli: one being the same category as the test stimulus, the other being the control stimulus. Houses served as the control adaptor stimuli to “objects of expertise” (faces, Chinese characters, and English words), and the objects of expertise were the control adaptor stimuli to houses. Therefore, there were eight conditions: FF, HF, CC, HC, WW, HW, HH, OH. For example, HF refers to the condition where faces, used as test stimuli, were preceded by house adaptors. In each of the eight experimental blocks, the eight conditions were presented with equal frequency, and in random order. There were 72 trials in each block, 64 of which were non-target trials. No response was required on these non-target trials. The remaining eight trials per block were target trials, where a red outline shape aligned with the outer contours of the stimulus shape. The goal of using the target trials was to focus participants’ attention on the task. The target stimulus, namely the red outline shape, was presented with equal probability as adaptor stimuli or test stimuli in the target trails. These target trials were randomly intermixed with the non-target trials. Participants were instructed to press a response button following the second picture presentation when they detected a target stimulus. Response buttons were counterbalanced across participants.
EEG Recording and Data Analysis

EEG was recorded using a 128-channel HydroCel Geodesic Sensor Net, with an electrode placed on the Vertex (Cz) serving as reference for the online recording. Electrode impedances were kept below 50 kΩ. Signals were digitized at a 500Hz sampling rate and amplified with a 0.1–200Hz elliptical bandpass filter. EEG data were offline digitally filtered with a 0.3–30Hz bandpass filter and epoched from 200msec. before to 800msec. after stimuli onset with a 100msec. pre-stimulus baseline. Trials with artifacts exceeding ±100μV were rejected. Any participant with more than 30% bad segments would be excluded from the group average. A minimum of 50 good trials in each stimulus category was required to retain a participant’s data for the analyses. The remaining EEG data were re-referenced to the average of channels.

EEG data were analyzed for non-target trials only. A group of channels over the left occipitotemporal regions (channels 58, 64, 65) and right occipitotemporal regions (channels 90, 95, 96) were analyzed where the N170 components were maximal. To reduce the number of levels in the statistical analyses, these peak amplitudes and latencies were then averaged across the three channels chosen for each hemisphere. EEG waveforms were averaged separately for each presentation condition. Based on visual inspection of the individual data, the N170 time-window was defined as 130–210msec. for adaptor stimuli and 140–220msec. for test stimuli. The N170 responses evoked by adaptors were analyzed in a repeated-measures multivariate analysis of variance (MANOVA) for Adaptor Type (faces, Chinese characters, words, and houses) and Hemisphere (left and right). The N170 peak amplitudes and latencies elicited by test stimuli were each analyzed in a MANOVA for Test Type (Faces, Chinese characters, Words, and Houses), Paired Condition [Same category (FF, CC, WW, or HH), or Different category (HF, HC, HW, or OH)], and Hemisphere (Left, Right). The term “adaptation effect” used throughout this manuscript refers to a significant difference in N170 amplitude between a condition in which the paired condition was same category (e.g., FF) compared to the corresponding baseline condition in which paired condition was different category (e.g., HF).

Results

Behavioral Results

Participants’ accuracy was consistently over 90% (M=94.28%) for target trials, with the error rate less than 0.1% for non-target trials. Mean response time (RT) was approximately 536msec. There was no difference in accuracy or response time across the four stimulus types.

ERP Results

ERP responses to adaptor stimuli.—A two-way, repeated-measures ANOVA of N170 peak amplitudes and latencies were conducted for Adaptor Type
(Faces, Chinese characters, English words, and Houses) and Hemispheres (Left, Right). The results are shown in Fig. 1 and Table 1. A main effect of adaptor type on N170 amplitude \( (F_{3,57} = 12.01, p < .001, \eta^2_p = 0.39) \) and an adaptor type × hemisphere interaction \( (F_{3,57} = 3.85, p = .05, \eta^2_p = 0.17) \) were found. Post hoc tests revealed that the N170 amplitudes elicited by houses were much smaller than those for faces \( (t_{19} = 5.15, p < .001, d = 0.62) \), Chinese characters \( (t_{19} = 3.69, p = .002, d = 0.58) \), and English words \( (t_{19} = 5.26, p < .001, d = 0.63) \) in the left hemisphere, and in the right hemisphere the N170 amplitudes elicited by faces were much larger than for Chinese characters \( (t_{19} = 3.80, p = .001, d = 0.63) \) and houses \( (t_{19} = 5.96, p < .001, d = 0.82) \). There was a main effect of adaptor type on N170 latency \( (F_{3,57} = 6.38, p = .002, \eta^2_p = 0.25) \). Post hoc tests revealed that the N170 latency for Chinese characters was earlier than that for houses \( (t_{19} = 2.99, p = .008, d = 0.47) \) or faces \( (t_{19} = 4.45, p < .001, d = 0.61) \).

**ERP responses to test stimuli.**—The results of test stimuli analysis are shown in Fig. 2 and Table 2. A three-way repeated-measures ANOVA of

![Fig. 1. The averaged N170 waveforms elicited by adaptor stimuli at the left and right hemispheres separately.](image)

<table>
<thead>
<tr>
<th>Adaptor Stimulus Type</th>
<th>Amplitudes (μV)</th>
<th>Latencies (msec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LH</td>
<td>RH</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Chinese character</td>
<td>−4.71</td>
<td>2.79</td>
</tr>
<tr>
<td>English word</td>
<td>−4.88</td>
<td>2.52</td>
</tr>
<tr>
<td>Face</td>
<td>−4.86</td>
<td>2.96</td>
</tr>
<tr>
<td>House</td>
<td>−3.14</td>
<td>2.76</td>
</tr>
</tbody>
</table>
N170 peak amplitudes and latencies were conducted for Paired condition (Same, Different), Test type (faces, characters, words, houses), and Hemispheres (left, right). The analysis of N170 peak amplitudes yielded a significant main effect of paired condition ($F_{1,19} = 37.12$, $p < .001$, $\eta^2_p = 0.66$) and test type ($F_{1,19} = 11.43$, $p < .001$, $\eta^2_p = 0.38$). The interaction test type × paired condition was statistically significant ($F_{3,57} = 13.21$, $p < .001$, $\eta^2_p = 0.41$). Post hoc $t$ tests revealed that the N170 amplitude in the FF condition was significantly smaller than that in the HF condition ($t_{19} = 7.83$, $p < .001$, $d = 0.81$).

Fig. 2. The N170 amplitudes elicited by the test stimuli in different conditions at the left and right hemispheres separately.
the N170 amplitude in the CC condition was significantly smaller than that in the HC condition \( (t_{19} = 3.95, p = .001, \eta^2_p = 0.44) \), and the N170 amplitude in the WW condition was significantly smaller than that in the HW condition \( (t_{19} = 4.77, p < .001, \eta^2_p = 0.57) \), but the N170 amplitude in the HH condition was not larger than that in the OH condition, despite a medium effect size \( (t_{19} = 1.80, p = .09, \eta^2_p = 0.40) \). The interaction test type × hemisphere was significant \( (F_{3,57} = 4.20, p = .020, \eta^2_p = 0.18) \). Post hoc \( t \) tests indicated that the N170 amplitude elicited by Chinese characters was stronger in the left hemisphere than in the right hemisphere \( (t_{19} = 2.09, p = .05, \eta^2_p = 0.38) \). The analysis of N170 latency yielded a significant main effect of paired condition \( (F_{1,19} = 17.58, p < .001, \eta^2_p = 0.48) \) and test type \( (F_{1,19} = 3.36, p = .03, \eta^2_p = 0.15) \). There was a significant interaction test type × paired condition \( (F_{1,19} = 49.81, p < .001, \eta^2_p = 0.72) \). Post hoc \( t \) tests revealed that the N170 latency was earlier in CC relative to HC \( (t_{19} = 8.51, p < .001, \eta^2_p = 0.80) \), and earlier in WW than HW \( (t_{19} = 7.89, p < .001, \eta^2_p = 0.93) \) but later in the HH condition than in the OH condition \( (t_{19} = 2.97, p = .008, \eta^2_p = 0.40) \).

**DISCUSSION**

Both faces and words can elicit much stronger N170 response than other object categories in early perception (Bentin, *et al*., 1996). Previous ERP adaptation studies have shown that faces, which show a specific response in early perception, can elicit significantly reduced N170 amplitude when preceded by faces relative to other categories of stimuli (Kovács, *et al*., 2006; Eimer, *et al*., 2010, 2011; Nemrodov & Itier, 2011, 2012). But whether words, the other stimuli with a specific N170 response in early percep-

<table>
<thead>
<tr>
<th>Test Stimulus Type</th>
<th>Amplitudes (μV)</th>
<th>Latencies (msec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LH</td>
<td>SD</td>
</tr>
<tr>
<td>CC</td>
<td>-7.06 3.58</td>
<td>-5.91 2.92</td>
</tr>
<tr>
<td>FF</td>
<td>-6.29 2.99</td>
<td>-6.20 3.54</td>
</tr>
<tr>
<td>EE</td>
<td>-6.44 2.57</td>
<td>-5.83 2.86</td>
</tr>
<tr>
<td>HH</td>
<td>-6.07 3.03</td>
<td>-6.13 3.67</td>
</tr>
<tr>
<td>HC</td>
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<td>-7.56 4.02</td>
</tr>
<tr>
<td>HF</td>
<td>-9.09 3.55</td>
<td>-9.51 4.61</td>
</tr>
<tr>
<td>HE</td>
<td>-8.77 3.54</td>
<td>-7.37 3.75</td>
</tr>
<tr>
<td>OH</td>
<td>-4.65 3.01</td>
<td>-5.14 3.36</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>Test Stimulus Type</th>
<th>Latencies (msec.)</th>
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<tbody>
<tr>
<td></td>
<td>LH</td>
</tr>
<tr>
<td>CC</td>
<td>170.70 13.57</td>
</tr>
<tr>
<td>FF</td>
<td>184.13 13.72</td>
</tr>
<tr>
<td>EE</td>
<td>175.10 13.44</td>
</tr>
<tr>
<td>HH</td>
<td>184.70 13.20</td>
</tr>
<tr>
<td>HC</td>
<td>180.37 13.62</td>
</tr>
<tr>
<td>HF</td>
<td>185.37 13.31</td>
</tr>
<tr>
<td>HE</td>
<td>188.47 18.04</td>
</tr>
<tr>
<td>OH</td>
<td>179.20 14.60</td>
</tr>
</tbody>
</table>
tion, can produce a similar adaptation effect is still unclear. The main goal of the current study was to explore whether printed language can also produce word-related N170 adaptation effects in a short ISI of 200 msec.

In the present study, face-type adaptor stimuli elicited a larger N170 response than house adaptors. This result is consistent with many previous N170 studies (Eimer, 2000; Rossion, et al., 2003; Itier & Taylor, 2004; Maurer, et al., 2005; Itier, et al., 2006; Yum, et al., 2011). Moreover, in this experiment, N170 amplitude triggered by face stimuli was generally larger on trials with house-type adaptor stimuli relative to trials where face-type adaptor stimuli were presented. This result replicated the typical face-related N170 adaptation effect produced in the most previous studies (Kovács, et al., 2006; Eimer, et al., 2010, 2011; Nemrodov & Itier, 2011, 2012).

Importantly, the results showed that the N170 amplitudes evoked by printed language (English word/Chinese character) test stimuli were significantly larger on trials with house-type adaptor stimuli relative to trials where printed language-type adaptor stimuli were presented, namely, there was a word-related N170 adaptation effect. To the authors’ knowledge, this is the first study which showed that both alphabetic words (e.g., English words) and non-alphabetic words (e.g., Chinese characters) can produce a word-related N170 adaptation effect. The results are not consistent with the results of the word-related N170 adaptation effect in both Maurer, et al. (2008) and Mercure, et al. (2011); they demonstrated that words can not elicit reliably reduced N170 amplitude when preceded by their within-category stimuli relative to other stimuli categories. The current results are similar to Fu, et al.’s (2012), who found N170 amplitudes triggered by upright Chinese character stimuli were significantly larger on trials with inverted Chinese character-type adaptor stimuli relative to trials where upright Chinese character-type adaptors were presented in a short ISI (500–800 msec., M = 650 msec.).

There are many factors that could contribute to the inconsistency in word-related N170 adaptation effect. The current results suggest that ISI may be the most important factor in determining word-related adaptation. The ISIs both in this study (200 msec.) and Fu, et al. (2012; 650 msec.) were much shorter than that in Maurer, et al. (2008; 1500 msec.) and Mercure, et al. (2011; 1000 msec.). Kovacs, Zimmer, Harza, & Vidnyánszky (2007) showed that ISI has an effect on face adaptation. Recently, Kuehl, et al. (2013) investigated the effect of ISI on N170 amplitude adaptation, using five levels of ISI. They found that strong N170 adaptation effects were found for an ISI of 400 msec. but not for ISIs of 800 msec. or longer. Harris and Nakayama (2007) found the adaptation effect for the three ISIs (100, 200, or 300 msec.), but not for the ISI of 500 msec. One should be cautious in assessing the role of ISI in adaptation, as a face-specific adapta-
tion effect was almost obtained in both the short and long ISI conditions of the previous studies (Kovács, et al., 2006; Harris & Nakayama, 2007, 2008; Jacques, et al., 2007; Maurer, et al., 2008; Eimer, et al., 2010, 2011; Vizioli, Rousselet, & Caldara, 2010; Mercure, et al., 2011; Nemrodov & Itier, 2011, 2012; Fu, et al., 2012).

Another important factor may be differences in the adaptor stimuli. In the present study, houses were used as the adaptor stimuli relative to word-type test stimuli, whereas faces were used as the adaptor stimuli in Maurer and his colleagues’ (2005, 2008) studies and inverted Chinese characters were used as the adaptor stimuli in Fu’s studies. Many studies show that variations in the adaptor stimuli contribute to the face-specific N170 adaptation effect. Eimer, et al. (2010) found that different adaptor stimuli, namely eyes or houses, produced different effects on responses to the upright face-type test stimuli. (Nemrodov & Itier (2011, 2012) also found that the amplitude of the N170 to faces depended on the stimuli participants’ N170 had adapted to: eyes, houses, mouths, eyeless-faces, or mouthless-faces. The observations in Kovács, et al.’s (2006) study also strongly suggest that hand-type adaptor stimuli and other control adaptor stimuli had different effects on adaptation to facial stimuli as indicated by the N170 component. Because photos of houses served as adaptor stimuli in this study but photos of faces, or other categories (e.g., cars, non-words) served as adaptor stimuli in the two English word studies, this difference of adaptor stimuli may have contributed to the inconsistency in the word-related N170 adaptation effect. So, the adaptor stimuli may play an important role in the word-related adaptation effect. Further study is needed to evaluate this issue by directly comparing the word adaptation effect with different categories of stimuli as adaptors.

However, in the present study the N170 amplitudes triggered by house-type test stimuli were marginally significantly larger on trials with house-type adaptor stimuli relative to trials where word-type adaptor stimuli were presented, which was inconsistent with the predictions of the adaptation method, according to which the response to house test stimuli preceded by house adaptor stimuli should have yielded smaller amplitudes. The result was consistent with the previous study in which Nemrodov and Itier (2012) found that the house test stimuli preceded by house adaptor stimuli elicited larger amplitudes than when other categories of adaptor stimuli were presented. Together with the current results and Nemrodov and Itier’s (2012), it may reflect an enhancement mechanism, and the house-type stimuli do not elicit the same adaptation pattern as face stimuli because the N170 response is not preferentially sensitive to houses.

The current study shows that both words and faces can produce the N170 adaptation effect but picture of houses do not, which suggests that
“expert stimuli” (for example, faces and words) have some specific mechanisms for N170 adaptation. These results may provide new insights into the neural processes that contribute to the N170 component.

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