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Semantic Processing of Phonetic Radicals in Reading Chinese Characters*

Zhou Xiaolin

(*Center for Brain and Cognitive Sciences, and Department of Psychology, Peking University, Beijing*, 100871)

William Marslen-Wilson

(*MRC Cognition and Brain Sciences Unit, Cambridge, United Kingdom*)

Abstract

Most complex Chinese characters are composed of a semantic radical on the left and a phonetic radical on the right, which may provide information concerning the pronunciation of the whole character. A semantic judgement task was used to investigate whether sublexical processing of phonetic radicals embedded in complex characters is purely a phonological event, involving activation of phonological information associated with the phonetic radicals, or whether it is also a semantic event, involving activation of semantic properties related to the radicals, which are meaningful characters on their own. Significant inhibitory effects was found for complex characters whose phonetic radicals were semantically related to the other member of the consecutively presented pair of characters. The magnitude of the inhibitory effects was generally not influenced by the regularity of phonetic radicals in providing phonological information for the whole characters, nor by the presentation order of complex characters and semantic associates of the phonetic radicals. It is argued that, in reading Chinese, phonetic radicals embedded in complex characters are decomposed from visual input and used to activate their own phonological and semantic properties, in parallel to the processing of whole characters.

Key words reading Chinese, Chinese characters, sublexical processing, phonetic radicals.

1 Introduction

The Chinese writing system is often described as logographic or morpho-syllabic, where the basic orthographic units, the characters, correspond directly to morphemic meanings and to syllables in spoken form. With some exceptions, each character represents one morpheme and has one pronunciation, although different characters may have the same pronunciations. Modern Chinese characters can be broadly differentiated into two categories: simple and complex, both of which are composed of strokes and arranged in squares of similar size. Simple (or integrated) characters make up about 5% of the total characters in Modern Chinese. They are holistic visual patterns that cannot be divided meaningfully into sub-lexical units. Complex (or compound) characters constitute about 95% of all modern Chinese characters and most of these characters are composed of a semantic radical on the left and a phonetic radical on the right (e.g., 议 yi[4], *discuss*, in which the phonetic radical is 义 yi [4], *righteousness*. Numbers in brackets represent the lexical tones of syllables), although some arrange

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their radicals in other ways[1,2].

Linguistically, while semantic radicals have the function of indicating the semantic category of morphemes corresponding to the whole characters, phonetic radicals have the function of pointing to the pronunciations of these characters. However, due to the evolution of the writing system, many complex characters are no longer pronounced in the same way as their phonetic radicals. Less than one third of complex characters ("regular" characters) have exactly the same pronunciations as their phonetic radicals[3,4], while about one third are totally irregular ("irregular" characters) and their pronunciation has no relationship to their phonetic radicals. The final one third share some aspects of phonology with their phonetic radicals. Most phonetic radicals can be involved in both regular and irregular characters. Moreover, most phonetic radicals are also meaningful characters by themselves, even though their meaning usually has nothing to do with the meaning of complex characters containing these radicals.

There have been a number of studies on the sublexical or sub-character processing of phonetic radicals in reading Chinese characters[5~14]. With few exceptions[11,13,14], these studies have concentrated on phonological activation of phonetic radicals and the influence of this activation on phonological processing of whole characters. Seidenberg[9], for example, found that regular complex characters —— that is, characters having the same pronunciations as their phonetic radicals —— were named faster than frequency-matched simple characters. This effect, however, was restricted mostly to low frequency characters. Using a primed naming task, Zhou and Marslen-Wilson[14] demonstrated more directly the activation of phonological information associated with phonetic radicals embedded in complex characters. High and low frequency irregular complex characters (e.g., 猜 cai[1], *guess* , in which the phonetic radical was 青 qing[1], *blue*) were used as primes, while targets were characters (e.g., 轻 qing[1], *light*) that were homophonic to the phonetic radicals embedded in the complex characters but not to the characters themselves. The authors found that targets preceded by low frequency complex characters were named faster than when they were preceded by unrelated characters. Targets preceded by high frequency complex characters, however, did not show significant facilitation in naming.

These findings suggest that in processing complex characters, phonetic radicals are decomposed from the visual input and used to access their own phonological representations as well as representations of other characters containing these radicals, leading to a cooperative and competitive interaction between the phonological activation of whole characters and of their phonetic radicals[9,13,14]. An alternative account, however, was also proposed [15,6] . According to this account, sublexical processing of phonetic radicals in reading complex characters is essentially the same as the process of using grapheme-phoneme correspondences in reading alphabetic words. The over-learned radical-sound correspondences subserve the rule-like computation of "prelexical" or "nonlexical" phonology for the whole characters. Thus on this account, sublexical processing of phonetic radicals is purely a phonological event, involving only computation from orthography to phonology.

The main purpose of this study is to investigate whether sublexical processing of phonetic radicals embedded in complex characters is restricted just to the activation of their phonological representations. We use a semantic judgment task to examine whether the semantic properties associated with these phonetic radicals, since they are meaningful characters on their own, are also activated in the recognition of complex characters. If we obtain evidence for semantic activation of phonetic radicals in reading complex characters, this evidence will allow us to reject the "prelexical" or "nonlexical" phonology account of sublexical processing of phonetic radicals.

Zhou and Marslen-Wilson [11,13,14] have investigated this issue in a primed naming study. They observed facilitatory priming effects for target characters (e.g., 东 dong[1], *east*), which were not semantically related to the complex character primes themselves (e.g., 洒 sa[3], *spray*) but to the phonetic radicals (e.g., 西 xi [1], *west*) embedded in the primes. They also found an inhibitory effect for complex character targets, which were preceded by primes semantically related to the phonetic radicals embedded in the targets but not to the targets themselves. The authors argued that sublexical processing of phonetic radicals is both a phonological and a semantic event and that there are no fundamental differences between sublexical of phonetic radicals and lexical processing of simple and complex characters.

In the present semantic judgment task, participants were asked to decide whether a pair of consecutively presented characters were semantically related. The crucial comparison was for characters like 洒 (sa[3], *spray*) and 东 (dong[1], *east*) that are not semantically related as wholes, but where the phonetic radical (e.g., 西 xi(1), *west*) embedded in the complex character is related to the other member of each pair. If semantic properties of the embedded phonetic radical are activated in reading the complex character, the semantic relation between this radical and the other character should send a positive signal to the decision system and make it difficult to reject the pair of characters as unrelated. If, on the other hand, sublexical processing of the phonetic radical is purely a phonological event, this pair of characters will not be related at either the whole-character level or the sublexical level. They should not be more difficult to reject than appropriate controls in the judgment task.

An important part of the present experiment is the use of both regular and irregular complex characters. This was not only to examine whether the potential sublexical semantic activation is uniform across different types of complex characters, but also to examine to what extent sublexical phonological activation contributes to this sublexical semantic activation. For irregular characters like 洒 (sa[3], *spray*), phonological activation of the whole characters should compete with sublexical phonological activation of their phonetic radicals (e.g., 西 xi[1], *west*), hence reducing the level of sublexical phonological activation. For regular complex characters like 谓 (wei[4], *say*), however, phonological processing of the whole characters and phonological processing of their phonetic radicals (e.g., 胃 wei[4], *stomach*) support each other. If sublexical semantic activation of phonetic radicals is mediated or at least influenced by phonological activation of these radicals, the level of sublexical semantic activation and hence the interference effect in semantic judgment should be different for the two types of complex characters. Thus using both regular and irregular characters in this experiment could shed additional light on the controversial issue of whether semantic activation in reading Chinese characters is predominantly mediated by phonological activation or through direct mapping between orthography and semantics.[16,17]

This study also manipulated the position of complex characters in the critical pairs. The regular or irregular complex characters were presented either as the first or the second character. If decomposition of phonetic radicals and access to their semantic properties is induced by the consecutive presentation of paired stimuli, then larger interference effects should be observed when the complex characters are presented as the second characters than when they are presented as the first characters. The presentation of characters which are semantic associates of the phonetic radicals embedded in the complex second characters should encourage their decomposition and semantic activation.

The stimulus asynchrony onset (SOA) between the first and second characters was set at 100 ms. This short SOA was used to minimize possible competition effects that could reduce sublexical processing effects in complex characters presented as the first character. A longer SOA would give the semantic (and phonological, for irregular characters) activation of the whole complex characters enough time to suppress the semantic (and phonological) activation of their phonetic radicals. On the other hand, previous studies using this and similar tasks[18] suggest that participants could have difficulties in identifying the first characters if the SOA is shorter than 100 ms.

2 Method

2.1 Design and Materials

Sixty regular complex characters and 52 irregular complex characters were selected as the critical stimuli. Forty of the irregular characters did not share any of their pronunciation with the embedded phonetic radicals. A minority shared either their consonants (8 out 52) or their vowels (4 out 52) with their phonetic radicals. All the phonetic radicals had strong semantic associates that were used as the other member in each pair. For example, the irregular character 洒 (sa[3], *spray*) was paired with 东 (dong[1], *east*), which is semantically related to the embedded phonetic radical 西 (xi[1], *west*); the regular character 谓 (wei[4], *say*) was paired with 肚 (du[4], *belly*), which is a semantic associate of the phonetic radical 胃 (wei[4], *stomach*). The semantic relatedness between the phonetic radicals and the other members were checked against a database in which the semantic relatedness between pairs of characters were judged by at least 15 undergraduate students on a 9-point scale (1=totally unrelated and 9=very related). Average relatedness was 8.3 for irregular characters (ranging from 7.3 to 9.0) and 8.2 for regular characters (ranging from 7.1 to 9.0). The regular or irregular complex characters, as a whole, were not semantically related to the other member of each pair.

Only complex characters with an internal left-right structure were selected, with the embedded phonetic radicals always on the right side of the complex characters. This is not only because they constitute the major type of complex characters in Chinese, but also because they are easier to decompose in perceptual analyses than characters with other structures[19], so that the effects of their sublexical processing should be easier to detect. These complex characters were also of relatively low frequency. The average frequency was 85 per million for the irregular characters and 25 per million for the regular characters. The reason for selecting low frequency complex characters was that visual decomposition and sublexical processing are more likely to take place for low rather than high frequency characters[9,14]. However, due to the distribution of characters in Chinese[20], we could not balance the frequencies of regular and irregular complex characters. Anyway, we were not interested in comparing regular and irregular characters directly. The visual complexity of these characters, which correlates with their frequency, was not perfectly matched either. The average number of strokes, which measures visual complexity, was 8.7 per character for irregular characters and 10.7 per character for regular complex characters. The average frequency of the other paired characters (i.e., semantic associates of the phonetic radicals) was 1161 per million for the irregular group and 864 for the regular group. The average frequency of the embedded phonetic radicals, when they are used as independent characters, was 1137 per million for the irregular group and 756 for the regular group. Clearly, they were much higher than the frequencies of the complex characters having them as phonetic radicals.

The position of each pair of test characters was reversed so that the complex characters were either presented first (e.g., 洒 (sa[3], *spray*) - 东 (dong[1], *east*) or second (e.g., 东 (dong[1], *east*) - 洒 (sa[3], *spray*). Unrelated control pairs were created by re-pairing the first characters with the second characters in the same stimulus group, so that the same set of stimuli were used across the related and unrelated conditions. For example, for two critically related pairs having irregular complex characters as the first characters, 洒 (sa[3], *spray*) - 东 (dong[1], *east*), and 猜 (cai[1], *guess*) - 紫 (zi[3], *purple*), their unrelated control pairs were, respectively, 猜 (cai[1], *guess*) - 东 (zi[3], *east*) and 洒 (sa[3], *spray*) - 紫 (zi[3], *purple*).

For the regular and irregular groups of stimuli, a Latin square design was used to assign the pairs of characters into 4 counter-balanced test versions. This design would allow the same characters appear only once in a version. In each version, half of the 112 pairs were critically related. Among the related 56 pairs, half of them took the complex characters as the first character and half as the second character. There were 13 irregular characters and 15 regular characters acting as the critically related first or second characters. Thirty-four pairs of characters that were neither semantically, nor phonologically, nor orthographically related were used as fillers and added to each test version. These, together with the critical stimuli, required "no" responses in the semantic judgment task. Another 150 pairs of semantically related characters were also added to each test version. The character pairs could be either synonyms, antonyms, category coordinates, or functionally related. Characters and syllables used in the critical stimuli were not used again in fillers. A single pseudo-random ordering was used to arrange the stimuli so that, across the four test versions, pairs of characters having the same first or second characters appeared at the same positions. Thirty pairs of practice items, containing items related in the same way as critical pairs, were also used. The SOA between the first and second characters was set at 100 ms.

2.2 Procedure

All characters were generated by a computer word processing program and stored as individual image files on a hard disk. Each character was in 48-point *songti* font and was about 2.4 cm × 1.6 cm in size. The presentation of stimuli to participants and recording of reaction times were controlled by the dual-screen version of DMASTR. In each trial, an eye fixation signal ("+") was first presented at the center of a computer screen for 300 msec, followed by a 300 msec blank interval. The first character was then presented for 100 msec and overwritten immediately by the second character, which was presented for 400 msec. There was a 3-second interval between the disappearance of the last target and the appearance of the next eye fixation point.

Participants were tested individually in a quiet room. They were seated about 60 cm from screen and were asked to judge as quickly and as accurately as possible whether a pair of consecutively present characters were related in meaning. Each participant saw first a list of 30 prime-target practice items. There was a break after practice and two breaks in the main test session. The first three pairs after each break were always fillers.

2.3 Participants

A total of 60 undergraduate students at Beijing Normal University were tested. All of them were native speakers of Mandarin Chinese. They were paid for their participation.

3 Results

Three participants were excluded from analyses, two because of high response error rates (over 20%) and one because of his very long reaction times (mostly over 1000 ms). Four pairs of items in the regular group were also excluded, because over half of subjects made incorrect ("yes") responses in the related condition. Excluding participants and items did not change the pattern of effects. Mean reaction times, based on correct "no" responses, and error rates are reported in Table 1.

Table 1 Mean reaction times (ms) and error percentages

stimulus	Complex as the First			Complex as the Second		
	Related	Control	Effect	Related	Control	Effect
Regular	705	651	−53	703	647	−56
	(10.9)	(2.2)	(−7.7)	(5.8)	(2.7)	(−3.1)
Irregular	736	687	−49	727	674	−53
	(9.1)	(5.3)	(−3.8)	(9.1)	(4.9)	−(4.2)

Analyses of variance (ANOVAs) were conducted for both reaction times and error rates, with relatedness (related vs. control) and position of complex characters (the first vs. the second) as within-participant, within-item factors and stimulus group (regular vs. irregular) as a within-participant, between-item factor. In the analyses of reaction time, the main effect of relatedness was highly significant by participants, $F1(1, 56) = 97.488$, $p < 0.001$, and by items, $F2(1, 106) = 65.357$, $p < 0.001$. Responses were slower when the phonetic radicals of the complex characters were semantically related to the other member of the pairs. The main effect of stimulus group was significant, $F1(1, 56) = 26.506$, $p < 0.001$, $F2(1, 106) = 9.368$, $p < 0.01$, indicating that responses to regular stimuli were faster than responses to irregular stimuli. The main effect of position of complex characters was not significant, $F1(1, 56) = 1.112$, $p > 0.1$, $F2(1, 106) = 1.637$, $p > 0.1$, and there were no secondary interactions between position, stimulus group, or relatedness ($F1 < 1$, $F2 < 1$). It is clear from Table 1 that all complex characters, regardless of their regularity and regardless of their position, were about 53 ms more difficult to reject when they were related to the other characters than when they were not related.

The error pattern generally followed the reaction times, except that the effect for regular characters as the first characters was much larger than effects in other comparisons. Statistical analyses found a significant main effect of relatedness, $F1(1, 56) = 65.052$, $p < 0.001$, $F2(1, 106) = 31.282$, $p < 0.001$. Participants made more incorrect responses when phonetic radicals of complex characters were related to the other characters than when they were not. The main effect of stimulus group was significant by participants, $F1(1, 56) = 7.980$, $p < 0.01$, but not by items, $F2(1, 106) = 2.704$, $p > 0.1$. The main effect of position was significant, $F1(1, 56) = 5.420$, $p < 0.05$, $F2(1, 106) = 4.148$, $p < 0.05$, with more errors to complex characters when they were the first rather than the second characters. However, the interaction between position and relatedness was significant, $F1(1, 56) = 7.457$, $p < 0.01$, $F2(1, 106) = 4.854$, $p < 0.05$, as was the three-way interaction between position, relatedness, and stimulus group, $F1(1, 56) = 6.447$, $p < 0.05$, $F2(1, 106) = 5.955$, $p < 0.05$. It is clear from Table 1 that these interactions were mainly due to the higher error rate for regular complex characters at the first character position in the related condition.

4 Discussion

The data of this experiment are very clear. Whether complex characters were regular or irregular complex characters and whether they were presented as the first or the second characters, significant inhibitory effects were found in semantic judgment when the phonetic radicals of these characters were semantically related to the other character of the consecutively presented pairs. A larger inhibitory effect was also found for regular complex characters presented as the first characters, although this increased effect appeared only in error rates, not in reaction times. These findings strongly suggest that in reading complex characters, the embedded phonetic radicals are decomposed and used to activate their own semantic representations, in parallel to the processing for the whole characters.

Before we move on to the potential theoretical implications of these findings, we need to make sure that these effects were due to automatic processes of decomposition and access to semantics in reading Chinese, rather than due to the particular experimental design or the demand of experimental task. One may argue that the presentation of semantic associates of phonetic radicals induces readers to decompose phonetic radicals from complex characters and that the task demands of semantic judgment induce semantic activation of these radicals. While we cannot completely rule out this argument, we offer three observations indicating that the experimental design and task demands cannot not be wholly or mainly responsible for the pattern of effects. Firstly, if visual decomposition and sublexical semantic activation is a processing strategy under the control of the reader, this processing should not be carried out because the sublexical semantic activation can only hamper the processing of whole target characters. Secondly, if the pattern of effects was induced by the experimental design and the task, we should observe larger interference effects when semantic associates are presented as the first rather than the second characters. The associates should be able to act as contextual cues or as primes to the decomposition of subsequently presented complex characters. Here we generally obtained equal inhibitory effects for complex characters presented as the first or second characters. Thirdly, Zhou and Marslen-Wilson[13, 14] found both facilitatory effects in primed naming when irregular complex characters were presented as primes and semantic associates of the embedded phonetic radical were presented as targets, and inhibitory effects when the positions of these complex characters and the semantic associates were reversed. The pattern of effects in primed naming, consistent with the present study, is hard to be accommodated by a strategy account.

What are then the implications of sublexical semantic activation for theories of visual word recognition? In most theories of visual word recognition, sublexical processing of letter strings in reading alphabetic scripts is primarily a phonological event, computing phonological output for the whole words[21], and this phonological activation seems to play a fundamental role in driving semantic activation of the whole word [22~26]. Although in connectionist theories sublexical orthographic units are also the input to orthography-to-semantics networks computing semantic outputs, these semantic outputs are primarily for the whole words, not for the sublexical orthographic units, even when these units happen to be words themselves (e.g., *diver* in *divergent*).

The demonstration of sublexical semantic activation in reading Chinese, however, indicates clearly that sublexical processing of phonetic radicals is not the same as sublexical processing of letter strings in reading alphabetic words. Unlike earlier suggestions that sublexical processing of phonetic radicals underlies the phonological activation of whole characters, allowing for a form of phonological mediation to semantics in reading Chinese[6,15], sublexical processing of phonetic radicals is both a phonological event, given the findings discussed in Introduction, and a semantic event, given the findings here and in Zhou and Marlen-Wilson[13,14]. Semantic properties associated with phonetic radicals are activated even though its activation can only interfere with the processing of whole characters. Thus, sublexical processing of phonetic radicals is on par with lexical processing of simple or complex characters and there is no fundamental difference between them.

This does not say that sublexical processing of phonetic radicals has no function in phonological or semantic activation of whole words. Regularity and consistency effects in naming[5,7~9] indicate that phonological activation of phonetic radicals interacts with phonological activation of whole characters. Phonological activation of phonetic radicals may also interact with semantic activation of whole characters. In this study, we observed a higher error rate for regular complex characters presented as the related first characters. This effect suggests that semantic activation of phonetic radicals can be influenced by its phonological activation which, for regular characters, is supported by phonological activation of whole characters. Such influence is, however, limited and only in a short period, as we did not observe a similar effect for the "complex as the second" stimuli. Conversely, sublexical phonological activation of phonetic radicals embedded in regular complex characters could also support phonological activation of the whole characters, enabling a phonologically mediated semantic activation of these characters, as demonstrated in Zhou and Marslen-Wilson[17].

One might ask why there is automatic semantic activation of phonetic radicals embedded in complex characters in reading Chinese. After all, phonological activation of phonetic radicals may sometimes aid the processing of whole characters, but semantic activation of phonetic radicals almost always interferes with the processing of whole characters. As Zhou and Marslen-Wilson[13] argued, sublexical phonological and semantic activation of phonetic radicals in reading complex Chinese characters are constrained by the structure of these characters, by the function of the embedded phonetic and semantic radicals, and by learning processes in acquiring these characters. Structurally, phonetic radicals are integrated orthographic units, whose constituents (e.g., strokes) have no systematic correspondences to phonology or semantics. There is usually a clear visual separation between phonetic and semantic radicals, at least for complex characters with left-right structure. This provides cues for the visual decomposition of phonetic and semantic radicals in lexical access. Functionally, both phonetic and semantic radicals can have their own semantic properties. Most phonetic radicals and some semantic radicals also have their own phonological properties. Phonetic radicals are not only meaningful characters by themselves, being acquired very early in learning and having much higher frequency than complex characters containing them[4,14], but also are repeatedly used in different characters. Complex characters are therefore more similar to compound words rather than to monomorphemic words, having functionally salient components. It is not strange, therefore, for sublexical processing in complex characters to behave similarly to morphemic processing in reading Chinese compound words[27~29]. Furth-ermore, the relations between phonetic and semantic radicals and the complex characters are either explicitly or implicitly taught to children when they learn characters. For example, one way to teach children to learn characters, used by some parents and in some schools in the Mainland

China, is to group together characters with the same phonetic radicals and to ask children to pay special attention to the structure and composition of these characters. Also, since a common way for Chinese dictionaries to arrange characters is to group characters according to their orthographic structure and common components (usually semantic radicals) and to use these components as indexes, in using dictionaries the reader has to decompose characters and use their critical components as searching cues. Phonetic radicals are usually learnt earlier than complex characters and have higher frequencies than the characters containing them. All these properties make phonetic radicals much salient orthographic and functional units in complex characters. Decomposing such units from visual input and activating their corresponding phonological and semantic properties in the lexicon thus become not only natural but also compulsory.

To summarize, using a semantic judgment task, the present study found that semantic properties associated with phonetic radicals embedded in either regular or irregular complex characters are automatically activated in processing whole characters. It is argued that, in reading Chinese, phonetic radicals embedded in complex characters are decomposed from visual input and used to activate their own phonological and semantic properties, in parallel to the processing of whole characters. There are no fundamental differences between sublexical processing of phonetic radicals and lexical processing of simple or complex characters.

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汉字形声字声旁的语义加工

周晓林

(北京大学脑科学与认知科学中心,北京大学心理学系,北京 100871)

William Marslen-Wilson

(英国医学研究基金会剑桥认知与脑科学研究所)

摘 要 作为汉字书写系统和意义表达基本单位的汉字可分为独体字(占5%)和合体字(占95%)两大类。绝大多数合体字由两部分组成:义旁(通常在左边)和声旁(通常在右边)。声旁能够为这些合体字提供语音信息。根据声旁的读音与整字的读音是否一致,可把合体字分为规则字和不规则字。本研究的目的在于考察合体字声旁的亚词汇加工是否仅仅是一个纯粹的语音事件,只涉及声旁的语音加工,还是同时也是一个语义事件,涉及到声旁语义信息的激活。要求被试对屏幕上先后呈现的合体字(如"冯")和与其声旁语义相关的字("牛")作语义相关判断。整字之间并无语义关系,被试正确的反应应是"否"。实验结果表明,相对于完全无关的控制组(如"冯——后")来说,被试对声旁相关组的反应明显减慢,出现了抑制效应。这种效应基本不受整字的读音规则性和呈现顺序的影响。这些实验结果表达了合体字加工中的分解和平行激活过程。在整字加工的同时,声旁在心理词典中的语音和语义表征得到了激活。汉字声旁的亚词汇加工既是个语音事件,也是个语义事件,与词汇水平的加工没有本质的区别。

关键词 中文阅读,汉字,声旁,亚词汇加工,语义加工。

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