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# Processing Evidence for the Grammatical Encoding of the Mass/Count Distinction in Mandarin Chinese

**Panpan Yao[1] · Linnaea Stockall[2] · David Hall[3] · Hagit Borer[4]**

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**Abstract**
Using the Visual World Paradigm, the current study aimed to explore whether the mass/count distinction is determined by syntax in Mandarin Chinese, focusing on classified nouns in nominal phrases. By using dual-role classifiers, ontological count and mass nouns, and phrase structures with and without biased syntactic cues we found that the mass/count distinction is initially computed using phrase structure but can be overridden in cases where the syntax is incompatible with nouns' ontological meanings. The results indicate that in Mandarin Chinese, syntactic cues can be rapidly used to make predictions about upcoming information in real time processing.

**Keywords** Mandarin Chinese · Mass/count distinction · Visual world paradigm · Syntactic prediction · Anticipatory eye movements · Lexical semantics

## Introduction

Nominal phrases are constructed in different ways in different languages. In the current study, we focus on the mass/count distinction in classifier languages such as Mandarin Chinese, in which the mass/count distinction is marked differently compared to numeral languages like English. In English, the mass/count distinction is reflected through overt

✉ Panpan Yao
yaopp@blcu.edu.cn

Linnaea Stockall
l.stockall@qmul.ac.uk

David Hall
d.t.hall@qmul.ac.uk

Hagit Borer
h.borer@qmul.ac.uk

[1] School of Psychology, Beijing Language and Culture University, #15 Xueyuan Street, Haidian District, Beijing, China

[2] Department of Linguistics, Queen Mary University of London, ArtsOne. 1.10, London, UK

[3] Department of Linguistics, Queen Mary University of London, ArtsOne. 1.21, London, UK

[4] Department of Linguistics, Queen Mary University of London, ArtsOne. 1.12, London, UK

singular (e.g., articles) and plural (e.g., plural morphemes) markings (e.g., Chierchia, 1998a, 1998b; Pelletier, 2012). Only count nouns can be accompanied by an indefinite article but not mass nouns. When expressing plurality, count nouns combine with plural morphemes and occur with numerals directly, while mass nouns resort to measure words which undergo inflectional plural changes. Furthermore, the quantifiers modifying count nouns and mass nouns are different. Count nouns occur with 'many', while mass nouns occur with 'much'. Unlike English, Mandarin Chinese has no number morphology to mark singularity or plurality on nouns[1] (e.g., Li & Thompson, 1981). Bare nouns in Chinese have great flexibility in their contextual interpretations with respect to number and (in)definiteness. For example, the bare noun *mao* 'cat' could have at least four possible interpretations, i.e. 'a cat', 'cats', 'the cat' and 'the cats', given the appropriate syntactic and/or semantic contexts. No matter what meaning is intended, the form of the noun does not change. Additionally, Chinese has neither a definite nor indefinite article in the nominal domain. Definiteness is expressed in various ways, such as through demonstratives such as *zhe* 'this' or *na* 'that', while indefiniteness is expressed through numeral phrases. Furthermore, nouns in Chinese cannot be modified by numerals directly. A classifier is obligatory when combining a noun with a numeral (e.g., Tang, 1990).

Due to the lack of a number morphology system in Mandarin Chinese, some researchers have argued that unlike English, the mass/count distinction is not grammatically marked in Chinese (Allan, 1980; Chierchia, 1994, 1998a, 1998b; Krifka, 1995; Li, 2013). However, other researchers have argued that the mass/count distinction is not absent in Chinese syntax, it is realized at the classifier level (Borer, 2005; Cheng & Sybesma, 1998, 1999, 2012; Pelletier, 2012). Among the latter group of researchers, there is a debate about what determines the mass/count distinction in nominal phrases in Chinese. Some researchers have argued that nouns in Chinese are lexically unmarked or unspecified for mass/count meanings; the mass/count distinction is determined by syntax through a classifier projection (the syntactic approach, Borer, 2005; Pelletier, 2012). Other researchers, on the other hand, have claimed that the mass/count distinction is marked semantically in nouns in Chinese, and that classifiers are merely reflections of the mass/count semantic status of nouns on phrases. In this lexical approach the mass/count distinction is determined by the properties of nouns, and not those of classifiers (Cheng, 2012; Cheng & Sybesma, 1998, 1999; Doetjes, 1997).

Previous studies which focused on Chinese bare nouns (Lin & Schaeffer, 2018) and nominal phrases with count-classifiers and nouns (Huang & Lee, 2009) found evidence supporting the syntactic approach but arguing against the lexical approach (More detailed information about these studies will be introduced in Previous studies Section). Although these studies support the syntactic approach, there still remains unanswered questions that challenge the full validity of this approach, since they did not take the syntactic environment that a noun appears in into consideration, which is crucial for the syntactic approach. Thus, the current study aims to test this approach through a broader range of nominal phrases with different kinds of syntactic structures, classifiers and nouns. To be specific, the current study explores whether the mass/count distinction of classified nouns is determined by syntax in Chinese reading, using a Visual World Paradigm experiment conducted

[1] Some researchers claim that '-men' is a plural morpheme in Mandarin Chinese which can only occur with pronouns and nouns with a [+human] feature (Choi et al., 2017; Iljic, 1994). We put aside a discussion of '-men' in this study, and leave open the question of whether there is a plural morpheme in Mandarin Chinese comparable to that in English.

with a group of native Mandarin speakers. As our results show, in Chinese nominal phrases, syntax determines the mass/count interpretation of classified nouns. However, we found that when there is a conflict between the reading that a speaker typically assigns to a noun due to linguistic experience (Lin & Schaffer, 2018) and the one generated by the syntax, syntax can be overridden.

## Background

### Theoretical Approaches

Since there is no number morphology in Mandarin Chinese, the question of how the mass/count distinction is encoded in Chinese nominals has attracted a lot of attention. There are two main theoretical approaches: the lexical approach (Cheng, 2012; Cheng & Sybesma, 1998, 1999; Doetjes, 1997) and the syntactic approach (Borer, 2005; Pelletier, 2012).

Doetjes (1997) argued that the mass/count distinction at the syntactic level is different from that attested at the semantic level. At the syntactic level, the mass/count status of a noun depends on its distribution. If a noun can be morphologically pluralized, can be counted by numerals directly, and can combine with the indefinite determiner '*a*', it is a count noun. Otherwise, it is a mass noun. At the semantic level, on the other hand, the mass/count status of a noun depends on the domain of its denotation. If the denotation of a noun specifies what counts as its units or minimal parts, it is a count noun. Otherwise, it is a mass noun. In Doetjes's system, all nouns in Chinese are syntactically mass nouns, since they lack number morphology. However, there are semantic mass/count distinctions: some nouns in Chinese denote individual or unit information (e.g., *shu* 'book', *gou* 'dog'). Based on this observation, Doetjes divided nouns in Chinese into two groups, 'mass mass nouns' and 'count mass nouns'. 'Mass mass nouns' are nouns which behave like mass nouns and also do not denote information about units, like *shui* 'water'. 'Count mass nouns' are nouns which behave syntactically like mass nouns but still specify what counts as a unit, like *gou* 'dog'. In this way, the mass/count distinction is semantically encoded at the lexical level in Chinese.

Cheng and Sybesma (1998, 1999; Cheng, 2012), along with Doetjes (1997), argue that Chinese nouns are semantically marked as count or mass based on their denotations. This semantically marked mass/count distinction in nouns is syntactically reflected through the classifier system. Classifiers in Mandarin can be divided into two groups based on their functions: count-classifiers, which simply name the unit that entities naturally have (e.g., *duo* is a count-classifier which names the unit a flower naturally has); and massifiers, which create units to measure substances and pluralities (e.g., *di* 'drop' is a massifier which creates a unit to measure liquid). Count-classifiers occur with count nouns with individual readings, while massifiers occur with either mass nouns or count nouns with plural/divided-portion readings (detailed introduction of classifiers in Chinese are presented in part 2 in this Background section). According to Doetjes (1997) and Cheng and Sybesma (1998, 1999), even though there is no number marking on nouns, nor definite/indefinite articles in Mandarin Chinese, Chinese nouns have either count or mass readings based on their semantic denotations. When embedded in syntactic structure, the phrase structure and classifier need to be appropriate for the semantic mass/count features of the noun, and so classifiers need to agree with these semantic count/mass features of the nouns. That is to

say, it would be ungrammatical to have a massifier co-occurring with a count noun with individual readings.

In contrast to Doetjes and Cheng & Sybesma, other researchers have argued that Chinese nouns are unmarked (Borer, 2005) or unspecified (Pelletier, 2012) for the mass/count distinction semantically. The mass/count readings of nominals are determined by their syntactic structure. Borer (2005) proposes that the mass/count distinction is not encoded at the lexical level cross-linguistically. In both numeral languages like English, and classifier languages like Chinese, nouns do not contain any grammatical information about their mass/count status; it is the syntactic structure that results in either mass or count interpretations.[2] To be specific, there is a classifier projection ($Cl^{max}$) which has the function of dividing nouns. A syntactic structure including a $Cl^{max}$ projection returns nominals with a count reading, while a syntactic structure without $Cl^{max}$ returns nominals with mass readings. In numeral languages with overt determiners, such as English, both plural inflections and the indefinite determiner can occupy the head of $Cl^{max}$ and accomplish the dividing function. In classifier languages like Chinese, it is the classifiers that do this job.

Different from Borer, Pelletier (2012) argues that instead of being altogether unmarked, nouns in Chinese in the lexicon are unspecified for mass/count meanings semantically. In this system, Chinese nouns in the lexicon are semantically flexible between count and mass, and can have either meaning in the corresponding context. Syntactically, however, Chinese nouns are unmarked for mass or count. When embedded in phrases, the phrase structure assigns a syntactic mass/count status to nouns, which then selects the appropriate mass/count semantic feature and deletes the opposite feature, resulting in a count or mass reading respectively. From this perspective, though diverging on how the mass/count distinction is encoded in nouns semantically (unmarked vs. unspecified), both Borer and Pelletier propose that in Chinese, the mass/count interpretations of nominals are determined by the syntactic structures they are embedded in.

## The Classifier System in Mandarin Chinese

Both approaches argue that the classifier system plays an important role in the mass/count markings in Chinese nominal phrases: for the lexical approach, classifiers reflect the mass/count distinction which is lexically marked on nouns; for the syntactic approach, classifiers assign/select the mass/count interpretations on nouns which are lexically unmarked/unspecified for mass or count. We now introduce some background on classifiers in Chinese.

The classifications of classifiers are different according to different researchers. For examples, Chao (1968) made a classification of six types of Chinese classifiers: individual classifiers, group classifiers, partition classifiers, container classifiers, temporary classifiers and standard measures. Lyons (1977) and Crofts (1994) divided classifiers into two groups: sortal and mensural classifiers. Li (2013) classified classifiers into four types based on the feature [±Counting] and [±Measure]. Yu (2020) isolated five types of classifiers: taxonomic classifiers, modificational classifiers, group classifiers, unit classifiers and quantitative classifiers. Cheng and Sybesma (1998) categorized classifiers into two types:

[2] Contrary to a common misperception, Borer (2005) explicitly states that listed items are not only devoid of mass/count properties, but are altogether devoid of category (i.e. cannot be 'nouns'), with both mass/count and categorial properties emerging exclusively from the syntactic context.

count-classifiers and massifiers. Considering the key research aim of the current study is to investigate how the mass/count distinction is encoded in classified nominal phrases, we adopted the classification of classifiers in Cheng and Sybesma (1998): classifiers in Chinese can be roughly divided into two groups based on their function: count-classifiers which simply name the unit that the entities naturally have; and massifiers which create a unit to measure substances and pluralities (Allan, 1977; Tai, 1992, 1994; Tai & Wang, 1990). Count-classifiers differ from massifiers in many different ways. First of all, count-classifiers do not have concrete lexical meanings,[3] and merely play a grammatical role when a noun needs to be counted. Massifiers, on the other hand, can sometimes be nouns with concrete meanings. Secondly, the associations between count-classifiers and nouns are usually fixed and rigid. Even though a few nouns can take more than one count-classifiers and have different interpretations accordingly, these classifier-noun associations are fixed. This is because count-classifiers always occur with ontological count nouns which inherently have discrete units. Thus count-classifiers may only name the units objects inherently have (Ahrens, 1994; Tai, 1992). However, massifiers and their associated nouns have comparatively loose and contingent associations (Ahrens, 1994; Tai, 1992). This is because massifiers create ways to measure entities which can be measured in different ways with an appropriate context. The same noun can therefore be associated with various different massifiers.

More relevant to the current study, there are two distributional differences between count-classifiers and massifiers (Cheng & Sybesma, 1998, 1999, 2005): only massifiers can be followed by the modification marker *de* (e.g., (1a) vs. (1b)), and only massifiers can be modified by adjectives like *da* 'big' and *xiao* 'small' (e.g., (2a) vs. (2b)). In other words, the structure [Num-Adj-Cl-(*de*)-N] can be treated as a massifier-biased structure (Li et al., 2008).

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| (1) | a. | *san* | *bei* | *(de)* | *shui* | b. | *liang* | *tou* | *(*de)* | *niu* |
| | | three | $CL_{cup}$ | DE | water | | two | $CL_{head}$ | DE | cow |
| | | 'three cups of water' | | | | | 'two cows' | | | |
| (2) | a. | *san* | *da* | *zhang* | *zhi* | b. | **san* | *da* | *zhi* | *gou* |
| | | three | big | $CL_{piece}$ | paper | | three | big | CL | dog |
| | | 'three big pieces of paper' | | | | | Intended reading: 'three big dogs' | | | |

Count-classifiers also differ from massifiers on the restrictions of classifier-noun pairings. Count-classifiers usually occur only with ontological count nouns (OCN) with countable singular readings, while not all massifiers are exclusively used with ontological mass nouns (OMN). Some massifiers can occur with either OMNs or with OCNs with plural/divided-portion readings. Examples are illustrated in (3).

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| (3) | a. | *yi* | *zhi* | *mao* | */*you* | b. | *yi* | *ping* | *shui/* | *ganlan* |
| | | one | CL | cat/ | *oil | | one | CL_bottle | water/ | olive |
| | | 'a cat/*an oil' | | | | | a bottle of water/olives/slices of olives' | | | |

[3] Some researchers have different opinions. For example, Yu (2020) claimed that some taxonomic classifiers (similar to count-classifiers in the current study) have concrete lexical meanings.

**Table 1** The differences between count-classifiers and massifiers

| | Count-classifier | Massifier |
|---|---|---|
| Semantic function | Naming units objects naturally have | Creating ways of measurement |
| Association with nouns | Fixed and rigid | Contingent |
| Insertion of *de* | × | ✓ |
| [Adj-Cl] order | × | ✓ |
| Cl-N pairing | Ontological count nouns only | Both ontological count and ontological mass nouns |

In (3a), the count-classifier *zhi* can occur with *mao* 'cat' which has discrete units, but not *you* 'oil' which does not. In (3b), *ping* 'bottle' is a massifier and can occur with *shui* 'water' which does not have specific units. It can also occur with *ganlan* 'olive', which ontologically is a count noun and expresses a plural reading or a divided-portion reading (slices of olives) in this specific case. The differences between count-classifiers and massifiers are summarized in Table 1.

In addition to the unambiguous count-classifiers and massifiers Mandarin Chinese has 'dual-role' classifiers (see the discussion in Zhang, 2012): these are count-classifiers when naming the individual unit of an object denoted by an OCN, but can also be massifiers which create a way of measuring substances or materials, as shown in (4).

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| (4) | a. | *yi* | *ba* | *jiandao/* | *yaoshi/* | *shaozi/* | *shazi/* | *shizi* |
| | | one | CL_handful | scissors/ | key/ | spoon/ | sand/ | pebble |
| | | 'one pair of scissors, a key/spoon, a handful of sand/pebbles' | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| b. | *yi* | *kuai* | *shoujuan/* | *yupei/* | *feizao/* | *dangao* |
| | one | CL_chunk | handkerchief/ | shaped jade/ | soap/ | cake |
| | 'a handkerchief/shaped jade, a bar of soap, a chunk of cake' | | | | | |
| c. | *yi* | *gen* | *huanggua/* | *xiangjiao/* | *toufa/* | *mugun* |
| | one | CL_rod | cucumber/ | banana/ | hair/ | stick |
| | 'a cucumber/banana, a (string of) hair, a stick' | | | | | |

In (4a), the classifier *ba* 'handful' can occur with both OCNs like *jiandao* 'scissors', or *yaoshi* 'key' and OMNs like *shazi* 'sand'. When it occurs with an OCN such as *yaoshi* 'key', it describes the unit a key ontologically has. When it occurs with an OMN such as *shazi* 'sand', it creates a way (handful) to measure the amount of the sand. In (4b), the classifier *kuai* 'chunk' describes the individual unit of a handkerchief or shaped jade when it occurs with the OCNs *shoujuan* 'handkerchief' and *yupei* 'shaped jade'. When it occurs with OMNs like *feizao* 'soap' and *dangao* 'cake', the massifier *kuai* indicates that 'soap' and 'cake' should be measured by chunks. In (4c), the classifier *gen* 'rod' can occur with OCNs like *huanggua* 'cucumber' and *xiangjiao* 'banana', as well as OMNs like *toufa* 'hair'. *Gen* describes the unit a cucumber or a banana ontologically has, but also creates a unit 'rod' to measure 'hair'.

Since these dual-role classifiers possess both count-classifier and massifier functions, they can be treated as ambiguous. Based on Cheng and Sybesma (1998, 1999), different structures of nominal phrases can be treated as syntactic cues for either count-classifier or

massifier. To be specific, the phrasal structure [Num-Adj-Cl] can be treated as a syntactic cue for a massifier (Li et al., 2008).

## Previous Studies

The findings from some previous studies cannot distinguish the syntactic approach from the lexical approach. For example, some studies found that native Chinese speakers are sensitive to the different functions of count-classifiers and massifiers: they map count-classifiers to objects with discrete units and clear boundaries, while map massifiers to substances without specific units (Cheung et al., 2012; Chien et al., 2003; Li et al., 2008). Also, nominal phrases with the structure [Num-Adj-Cl-de-N] were always mapped to unshaped substances without specific units or objects organized in plural sets, while phrases with the neutral structure [Num-Cl-Adj-N] were mapped to objects with discrete units (Li et al., 2008). These findings can be explained by both the syntactic approach and the lexical approach. For the syntactic approach, these findings indicate that different classifiers (syntax) assign either count or mass meanings to nominals. For the lexical approach, on the other hand, these findings reflect an agreement of the mass/count status between classifiers and nouns.

Some studies have investigated people's understanding of the ontological mass/count distinction by using quantity judgment task (Barner et al., 2009; Chien et al., 2003; Imai & Gentner, 1997; Imai & Mazuka, 2003, 2007; Lin & Schaeffer, 2018), and found that bare nouns in Mandarin Chinese can be counted based on number or volume, indicating that there are mass/count distinctions semantically marked on nouns: nouns that were counted based on number are count since they contain individual unit meanings; while nouns that were counted based on volume are mass since there is no discrete unit information in their semantic domain. However, these findings cannot rule out the syntactic approach, since the syntactic structures which return either count or mass nominal meanings could be covert according to Borer (2005). From this perspective, the mass/count interpretations observed with bare nouns could be either based on lexical denotations, or derive from a covert syntactic structure.

Evidence supporting the syntactic approach but arguing against the lexical approach was found recently (Huang & Lee, 2009; Lin & Schaeffer, 2018). Huang and Lee (2009) used a picture verification task to explore how the mass/count distinction is marked in Chinese. Participants were asked to select one picture out of two to map the bare nouns or non-bare nominal expressions given to them. They found that bare nouns can refer to individuated objects or portions of those objects (e.g., a whole chair or half of a chair can both be mapped to the bare noun *yizi* 'chair'). However, when nouns were associated with count-classifiers, participants only chose individuated objects, and not the portion/part of the objects (e.g., a whole chair was selected to map the phrase *yi zhang yizi* 'a chair'). The authors argued that this finding indicated that the mass/count meanings are unspecified for nouns, and that it is the classifier which assigns the mass/count meanings to the noun (but see Cheung et al., 2012).

Lin and Schaeffer (2018) used a quantity judgement test to examine the mass/count interpretation of unclassified nouns in Mandarin. Both adults and children were presented with scenes in which two characters were given a certain object/substance *X*, of different numbers and volumes, and were asked to answer the question of who had more *X*. Four types of ontological nouns were used: count, mass, flexible and object-mass. They found that adults allow both number-based and volume-based judgments for all nouns but

object-mass nouns. In other words, it is possible for the same bare noun to have both count and mass meanings. The authors argued that these findings support the syntactic approach that nouns are unspecified for mass/count meanings, and it is syntax that determines the mass/count distinction of nominals. The lexical approach, on the contrary, is inconsistent with these findings, since within that framework, unclassified nouns should always be lexically marked as count if they have ontological count meanings, or always be lexically marked as mass if they have ontological mass meanings. People's interpretations of the same bare nouns with respect to their mass/count denotations should be consistent. Combining the results reported so far, the syntactic approach seems do better than the lexical approach at characterizing the mass/count grammar in Mandarin.

Although those studies provided important steps in investigating the mass/count distinction in Mandarin, there are some limitations. First of all, in these studies, the different ontological types of nouns were selected based on their English counterparts' mass/count grammatical categories, which may be different from the ontological interpretation associated with speaker's world knowledge. For example, Lin and Schaeffer (2018) found that some OMNs in English can be counted in Chinese. Thus it is important to investigate whether syntax can determine the mass/count interpretations of classified Chinese nouns using nouns whose ontological type is rated by native Chinese speakers. In addition, previous studies looking into participants' understanding of nominals used off-line tasks in which participants have plenty of time and may use explicit task-dependent strategies to parse materials. It leaves the question open as to how people incrementally process nominals with regard to mass/count meanings in real time when appearing in different syntactic environments.

## The Present Study

In order to further explore whether syntax can determine the mass/count distinction of nominal phrases in Chinese, we conducted a Visual World Paradigm (VWP) experiment to explore native Mandarin speakers' on-line processing and interpretation of nominal phrases with different syntactic structures (neutral vs. massifier-biased) and the distinction between OMNs and OCNs. Compared to off-line tasks, an important advantage of the VWP eye-tracking technique is that saccadic eye movements are time-locked to the concurrent auditory input: they are the results of attention shifts towards targets which are triggered by the auditory input (Duebel & Schneider, 1996; Hoffman & Surbramaniam, 1995). Previous studies found that people can automatically make use of classifier information to build anticipations of upcoming words and direct their fixations to an anticipated picture before encountering the words (Huettig et al., 2010; Klein et al., 2012). Critically, the VWP allows us to not only track how phrases are interpreted in real time, but also to determine which interpretations are generated. In addition, the nouns in this study were classified as mass or count based on a Noun Rating Test conducted on native speakers, rather than on the basis of translation.

### Materials

The classifiers used in the current study are *gen* 'rod', *kuai* 'chunk', and *ba* 'handful'. All of these classifiers are dual-role classifiers with two possible interpretations: the count-classifier reading and the massifier reading.

A. Audio Sentence Materials

In the current study, we focused on the massifier-biased syntactic cue that only massifiers can be modified by adjectives. In other words, the phrase structure [Num-Adj-Cl-N] indicates that the classifier in this case is a massifier. A neutral structure with no massifier-biased cue (e.g., [Num-Cl-N]) would allow either a count-classifier or a massifier. When occurring in different structures, these dual-role classifiers would have different functions accordingly. In (5a) which is a neutral structure, the classifier *ba* can be interpreted as either a count-classifier expressing the 'unit' meaning or a massifier expressing the 'handful' meaning. When occurring in a massifier-biased structure in (5b), *ba* creates a way (handful) to measure the amount of keys, and it is a massifier.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| (5) | a. | *yi* | *ba* | *yaoshi* | b. | *yi* | *da* | *ba* | *yaoshi* |
| | | one | $CL_{unit/handful}$ | key | | one | big | $CL_{handful}$ | key |
| | | 'one key' or 'a handful of keys' | | | | 'one big handful of keys' | | | |

The three classifiers were all embedded in three different nominal phrase structures: C1 (Condition 1) with the structure [Num-Cl-N] as the baseline, C2 with the structure [Num-Cl-Adj-N] including an adjective to modify the noun, and C3 with the structure [Num-Adj-Cl-N] including an adjective to modify the classifier. The structures in C1 and C2 are neutral structures in which both count-classifiers and massifiers can occur, while the structure in C3 is a massifier-biased structure which only suits massifiers. Since the numeral *yi* 'one' in Mandarin can have a 'whole' meaning (Chao, 1968; Cheng & Sybesma, 1998; Paris, 1981), the numeral *san* 'three' was used in each nominal phrase. The adjectives *da* 'big' and *xiao* 'small' were used as adjectives in C2 and C3.[4] All the nominal phrases were judged as grammatical and acceptable by 20 native Mandarin speakers in an offline grammaticality test, in which a 5-point scale based on how acceptable the nominal phrases are was used (1 stands for unacceptable, while 5 stands for acceptable). The mean rating scores of nominal phrases in the three conditions were all around 4.5, and were not significantly different from each other ($ps > 0.9$).

### Noun Rating Test

A Noun Rating Test was conducted to select ontological count and mass nouns based on native Chinese speakers' judgments, which was done before the VWP experiment. Among a word pool containing 90 high frequency two-character nouns which can normally occur with one of the three classifiers, ten native Mandarin speakers (who did not participate in the VWP experiment) were asked to rate each noun for 'divisibility' (Cheng, 1973; Krifka, 1992), using a 5-point scale in which 1 stands for 'divisible' while 5 stands for 'indivisible'. They were told that a noun is 'divisible' if the entity denoted by it can be divided several times, and each part of it after being divided still has the original property. On the contrary, a noun is 'indivisible' if the entity denoted by it cannot be divided, or each part after being divided possesses different features from the original entity. Krifka (1992) argued

[4] Based on Cheng & Sybesma (1998), the adjectives *xiao* 'small' and *da* 'big' are the two most commonly used adjectives to modify classifiers, and thus, we hypothesize, the best cues to the massifier structure, so we only used these two adjectives.

that entities which are divisible are mass and entities which are not divisible are count. Based on the rating results, 12 OMNs (mean rating score = 1.58) and 12 OCNs (mean rating score = 4.39) were chosen. These nouns were grouped into pairs of an OCN with an OMN which shared the same classifier and the same tone of the first character (most of them share the same first syllable) to avoid a possible Phonological Competition Effect (Klein et al., 2012) and Tone Sandhi Effect (Yip, 2002). Furthermore, in each pair, the number of syllables of each character and the lexical frequency of OCNs and OMNs were matched. This resulted in five pairs of nouns for *kuai*, four pairs of nouns for *ba* and three pairs of nouns for *gen* (12 pairs in total, summarized in Table 16 in the Appendix), each embedded in the three syntactic conditions, for a total of 36 distinct stimulus pairs. Each of these nominal phrases was embedded in a carrier sentence [*qing cong pingmu shang de si fu tupian zhong xuan chu* + NP] 'From the four pictures, could you please choose + [NP]'.

B. Visual Displays

For each nominal pair a four picture display was created. Two pictures contained entities denoted by OMNs, and the other two contained objects denoted by OCNs. The pair of pictures for each noun-type varied in whether the picture was consistent with the size adjective modifying the classifier ([Adj-Cl]-Noun) or the size adjective modifying the noun (Cl-[Adj-Noun]). Because of the semantic difference between the classifier *ba* and the classifiers *gen* and *kuai* (*ba* is a collective classifier in its massifier use, while *gen* and *kuai* are dividers, see Cheng & Sybesma, 2012), pictures were organized in different ways. In addition, results related to the classifier *ba* and the classifiers *gen* and *kuai* are reported separately in the Results section.

i. Pictures for '*ba*'

In trials with the classifier *ba*, one of the two count-nominal-denoting pictures contained three solid individual objects (e.g., three spoons, the 'Cl-[Adj-OCN]' picture), and the other contained three groups of the same objects (e.g., three handfuls of spoons, the '[Adj-Cl]-OCN' picture). The two mass-nominal-denoting pictures both contained three groups of entities denoted by the OMNs. In the '[Adj-Cl]-OMN' picture the size of the group is consistent with the adjective (e.g., three big/small handfuls of pebbles), and in the 'Cl-[Adj-OMN]' picture, the size of the individual entity is consistent with the adjective but not the size of the group (e.g., three handfuls of big/small pebbles). Examples of the critical phrases for one mass/count nominal pair with the classifier *ba* are in (6), and the corresponding visual display is in Fig. 1A.

(6). Critical nominal phrases with the classifier *ba.*

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C1: | *san* | ***ba*** | *shaozi/ shizi* | | C2: | *san* | ***ba*** | ***da*** | *shaozi/ shizi* | | C3: | *san* | ***da*** | ***ba*** | *shaozi/shizi* |
| | three | **Cl** | spoon/ pebble | | | Three | **Cl** | **big** | spoon/ pebble | | | three | **big** | **Cl** | spoon/pebble |
| | 'three spoons/ three handfuls of spoons/pebbles' | | | | | 'three big spoons/ three handfuls of big spoons/ pebbles' | | | | | | 'three big handfuls of spoons/ three big handfuls of pebbles' | | | |

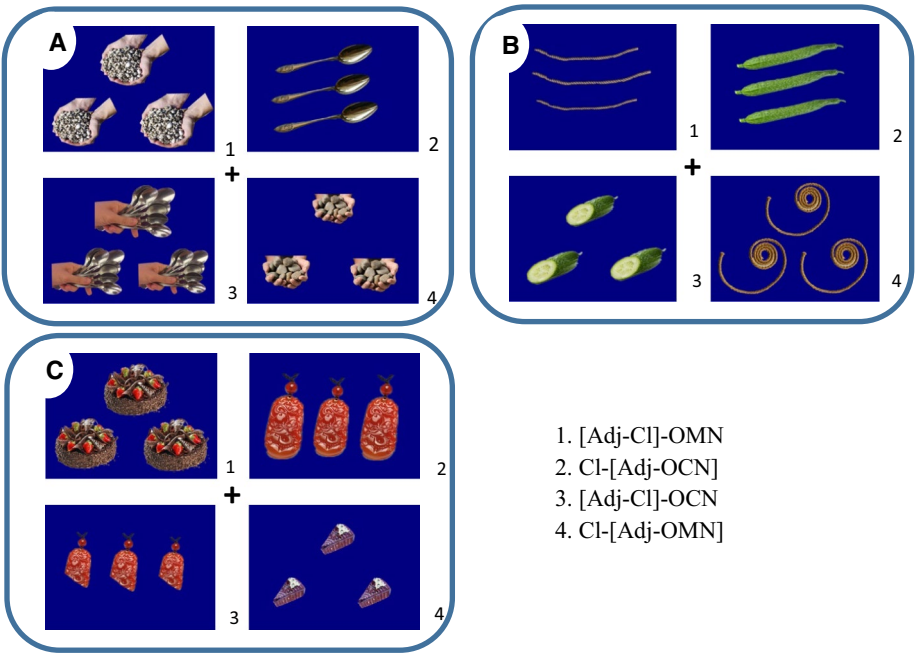


**Fig. 1** Examples of picture materials

ii. Pictures for '*gen*' and '*kuai*'

In trials with the classifier *kuai* and *gen*, one of the two count-nominal-denoting pictures contained three individual objects (e.g., three units of discrete shaped jade, the 'Cl-[Adj-OCN]' picture), the other one contained three divided parts of the same objects (e.g., three chunks of shaped jade, the '[Adj-Cl]-OCN' picture). The two mass-nominal-denoting pictures both contained three portions/units of substances. In the '[Adj-Cl]-OMN' picture, the size of the portion is consistent with the adjective (e.g., three big units of cake), and in the 'Cl-[Adj-OMN]' picture, the size of the portion is inconsistent with the adjective (e.g., three small units of big cake). Examples of the materials for *gen* are illustrated in (7), with the corresponding visual display in Fig. 1B. Sample materials for *kuai* are in (8) and Fig. 1C.

(7). Critical nominal phrases with the classifier *gen*.[5]

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C1: | *san* | ***gen*** | *huang-gua/ shengzi* | C2: | *san* | ***gen*** | ***xiao*** | *huang-gua/ shengzi* | C3: | *san* | ***xiao*** | ***gen*** | *huang-gua/ shengzi* |
| | three | **Cl** | cucum-ber/ string | | three | **Cl** | **small** | cucum-ber/ string | | three | **small** | **Cl** | cucum-ber/ string |

[5] 'Units' in these trials stands for either the individual units objects naturally possess or created measure units which can be described as 'long and thin'.

| | | |
|---|---|---|
| 'three units of cucumbers/ strings' | 'three units of small cucumbers/ three units of small strings' | 'three small units of cucumbers/ three small units of strings' |

(8). Critical nominal phrases with the classifier *kuai.*[6]

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C1: | *san* | ***kuai*** | *yupei/ dangao* | C2: | *san* | ***kuai*** | ***da*** | *yupei/ dangao* | C3: | *san* | ***da*** | ***kuai*** | *yupei/dangao* |
| | three | **Cl** | jade/cake | | three | **Cl** | **big** | jade/cake | | three | **big** | **Cl** | jade/cake |
| | 'three units of shaped jade/ three units of cake' | | | | 'three units of big shaped jade/ three units of big cake' | | | | | 'three big units of shaped jade/ three big units of cake' | | | |

## Picture Norming Test

In order to make sure that all the pictures were recognizable and understandable, a Picture Norming Test on ten native Mandarin speakers (who did not participate in the VWP experiment nor the Noun Rating Test) was conducted, in which participants were asked to judge whether the pictures were recognizable or not by using a 5-point scale, in which 1 stands for unrecognizable, while 5 stands for recognizable. They were also required to write down the names of the objects/substances in the pictures in Chinese. The results showed that the mean scores for all the pictures were above 4.5, indicating all the pictures were recognizable and acceptable. For the mass-nominal-denoting pictures, the consistency of the naming was 100%, and the names were exactly the nouns used in the current study. For the count-nominal-denoting pictures, however, there was some variations in the exact names generated due to the possibility of adding affixes such as *duan*, *tiao*, *suikuai* (which all have the meanings of 'pieces/fragments of something in certain shapes') to the object names. Given that with the classifiers *gen* and *kuai,* the '[Adj-Cl]-OCN' pictures depict pieces of whole objects, these modified names were provided for these pictures (e.g., *huanggua-duan* 'sections of cucumber' instead of *huanggua* 'cucumber'). However, apart from these morphological variants, all participants provided the same names for all objects.

There were 72 experimental sentences in total (12 pairs of nominals * 3 conditions). All the sentences were divided into three lists pseudo-randomly to make sure that each list only contained one of the three conditions of each sentence. There were 24 fillers in each list for a total of 48 sentences in each list. The critical nominal phrases in the fillers did not contain any classifiers.[7] These 144 sentences (72 critical items + 72 fillers) were digitally recorded by a female speaker of Mandarin in a sound-proofed booth, sampling at 44.1 kHz. Each participant was only tested on one of the three lists. The location of the four pictures in each trial was counterbalanced in each list. The whole experiment lasted around 30 min.

[6] 'Units' in these trials stands for either the individual units objects naturally possess or created measure units which can be described as 'chunk'.

[7] For example, 'From the four pictures on the screen, please choose + *yi xie xiao shizi* (some small pebbles)'. In the fillers, the quantifier *xie* 'some' which can occur with either count or mass nouns was used to replace classifiers. Adjectives *xiao* 'small' and *da* 'big' were used to modify nouns.

## Participants

Thirty native Mandarin speakers participated (15 females, 15 males). They were all students from Beijing Normal University, aged between 18 and 28 years old. Each participant was given ¥ 50 for their participation. The data was collected in Beijing Normal University, Beijing, China. The ethical protocol approval was obtained from Beijing Normal University.

## Procedure

SR Research Eyelink 1000 was used to measure participants' eye movements. Only the right eye's data were recorded and analysed. Following a nine-point calibration and validation, gaze-position error was less than 0.5°. Participants were tested in a sound-proof booth and seated 60 cm from a 19-inch monitor.

Participants were tested individually. Before the critical experimental trials, there were instructions and 10 practice trials, after which a standard 9-point grid calibration and validation was completed. During the experiment, participants were asked to choose one of the four pictures presented on the screen based on the sentence they heard from the headphones, by moving the mouse to click the corresponding picture. Participants' gaze was directed to a fixation dot in the middle of the screen prior to each trial to avoid the baseline effect (Barr et al., 2011; Hopp, 2016), and a trial would only start when participants fixated on the calibration dot stably. Participants' eye movements during the display of the audio materials and their responses were recorded.

## Predictions

### Anticipatory Eye-Movements (the Region of Classifiers and Adjectives)

Following the syntactic approach, the mass/count distinction is determined by phrase structure (syntax). Thus, we predict that in C1 and C2 there would be no significant concentration of eye-movements to any particular picture until participants hear the noun.[8] This is because there is no syntactic cue to the mass/count distinction in these two conditions. In C3 where the massifier-biased syntactic cue is present, participants should fixate on the mass- or plural-expressing pictures (the '[Adj-Cl]-OCN' picture and the '[Adj-Cl]-OMN' picture) on hearing the adjectives. This is because according to the incremental processing hypothesis (Eberhard et al., 1995; Pickering & Gambi, 2018), on hearing the [Num-Adj] sequence, participants should be able to predict that the upcoming word is a massifier. And this massifier anticipation should consequently assign/select a OMN reading (divided, with the classifier *gen* or *kuai*) or a plural reading (with the classifier *ba*) on the nouns. Thus, in the adjective region, more fixations should be landed on the pictures which express mass or plural meanings and show units of the size consistent with the adjective. The onset of the following classifier should only confirm this massifier-anticipation and thus the same fixation patterns were expected in the classifier region.

[8] The onset of the adjective (*da* 'big' & *xiao* 'small') in C2 could be used to incrementally restrict the interpretation to a subset of the possible targets in which the size of the objects/substance is consistent with the adjective. But this effect should not target only mass or count noun pictures.

### Convergence on an Interpretation (the Region of Nouns)

In C1 with no size adjective, participants should converge on the pictures purely based on their interpretations of nouns: OCNs with count readings should trigger fixations on the 'Cl-[Adj-OCN]' picture, OCNs with mass readings (plural sets/divided-portions) should trigger fixations on the '[Adj-Cl]-OCN' picture, OMNs should trigger fixations on either the 'Cl-[Adj-OMN]' picture or the '[Adj-Cl]-OMN' picture. In C2, participants should converge on the picture in which the size of the object is consistent with the adjective (i.e. either the 'Cl-[Adj-OCN]' or the '[Adj-Cl]-OMN' picture). According to the syntactic approach, the mass/count meanings are determined by syntax. Thus, regardless of whether the following noun is a OCN or a OMN, it should express a mass (for OMNs)/plural or divided-portion (for OCNs) meaning after the presence of a massifier in C3. In other words, participants should focus on mass/plural-expressing pictures (the '[Adj-Cl]-OMN' picture, the '[Adj-Cl]-OCN' picture) in the noun region in C3.

## Results

We report two dependent measures: participants' fixation distributions and their choice of pictures. The proportions of fixations in each picture tell us how participants predictively process each item of the nominal phrases in real time and the behavioral data reveal their final choices. The results of participants' fixation distributions are reported first, followed by participants' behavioral data.

### Fixation Proportions

Following Barr (2008), Huettig et al. (2011) and Mirman et al., (2008, 2014), the fixation proportions in VWP are often analyzed using Growth Curve Modelling or Multi-level logistic regression, treating the time sequence as a continuous factor and reflecting the changes of fixation proportions in each picture as the auditory input unfolds. However, in the current research, what we care about is how each item from the nominal phrase (especially the adjective, the classifier, and the noun) incrementally affects participants' on-line processing. To be specific, what we care about is how the fixation proportion changes in each region of interest (ROI). Therefore, Growth Curve Modelling and Multi-level logistic regression are not suitable, since we need to cut the time course into separate regions. Following Engelhardt and Ferreira (2010) and Tanenhaus et al. (1995) among other research investigating the processing of garden-path sentences (or temporally ambiguous phrases) in VWP, we used Linear Regression Modeling (Baayen et al., 2008) for each classifier in each ROI to test how the fixation proportions to the four pictures changed in different nominal phrases. ROI is defined that extended from 200 ms following the onset of a critical item (i.e., classifier/adjective/noun) to 200 ms following the offset of this item. This 200 ms buffer following the onset of a word is based on the mean time required to plan and launch an eye movement, and the typical lag observed between eye movements and fine-grained phonetic detail in the speech stream (Allopenna et al., 1998; Kukona et al., 2011). Fixation proportions to each picture in each ROI were calculated for 50 ms time-bins. The on-line processing of the items occurring before the nouns should not be affected by the mass/count status of the nouns so the fixation distributions in the ROI of classifier and adjective were analyzed by collapsing across count and mass nouns. Fixation distributions

in the ROI of noun were analyzed separately for count nouns and mass nouns. Since the key aim of the research is to investigate how fixation proportions in each picture changed on the occurrence of each critical item, we conducted priori custom contrasts to compare every two pictures successfully in each condition (Schad et al., 2020). The models included Picture (the four types of visual display: Cl-[Adj-OCN] picture, Cl-[Adj-OMN] picture, [Adj-Cl]-OCN picture, and [Adj-Cl]-OMN picture) in three conditions (C1, C2 and C3) as a fixed effect. Statistical analysis was conducted in R (R Development Core Team, 2015). All the figures in the current study were generated with ggplot2 (Wickham, 2009). Detailed results for each ROI are shown in the Appendix.

### The Classifier Region

***When the Classifier was* ba** In C1 and C2, on hearing *ba*, more fixations were landed on the '[Adj-Cl]-OCN' picture and the 'Cl-[Adj-OCN]' picture compared to the two mass-nominal-denoting pictures, $ps < 0.001$, and the difference between these two count-nominal-denoting pictures was not significant. In C3, more fixations were landed in each of the mass or plural-denoting pictures ('[Adj-Cl]-OCN', '[Adj-Cl]-OMN' and 'Cl-[Adj-OMN]') than the 'Cl-[Adj-OCN]' picture, $ps < 0.001$. The differences between any two of these three pictures were not significant. The bar plot of the fixation proportions in the classifier window is illustrated in Fig. 2-1A.

***When the classifier was* gen *and* kuai** When the classifier was *gen* and *kuai*, the fixation distribution patterns in the classifier region were similar to each other. Thus the results for these two classifiers are reported together. In C1 and C2, on hearing *gen/kuai*, participants distributed their fixations randomly among the four pictures. There was no significant difference between any two of the four pictures. In C3, more fixations landed on each of the mass or plural-denoting pictures ('[Adj-Cl]-OCN', '[Adj-Cl]-OMN' and 'Cl-[Adj-OMN]') than the 'Cl-[Adj-OCN]' picture, $ps < 0.001$. The differences between any two of these three pictures were not significant. The bar plot of the fixation proportions for *gen* and *kuai* are illustrated in Fig. 2-1B and 1C respectively.

### The Adjective Region

***When the Classifier was* ba** In C2, more fixations were landed in the count-nominal-denoting pictures ('[Adj-Cl]-OCN' and 'Cl-[Adj-OCN]') than the mass-nominal-denoting pictures ('[Adj-Cl]-OMN' and 'Cl-[Adj-OMN]'), $ps < 0.001$. The difference between the 'Cl-[Adj-OCN]' picture and the '[Adj-Cl]-OCN' picture was not significant, neither was the difference between the 'Cl-[Adj-OMN]' picture and the '[Adj-Cl]-OMN' picture. In C3, more fixations were landed in each of the mass or plural-denoting pictures ('[Adj-Cl]-OCN', '[Adj-Cl]-OMN' and 'Cl-[Adj-OMN]') than the 'Cl-[Adj-OCN]' picture, $ps < 0.001$. The differences between any two of these three pictures were not significant. The bar plot of the fixation proportions is illustrated in Fig. 2-2A.

***When the Classifier was* gen *and* kuai** The fixation distribution patterns for *gen* and *kuai* were similar to each other and are reported together. In C2 more fixations were landed in the '[Adj-Cl]-OMN' picture and the 'Cl-[Adj-OCN]' picture than the '[Adj-Cl]-OCN' picture or the 'Cl-[Adj-OMN]' picture, $ps < 0.001$. The difference between the 'Cl-[Adj-OCN]' picture and the '[Adj-Cl]-OMN' picture was not significant, nor was the difference between the

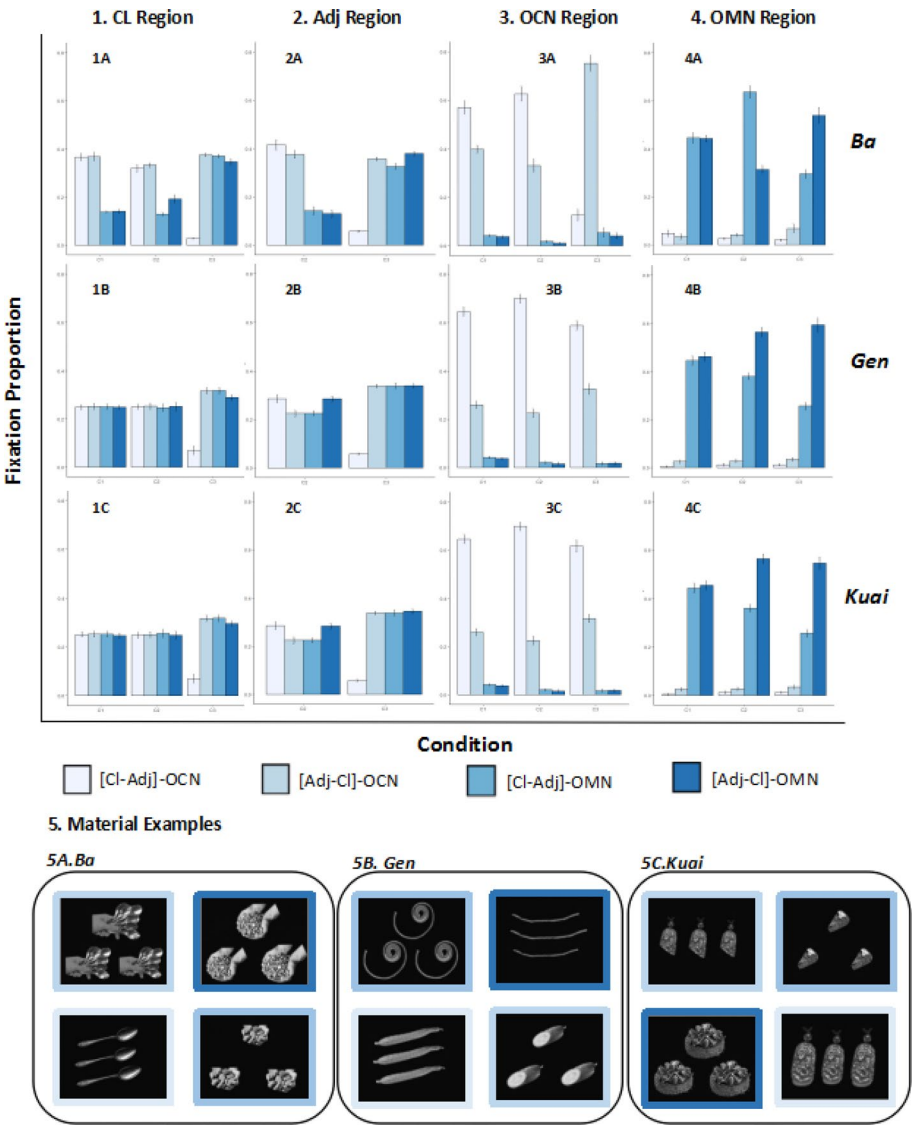


**Fig. 2** Fixation proportions in the ROIs (1-Classifier Region, 2-Adjective Region, 3-Count Noun Region, and 4-Mass Noun Region). When the classifier is **ba**, the corresponding plots are 1A, 2A, 3A and 4A. When the classifier is **gen**, the corresponding plots are 1B, 2B, 3B and 4B. When the classifier is **kuai**, the corresponding plots are 1C, 2C, 3C and 4C. The samples of visual materials with classifiers **ba**, **gen** and **kuai** are illustrated in 5A, 5B and 5C respectively

'[Adj-Cl]-OCN' picture and the 'Cl-[Adj-OMN]' picture. In C3 more fixations were landed in each of the mass or plural-denoting pictures ('[Adj-Cl]-OCN', '[Adj-Cl]-OMN' and 'Cl-[Adj-OMN]') than the 'Cl-[Adj-OCN]' picture, $ps < 0.001$. The differences between any two of these three pictures were not significant. The bar plot of the fixation proportions for *gen* and *kuai* are illustrated in Fig. 2-2B and 2C respectively.

## The Noun Region

### Ontological Count Nouns

(A). When the classifier was ba.

In C1 and C2, on hearing count nouns, more fixations were landed in the count-nominal-denoting pictures ('Cl-[Adj-OCN]' and '[Adj-Cl]-OCN') compared to the mass-nominal-denoting pictures ('Cl-[Adj-OMN]' and '[Adj-Cl]-OMN'), $ps < 0.001$, and the 'Cl-[Adj-OCN]' picture attracted more fixations than the '[Adj-Cl]-OCN' picture, $p < 0.001$. In C3, the '[Adj-Cl]-OCN' picture attracted significantly more fixations than the other three pictures, $ps < 0.001$. The differences between any two of these three pictures were not significant. The bar plot of the fixation proportions for the classifier *ba* is illustrated in Fig. 2-3A.

(B). When the classifier was gen *and* kuai.

The fixation distribution patterns for *gen* and *kuai* were similar to each other and are reported together. In all three conditions, participants exhibited the same fixation proportion patterns: on hearing count nouns, more fixations were landed in the count-nominal-denoting pictures than the mass-nominal-denoting pictures, $ps < 0.001$, and the 'Cl-[Adj-OCN]' picture attracted more fixations than the '[Adj-Cl]-OCN' picture, $ps < 0.001$. The bar plot of the fixation proportions with the classifier *gen* and *kuai* are illustrated in Fig. 2-3B and 3C respectively.

### Ontological Mass Nouns

(A). When the classifier was ba.

In C1, more fixations were landed in the mass-nominal-denoting pictures than the count-nominal-denoting pictures, $ps < 0.001$, and with no significant difference between the mass-denoting pictures. In C2 more fixations were landed in the mass-nominal-denoting pictures than the count-nominal-denoting pictures, $ps < 0.001$, but there were more fixations in the 'Cl-[Adj-OMN]' picture than the '[Adj-Cl]-OMN' picture, $p < 0.001$. In C3 more fixations were landed in the mass-nominal-denoting pictures than count-nominal-denoting pictures, and there were more fixations to the '[Adj-Cl]-OMN' picture than the 'Cl-[Adj-OMN]' picture, $p < 0.001$. The bar plot of the fixation proportions with classifier *ba* is illustrated in Fig. 2-4A.

(B). When the classifier was gen *and* kuai.

The fixation distribution patterns for *gen* and *kuai* were similar to each other and are reported together. In C1 on hearing the mass nouns, more fixations were landed in the mass-nominal-denoting pictures than the count-nominal-denoting pictures, $ps < 0.001$, and the difference between the mass-nominal-denoting pictures was not significant. In C2 more fixations were landed in the mass-nominal-denoting pictures than count-nominal-denoting pictures, $ps < 0.001$, and there were more fixations to the '[Adj-Cl]-OMN' picture than the 'Cl-[Adj-OMN]' picture, $ps < 0.001$. The pattern in C3 was the same as in C2. The bar plot

**Table 2** Behavioural results

| | Condition 1 | | Condition 2 | | Condition 3 | |
|---|---|---|---|---|---|---|
| | Count (%) | Mass (%) | Count (%) | Mass (%) | Count (%) | Mass (%) |
| *Ba* | | | | | | |
| Cl-[Adj-OCN] | 80 | 0 | 95 | 0 | 1 | 0 |
| [Adj-Cl]-OCN | 20 | 0 | 5 | 0 | 99 | 0 |
| Cl-[Adj-OMN] | 0 | 49 | 0 | 75 | 0 | 5 |
| [Adj-Cl]-OMN | 0 | 51 | 0 | 25 | 0 | 95 |
| *Gen/Kuai* | | | | | | |
| Cl-[Adj-OCN] | 90 | 0 | 90 | 0 | 95 | 0 |
| [Adj-Cl]-OCN | 10 | 0 | 10 | 0 | 5 | 0 |
| Cl-[Adj-OMN] | 0 | 45 | 0 | 25 | 0 | 20 |
| [Adj-Cl]-OMN | 0 | 55 | 0 | 75 | 0 | 80 |

of the fixation proportions with the classifier *gen* and *kuai* are illustrated in Fig. 2-4B and 4C respectively.

### Behavioural Data

In analyzing participants' behavioral data, their choices of the target picture in different conditions and with mass/count nouns were calculated. Since participants' responses were similar for *gen* and *kuai*, their final choices with these two classifiers were collapsed. Participants' choices for the final target picture are summarized in Table 2.

From Table 2 we can see different patterns for the classifier *ba* and the classifiers *gen* and *kuai*. In C1, there was no important difference: for all three classifiers, most participants (> 80%) chose the 'Cl-[Adj-OCN]' picture as the target picture when the noun was count, while the 'Cl-[Adj-OMN]' and the '[Adj-Cl]-OMN' picture were each selected half of the time when the noun was mass. However in C2 while most participants (> 90%) chose the 'Cl-[Adj-OCN'] picture when the noun was count regardless of classifiers, when the noun was mass, most of them (> 75%) chose the 'Cl-[Adj-OMN]' picture with *ba*, but chose the '[Adj-Cl]-OMN' picture with *gen* and *kuai*. In C3, the classifier made no major difference if the noun was mass: in that case most participants chose the '[Adj-Cl]-OMN' picture (> 80%). But when the noun was count, 99% of participants chose the '[Adj-Cl]-OCN' picture with *ba*, while 95% of them chose the 'Cl-[Adj-OCN]' picture with *gen* and *kuai.*

## Discussion

### The Syntactic Approach

First of all, we found that, consistent with the syntactic approach, the onset of the adjective in C3 did trigger fixations on the mass/plural-expressing pictures: the '[Adj-Cl]-OCN' picture, the '[Adj-Cl]-OMN' picture and the 'Cl-[Adj-OMN]' picture. This finding indicated that participants were sensitive to the massifier-biased syntactic structure [Num-Adj-Cl-N].

On hearing the adjective directly following the numeral, participants started to anticipate that the upcoming item should be a massifier, and consequently expect a mass/plural-meaning-denoting nominal. At this time point, they shifted their attention and fixations to the mass/plural-expressing pictures. This finding is consistent with previous studies that massifiers select nouns expressing mass or plural meanings (Cheung et al., 2012; Chien et al., 2003; Li et al., 2008). But, critically, this study is the first to examine the time course of this selection process, and to show that the syntactic cue of Adj-Cl word order is sufficient to lead listeners to generate expectations about the semantics of the noun they have not yet heard.

In addition, we found that in C1 and C2, which are neutral conditions, with dual-role classifiers, in most cases count nominals were interpreted as objects with discrete units, as participants fixated on the 'Cl-[Adj-OCN]' picture and chose it as their final decision. Occasionally, however, participants interpreted count nominals in these neutral conditions as plural sets (5%-20% with *ba*) and divided objects (10% with *gen/kuai*). This finding indicates that, though categorized as OCNs based on their divisibility, these nouns are compatible with both count and mass interpretations. This is consistent with Huang and Lee (2009) and Lin and Schaeffer (2018)'s findings that in Chinese, the same nouns are compatible with both count and mass interpretations. This observation can be explained by the syntactic approach. To be specific, Pelletier (2012) claims that Chinese nouns are semantically marked as both count and mass, and they are therefore flexible regarding mass/count interpretation. Borer (2005) proposes that nouns could get either count or mass interpretations, depending on their covert syntactic structure.

In the Noun region in C3, the massifier-biased structure, we observed different patterns with different classifiers. When the classifier was *ba*, on hearing an OCN, participants directed significantly more fixations to, and clicked on, the '[Adj-Cl]-OCN' picture. This is consistent with the prediction that massifier *ba* gives rise to a nominal-with-a-plural-set meaning, and also consistent with the prediction made by the syntactic approach that OCNs would be compatible with plural meanings in a mass syntactic structure. However, with the classifiers *gen* and *kuai*, which are dividers when they are interpreted as massifiers, when participants encountered the final OCN, they overwhelmingly switched their fixations away from the mass-nominal-denoting pictures towards the 'Cl-[Adj-OCN]' picture, which preserves the 'whole/indivisible object' interpretation of the OCN, but is inconsistent with the syntax of the phrase they were listening to. The patterns with *gen* and *kuai* indicated that the massifier structure is not enough to coerce a mass interpretation for OCNs.

This divergence in the noun region in C3 between *ba* and *gen/kuai* is understandable if we consider the semantic difference between these classifiers and the results of the Noun Rating Test. Recall that nouns were categorized as OCNs because the objects they denoted were not likely to be divided. When OCNs occurred in C3 with the classifier *gen/kuai* which have the 'divider' meaning, there would be a conflict between semantic properties of the massifiers and the nouns: the massifiers create a certain measurement by dividing the entities denoted by the nouns, while the entities denoted by the nouns cannot be divided. The observation that participants preferred the 'Cl-[Adj-OCN]' picture rather than the '[Adj-Cl]-OCN' picture in C3 when the classifier was *gen/kuai* indicates that when there was a conflict between semantic properties of classifiers and OCNs, world knowledge associated with OCNs won. As a consequence, in C3, even though the [Adj-Cl] word order should force a massifier interpretation for *gen/kuai*, participants still chose the picture corresponding to the 'Cl-[Adj-OCN]' interpretation (in which the objects denoted by the OCN were presented in their natural discrete units) over the picture corresponding to the '[Adj-Cl]-OCN' interpretation (in which the objects were divided). This finding is consistent

with the claim in Cheng et al. (2008) that Mandarin offers very little possibility of *grinding*, which they propose derives from the lack of obligatorily present countability markers of the type that English has. When the classifier was *ba*, there was no conflict between classifier structures and nouns' ontological meanings in C3, since the plural meanings of OCNs are appropriate for the 'group' meanings of massifier *ba*. Thus, the picture associated with '[Adj-Cl]-OCN' was fixated most frequently and chosen as the final target by participants.

Based on the totality of our findings, we argue that Chinese nouns are grammatically unspecified or unmarked for mass/count meanings. In phrases, nouns' mass/count interpretation is determined by classifiers or syntactic structures (consistent with the syntactic approach). However, when readers' common sense interpretation of nouns does not fit with the syntactic structures in which they appear, the syntax is set aside. In other words, while nominal syntax determines the mass/count interpretation of the classified nouns, that syntax is overridden when it conflicts with world knowledge as associated with the ontological meaning of nouns.

It should be noted that in some accounts, a noun's ontological information/common sense interpretation/world knowledge can also be treated as lexical semantic meanings (e.g., Krifka, 1992). It is very difficult to separate lexical semantic meanings and world knowledge apart. Furthermore, mass/count coercion (e.g., packaging, grinding, see Cheirchia, 2010) or contextual-based counting (Rothstein, 2010) is available in some accounts which are lexical based. From this perspective, the 'lexical approach' in the current research refers to a strong and inflexible version of lexical account, which claims that there is an active [+count] feature of nouns which must be matched by the syntactic framing. In other words, the presence of count-classifiers is a syntactic realization of the lexically marked countability of OCNs. It would be altogether ungrammatical within this lexical approach to have a massifier co-occurring with an OCN denoting individual meanings. The evidence in the current study argued against this strong and inflexible version of lexical approach. Participants rated the nominal phrases in C3 with *gen* and *kuai* as grammatical and acceptable. And they consistently mapped the 'Cl-[Adj-OCN]' picture to the [Num-Adj-Cl-OCN] phrases in both real time processing (eye movements) and the behavioral task (button press responses). These observations are not compatible with this strong and inflexible lexical approach.

### Differences Between the Classifiers

In addition to the noun region, the division between *ba* and *gen*/*kuai* has been observed in the ROIs of classifiers and adjectives. The possible reasons behind this division are discussed here in each ROI.

### The Classifier Region

In the ROI of classifier, we found that in both neutral conditions (C1 and C2), fixations were biased towards count or mass pictures based on different classifiers: with *ba*, participants fixated more on the count-nominal-denoting pictures than the mass-nominal-denoting pictures, while with *gen* and *kuai*, the fixations were randomly distributed among the four pictures. These different fixation patterns suggest that these dual-role classifiers may have different biases towards co-occurrence with OCNs or OMNs in the absence of any constraining information.

**Table 3** The averages of co-occurrence frequency (per million)

| | *Ba* | | | *Gen* | | | *Kuai* | | |
|---|---|---|---|---|---|---|---|---|---|
| | OCN | OMN | *diff* | OCN | OMN | *diff* | OCN | OMN | *diff* |
| Frequency | 0.68 | 0.64 | −0.05 | 0.35 | 0.51 | 0.15* | 0.43 | 0.59 | 0.16* |

The bias of occurring with OCNs or OMNs may be caused by these classifiers' co-occurrence frequency with OMNs versus OCNs. Using two Mandarin corpora (National Language Resources Monitoring and Research Centre) and the number of Baidu (Mandarin Chinese version of Google) hits (May 2019) (Blair et al., 2002; Pollatsek et al., 2010), the co-occurrence frequency counts of the OCNs and OMNs used in the current research with the three classifiers were calculated, and are illustrated in Table 3.

Table 3 showed that when the classifier was *ba*, the difference of the co-occurrence frequency between count and mass nominals was not significant, $p = 0.35$; while when the classifier was *gen* and *kuai*, mass nominals had significantly higher co-occurrence frequency than count nominals, $ps < 0.01$, represented by *. This classifier-noun co-occurrence frequency pattern does not offer any obvious explanation for our finding that participants expect *ba* to be followed by count nominals but have no biases for *gen* and *kuai*. Further research will be required to explore this issue.

## The Adjective Region

An unexpected contrast between *ba* and *gen/kuai* has been observed in the ROI for adjective in C2, where the adejctive is modifying the noun. We expected that participants would be more likely to fixate on pictures in which the sizes of the objects were consistent with the adjective. We did find such an effect for *gen* and *kuai*, in which more fixations were landed in the '[Adj-Cl]-OMN' picture and the 'Cl-[Adj-OCN]' picture than the other two pictures in the adjective region, which suggests that participants did use the size information of the adjective to restrict the possible targets for these classifiers. However, for *ba*, we did not observe this pattern. Instead, we found that the same preference for count-nominal-denoting pictures over the mass-nominal-denoting pictures observed in the classifier region persists in the adjective region, with no differences between the count-nominal-denoting pictures.The lack of such an adjective-sensitive effect for *ba* may be due to the difference between what it means to be a small or large object in a handful, vs. a small or large piece of an object. Without a reference scale, participants may have found it difficult to rapidly determine whether the objects in the handfuls were consistent with the size adjective, though their behavioural response showed that they did eventually figure it out.

## Syntactic Before Semantic Interpretation?

In the adjective region, in C2, for *gen* and *kuai*, we found that the size information of adjectives can be used rapidly to predict upcoming nouns and to narrow down possible targets. If so, why did participants fixate on the 'Cl-[Adj-OMN]' picture in this region in C3? In C3, the mass/plural-expressing pictures (the '[Adj-Cl]-OCN' picture, '[Adj-Cl]-OMN' picture, and the 'Cl-[Adj-OMN]' picture) all have more fixations than the count-expressing picture (the 'Cl-[Adj-OCN]' picture), with no significant differences between them. Earlier, we

argued that this pattern can be treated as evidence that participants were sensitive to the mass-biased structure. However, why did participants not use the size information of adjectives in C3, which should have excluded the 'Cl-[Adj-OMN]' picture in which the size of the groups is not consistent with the adjective?

We hypothesize that this pattern indicates that different aspects of an adjective are interpreted depending on its position in a nominal phrase. Note that, the [Cl-Adj] word order is more frequent than the [Adj-Cl] word order in daily life. In other words, an adjective has a comparatively salient location when occurring directly after a numeral in the [Num-Adj-Cl-Noun] structure. When occurring in an unmarked structure like in C2 ([Num-Cl-Adj-N]), semantic information of an adjective is automatically used to make predictions in real time processing; there is no special syntactic information of the adjective but modifying the following noun. However, when occurring in a massifier-biased structure like in C3 ([Num-Adj-Cl-N]), the massifier-biased syntactic cue that the special location of an adjective provided is most rapidly activated and used for predictive parsing, overriding semantic information encoded in it. To be specific, the salient location of an adjective in C3 caused participants to initially focus on the syntactic cue that the upcoming item is a massifier, rather than the semantic information regarding the size of the classifier. Nonetheless, the semantics of the adjectives were still retrieved and applied in the massifier context in later processing. In C3, on hearing OMNs, participants reliably chose the '[Adj-Cl]-OMN' picture (in which the size of the unit is consistent with the adjective) as the target instead of the 'Cl-[Adj-OMN]' picture.

The use of semantic and syntactic information in different stages has been found and discussed by many researchers (Gambi et al., 2016; Kuperberg, 2007; MacDonald et al., 1994; Snedeker & Trueswell, 2004). One representative account is the Structural Account (or two-stage model), proposed by Frazier (1979, 1987). She claimed that when people comprehend or produce a sentence, the initial parsing/organizing is based purely on syntactic information; other types of information such as semantic, lexical or pragmatic information only play a role in later stages. In the current study we argue that, compared to the structure [Num-Cl-Adj-N] in C2, the adjectives in the structure [Num-Adj-Cl-N] in C3 have a special syntactic role—forcing the following classifier to be a massifier. In C3 the cue associated with the adjective's salient syntactic position is used immediately, while its semantic information is used in later processing stages. Thus, the different patterns on hearing the same adjective which is embedded in different positions ([Cl-Adj] vs. [Adj-Cl]) suggest that when on-line processing an item in a salient/unusual position, it's syntactic information is processed before semantic information.

### Syntactic Predictive Processing

Apart from exploring whether the mass/count distinction is determined by syntax in Mandarin, the current study also shed light on syntactic predictive processing in Mandarin. Previous studies in other languages have found that syntactic information can be used automatically in on-line processing to make predictions, especially morpho-syntactic information (e.g., case marker, Kamide et al., 2003; Kamide et al., 2003; gender agreement, Van Berkum et al., 2005; Wicha et al., 2004; articles, DeLong et al., 2005; tense, Altmann & Kamide, 2007). In Mandarin, due to the general lack of morphology, the main syntactic cue available for investigation is word order. In the current study, the manipulated materials can be treated as pure syntactic cues: nominals in different conditions have the same number, classifier, adjective and noun, but in different orders. The different orders led participants

to have different anticipations and interpretations for the phrase in on-line processing. This finding indicates that native Mandarin speakers can automatically use the [Adj-Cl] word order as a pure syntactic cue to build anticipations in on-line processing.

## Conclusion

Aiming to examine whether the mass/count distinction of classified nouns is determined by syntax, the current study conducted a VWP experiment to test the syntactic approach. Instead of supporting or arguing against it, the results indicate a more complicated scenario. Our results suggest that syntax determines the mass/count interpretation of nominals only when syntax has no conflict with the ontological meanings of nouns. When there is a conflict, the ontological meaning has the final call. These results then raise the question of why the ontological meaning of nouns can take precedence over the syntax-driven interpretation in cases of incompatibility, and why nominals are more flexible and easily coerced by syntax in languages like English. Further research is needed to address these questions.

## Appendix

See Tables 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15 and 16.

**Table 4** Linear regression for the fixation proportions in the ROI of classifier when classifier is ba

| Contrast | Estimate | SE | t | *p* |
|---|---|---|---|---|
| (Intercept) | 0.25 | 0.003 | 94.481 | < 0.001 |
| *Condition 1* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | − 0.019 | 0.013 | − 1.445 | 0.149 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | 0.233 | 0.013 | 17.988 | < 0.001 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | − 0.019 | 0.013 | − 1.445 | 0.149 |
| *Condition 2* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | 0.017 | 0.013 | 1.285 | 0.199 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | 0.279 | 0.013 | 21.521 | < 0.001 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | − 0.017 | 0.013 | − 1.285 | 0.199 |
| *Condition 3* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | − 0.308 | 0.013 | − 23.769 | < 0.001 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | − 0.006 | 0.013 | − 0.482 | 0.630 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | 0.002 | 0.013 | 0.161 | 0.872 |

**Table 5** Linear regression for the fixation proportions in the ROI of classifier when classifier is gen

| Contrast | Estimate | SE | t | *p* |
|---|---|---|---|---|
| (Intercept) | 0.25 | 0.003 | 74.792 | < 0.001 |
| *Condition 1* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | 0.006 | 0.016 | 0.339 | 0.735 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | − 0.006 | 0.016 | − 0.339 | 0.735 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | 0.006 | 0.016 | 0.339 | 0.735 |
| *Condition 2* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | 0.006 | 0.016 | 0.339 | 0.735 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | − 0.003 | 0.016 | − 0.17 | 0.865 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | 0 | 0.016 | 0 | 1 |
| *Condition 3* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | − 0.278 | 0.016 | − 16.963 | < 0.001 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | 0 | 0.016 | 0 | 1 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | 0.011 | 0.016 | 0.679 | 0.498 |

**Table 6** Linear regression for the fixation proportions in the ROI of classifier when classifier is kuai

| Contrast | Estimate | SE | t | *p* |
|---|---|---|---|---|
| (Intercept) | 0.25 | 0.002 | 119.591 | < 0.001 |
| *Condition 1* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | − 0.005 | 0.01 | − 0.488 | 0.626 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | 0.003 | 0.01 | 0.325 | 0.745 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | 0.002 | 0.01 | 0.163 | 0.871 |
| *Condition 2* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | 0.002 | 0.01 | 0.163 | 0.871 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | 0 | 0.01 | 0 | 1 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | − 0.005 | 0.01 | − 0.488 | 0.626 |
| *Condition 3* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | − 0.298 | 0.01 | − 29.131 | < 0.001 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | 0 | 0.01 | 0 | 1 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | 0.002 | 0.01 | 0.163 | 0.871 |

**Table 7** Linear regression for the fixation proportions in the ROI of adjective when the classifier is ba

| Contrast | Estimate | SE | t | *p* |
|---|---|---|---|---|
| (Intercept) | 0.251 | 0.004 | 65.431 | < 0.001 |
| *Condition 2* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | 0.012 | 0.015 | 0.814 | 0.416 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | 0.407 | 0.015 | 26.498 | < .001 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | 0.013 | 0.015 | 0.814 | 0.416 |
| *Condition 3* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | − 0.309 | 0.015 | − 20.106 | < 0.001 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | − 0.004 | 0.015 | − 0.232 | 0.816 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | − 0.005 | 0.015 | − 0.349 | 0.728 |

**Table 8** Linear regression for the fixation proportions in the ROI of adjective when the classifier is gen

| Contrast | Estimate | SE | t | *p* |
|---|---|---|---|---|
| (Intercept) | 0.251 | 0.003 | 73.628 | < 0.001 |
| *Condition 2* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | 0.079 | 0.014 | 5.771 | < 0.001 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | 0.024 | 0.014 | 1.749 | 0.081 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | − 0.093 | 0.014 | − 6.821 | < 0.001 |
| *Condition 3* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | − 0.262 | 0.014 | − 19.238 | < 0.001 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | 0 | 0.014 | 0 | 1 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | 0 | 0.014 | 0 | 1 |

**Table 9** Linear regression for the fixation proportions in the ROI of adjective when the classifier is kuai

| Contrast | Estimate | SE | t | *p* |
|---|---|---|---|---|
| (Intercept) | 0.251 | 0.003 | 83.157 | < 0.001 |
| *Condition 2* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | 0.139 | 0.012 | 11.499 | < 0.001 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | − 0.021 | 0.012 | − 1.778 | 0.076 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | − 0.144 | 0.012 | − 11.973 | < 0.001 |
| *Condition 3* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | − 0.293 | 0.012 | − 24.301 | < 0.001 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | 0.01 | 0.012 | 0.83 | 0.407 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | − 0.014 | 0.012 | − 1.185 | 0.236 |

**Table 10** Linear regression for the fixation proportions in the ROI of count noun with classifier ba

| Contrast | Estimate | SE | t | *p* |
|---|---|---|---|---|
| (Intercept) | 0.25 | 0.007 | 38.171 | < 0.001 |
| *Condition 1* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | 0.194 | 0.032 | 6.032 | < 0.001 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | 0.325 | 0.032 | 10.119 | < 0.001 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | 0.013 | 0.032 | 0.389 | 0.697 |
| *Condition 2* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | 0.437 | 0.032 | 13.621 | < 0.001 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | 0.234 | 0.032 | 7.297 | < 0.001 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | 0.019 | 0.032 | 0.584 | 0.56 |
| *Condition 3* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | − 0.666 | 0.032 | − 20.724 | < 0.001 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | 0.669 | 0.032 | 20.821 | < 0.001 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | 0.05 | 0.032 | 1.557 | 0.12 |

**Table 11** Linear regression for the fixation proportions in the ROI of count noun with classifier gen

| Contrast | Estimate | SE | t | *p* |
|---|---|---|---|---|
| (Intercept) | 0.251 | 0.008 | 31.178 | < 0.001 |
| *Condition 1* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | 0.212 | 0.039 | 5.395 | < 0.001 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | 0.308 | 0.039 | 7.827 | < 0.001 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | 0.004 | 0.039 | 0.106 | 0.916 |
| *Condition 2* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | 0.204 | 0.039 | 5.183 | < 0.001 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | 0.325 | 0.039 | 8.251 | < 0.001 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | − 0.012 | 0.039 | − 0.317 | 0.751 |
| *Condition 3* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | 0.088 | 0.039 | 2.221 | 0.027 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | 0.358 | 0.039 | 9.097 | < 0.001 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | 0.037 | 0.039 | 0.952 | 0.342 |

**Table 12** Linear regression for the fixation proportions in the ROI of count noun with classifier kuai

| Contrast | Estimate | SE | t | *p* |
|---|---|---|---|---|
| (Intercept) | 0.25 | 0.006 | 44.111 | < 0.001 |
| *Condition 1* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | 0.33 | 0.028 | 11.875 | < 0.001 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | 0.203 | 0.028 | 7.287 | < 0.001 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | − 0.015 | 0.028 | − 0.54 | 0.59 |
| *Condition 2* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | 0.175 | 0.028 | 6.298 | < 0.001 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | 0.338 | 0.028 | 12.145 | < 0.001 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | 0.01 | 0.028 | 0.36 | 0.719 |
| *Condition 3* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | 0.327 | 0.028 | 11.785 | < 0.001 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | 0.223 | 0.028 | 8.007 | < 0.001 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | 0.02 | 0.028 | 0.72 | 0.472 |

**Table 13** Linear regression for the fixation proportions in the ROI of mass noun with classifier ba

| Contrast | Estimate | SE | t | *p* |
|---|---|---|---|---|
| (Intercept) | 0.25 | 0.007 | 36.136 | < 0.001 |
| *Condition 1* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | 0.012 | 0.034 | 0.369 | 0.712 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | − 0.328 | 0.034 | − 9.691 | < 0.001 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | -0.006 | 0.034 | − 0.185 | 0.854 |
| *Condition 2* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | − 0.012 | 0.034 | − 0.369 | 0.712 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | − 0.462 | 0.034 | − 13.66 | < 0.001 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | 0.178 | 0.034 | 5.261 | < 0.001 |
| *Condition 3* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | − 0.078 | 0.034 | − 2.307 | 0.022 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | − 0.25 | 0.034 | − 7.384 | < 0.001 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | − 0.253 | 0.034 | − 7.476 | < 0.001 |

**Table 14** Linear regression for the fixation proportions in the ROI of mass noun with classifier gen

| Contrast | Estimate | SE | t | *p* |
|---|---|---|---|---|
| (Intercept) | 0.252 | 0.006 | 40.44 | < 0.001 |
| *Condition 1* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | 0.025 | 0.031 | 0.818 | 0.414 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | − 0.4 | 0.031 | − 13.081 | < 0.001 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | 0.029 | 0.031 | 0.954 | 0.341 |
| *Condition 2* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | − 0.017 | 0.031 | − 0.545 | 0.586 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | − 0.283 | 0.031 | − 9.265 | < 0.001 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | − 0.267 | 0.031 | − 8.72 | < 0.001 |
| *Condition 3* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | − 0.058 | 0.031 | − 1.908 | 0.057 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | − 0.296 | 0.031 | − 9.674 | < 0.001 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | − 0.217 | 0.031 | − 7.085 | < 0.001 |

**Table 15** Linear regression for the fixation proportions in the ROI of mass noun with classifier kuai

| Contrast | Estimate | SE | t | *p* |
|---|---|---|---|---|
| (Intercept) | 0.25 | 0.004 | 58.629 | < 0.001 |
| *Condition 1* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | 0.005 | 0.021 | 0.239 | 0.811 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | − 0.383 | 0.021 | − 18.31 | < 0.001 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | − 0.03 | 0.021 | − 1.436 | 0.152 |
| *Condition 2* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | − 0.008 | 0.021 | − 0.359 | 0.72 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | − 0.277 | 0.021 | − 13.284 | < 0.001 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | − 0.293 | 0.021 | − 14.002 | < 0.001 |
| *Condition 3* | | | | |
| Cl-[Adj-OCN]–[Adj-Cl]-OCN | − 0.062 | 0.021 | − 2.992 | 0.003 |
| [Adj-Cl]-OCN–Cl-[Adj-OMN] | − 0.265 | 0.021 | − 12.686 | < 0.001 |
| Cl-[Adj-OMN]–[Adj-Cl]-OMN | − 0.253 | 0.021 | − 12.087 | < 0.001 |

**Table 16** The count & mass nouns selected in the noun rating test

| | Ontological count nouns | | Ontological mass nouns | |
|---|---|---|---|---|
| *Ba* | *Shaozi* | 'spoon' | *Shizi* | 'pebble' |
| | *Chizi* | 'ruler' | *Zhongzi* | 'seed' |
| | *Tongsuo* | 'locker' | *Hongdou* | 'red bean' |
| | *Yaoshi* | 'key' | *Muchai* | 'firewood' |
| *Gen* | *Huanggua* | 'cucumber' | *Shengzi* | 'string' |
| | *Xiangjiao* | 'banana' | *Xiangchang* | 'sausage' |
| | *Muahua* | 'fried twist' | *Mugun* | 'stick' |
| *Kuai* | *Yupei* | 'jade' | *Dangao* | 'cake' |
| | *Jimu* | 'building block' | *Huangyou* | 'butter' |
| | *Shoujuan* | 'handkerchief' | *Nailao* | 'cheese' |
| | *Huaban* | 'sketchpad' | *Xiangpi* | 'eraser' |
| | *Hongzhuan* | 'brick' | *Feizao* | 'soap' |

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## Declarations

**Conflict of interest** The authors declared that there were no conflicts of interest with respect to the authorship or the publication of this article.

**Consent to Participate** Informed consent was obtained from all individual participants included in the study.

**Ethical Approval** All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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