Event-related potentials (ERPs) serve as an ideal measure to address this issue because se

might simply be due to some idiosyncrasies of Chinese grammar, rather than reflecting the predictions of the two parsing models.

Second, results of some Chinese ERP studies might be subject to different interpretations. For instance, in an auditory ERP study on the BA construction, Ye et al. [24] created syntactic-category anomaly by deleting the object NP after BA and semantic anomaly by violating the semantic selection of the verb, as in the combined anomalies (e.g., , 'Exploiting the forest, the lumberjack BA (pine trees) cut'). They found broad negativities in the 300–500 ms range (N400) after the onset of the critical verb. But given that the critical verb occurred at the end of the sentence, such negativities could be related to sentence-final wrap-up processes [29]. Furthermore, Chinese is a tonal language and has many homophones, which means that different words share the same pronunciation. Given the auditory modality used in this study, the negativities could be partly due to semantic confusion caused by homophone activation.

Third, in terms of ERP experimental design, the criterion for syntactic category violation is less straightforward in Chinese than in strong configurational languages such as German. This applies to several studies including Wang et al. [28]. In the Chinese passive BEI construction, where the theme/patient precedes BEI, and the agent occurs after BEI. They created combined anomalies by using an intransitive verb (e.g. 'sob') which violated both (sub)categorization selection and semantic selection (given the preceding agent NP), as in 'The lost children were sobbed to mountain areas by outlaws'. The assumption here was that incorrect verb transitivity (verb-subcategorization violation) involves both syntactic violation and semantic mismatch. Wang et al. [28] observed an N400-P600 pattern in this condition. However, one might argue that this verb-subcategorization violation should not, in a strict sense, be considered as syntactic category violation, and hence the pattern of effect should not be taken as evidence against the syntax-first view. Indeed, this N400-P600 response for subcategorization violation has been demonstrated in several previous studies, including the study by Friederici herself [30].

Leaving aside the problematic manipulation of verb (in)transitivity, Zhang and colleagues' work on the BA construction appears to be especially enlightening [25,26]. In Experiment 1 of Zhang et al. [26], they created combined anomalies by replacing the post-adverbial verb (e.g., 'peel') with a noun (e.g. 'piano'), thereby violating both word category and semantic selection of a verb that is highly expected (given the syntactic frame of the BA construction and the preceding adverb 'slowly'), as in (Li Wei BA fresh pears slowly piano-le$_{PERF}$ two, 'Li Wei piano-ed two fresh pears slowly'). The N400 effect was found in combined anomalies, indicating that semantic integration persisted even when syntactic category-based structure building presumably failed. Yet given that the BA construction tested in Zhang et al. is specific to Chinese, their conclusion might not be generalized unless further evidence is obtained using some construction commonly shared between Chinese and German.

In the current study, we aimed to overcome the above difficulties, including the 'comparability'

We adopted the same design as Zhang et al. [26] in the BA construction by manipulating semantic consistency (consistent vs. inconsistent) and syntactic category (noun vs. verb) of the critical verb. We hypothesized that semantic anomaly would elicit an N400 effect, and syntactic-category anomaly would elicit a P600 effect. Critically, for combined anomalies, there would be no N400 effects according to the syntax-first model, but according to interactive/concurrent models, it would result in a strong N400 effect.

Method

Participants

Twenty-eight right-handed undergraduate and graduate native Chinese speakers from Peking University or neighboring universities were paid to participate in the experiment. Four were excluded from data analysis due to excessive eye or head movements artifacts (over 40% trials). The remaining 24 participants (13 female) aged between 19 and 25 years, with a mean age of 21.6 (SD = 1.86) years. No participants reported any cognitive or psychiatric disorders or vision deficit (after correction). Informed written consent was obtained from each participant before the test. This study was carried out in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of the Department of Psychology, Peking University.

Materials and norming tests

In our study, the structure of the passive stimuli was Det + NP1 (inanimate) + BEI + NP2 (animate) +ADV +V/N + Le (PERF) + FreqAdv. We added an aspect marker *le* and an adverbial modifier after the critical verb for two reasons. First, sentences can continue after the critical verb, allowing us to avoid the sentence-final wrap-up effects. Second, Chinese passive structures typically denote completion of an action [31,32], thus an aspect marker and a frequency-denoting adverbial modifier can convey a sense of completion associated with the verbs. All two-character human names serving as agent NPs are taken from Jiang and Zhou [33], with word frequencies and number of strokes well controlled across conditions.

All sentences were visually presented segment by segment (see Table 1; the word between two slashes presented as one segment in one screen). We manipulated the verb's semantic consistency (SEM) to its argument/patient NP (consistent vs. inconsistent) and its syntactic category

Table 1. Exemplar stimuli for the four critical conditions, with English translations.

a. CORRECT	/ / / / / /	
	Det/glass/ BEI/ Name/carefully/**wipe**/ASP/many times.	
	(That piece of glass is carefully **wiped** by Na Jiang many times.)	
b. SEMANTIC	/ / / / / / /	
	Det/plan/ BEI/ Name/carefully/**wipe**/ASP/many times.	
	(That plan is carefully **wiped** by Jie Hu many times.)	
c. SYNTACTIC	/ / / / / / /	
	Det/glass/ BEI/ Name/carefully/**dishcloth**/ASP/many times.	
	(That piece of glass is carefully **dishcloth** by Na Jiang many times.)	
d. COMBINED	/ / / / / / /	
	Det/plan/ BEI/ Name/carefully/**dishcloth**/ASP/many times.	
	(That plan is carefully **dishcloth** by Jie Hu many times.)	

The critical words are in bold.

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(SYN) (verb vs. noun), yielding four conditions in Table 1: CORRECT (SEM+, SYN+), SEMANTIC (SEM-, SYN+), SYNTACTIC (SEM+, SYN-), and COMBINED (SEM-, SYN-).

Five Norming pretests. We conducted five pretests to check various properties of the stimuli. The first test was conducted on all syntactic-category anomalous sentences (in the SYNTACTIC and COMBINED conditions), in which the critical region was a noun. A group of 20 participants who did not participate in the ERP test were asked to make the sentences more natural or acceptable by changing whichever word(s) they thought necessary. On average, 99% of the time participants correctly identified the anomalous nouns, and changed them to transitive verbs. These results showed that participants detected the syntactic-category anomaly at the critical region and expected the words to be verbs.

To further quantify the degree of semantic anomaly across conditions, we conducted a second pretest on comprehensibility/semantic acceptability of the critical sentences. A different group of 32 participants were asked to judge the comprehensibility of each sentence on a 5-point scale, with 1 meaning completely incomprehensible and 5 quite comprehensible. Table 2 shows the mean ratings in the four conditions. A repeated measures ANOVA with semantic consistency and syntactic category as two within-participant factors showed a significant effect of semantic consistency, $F(1, 31) = 662.64$, $p < 0.001$, a significant main effect of syntactic category, $F(1, 31) = 143.42$, $p < 0.001$, and a significant interaction between them, $F(1, 31) = 57.92$, $p < 0.01$. Further analysis showed that the comprehensibility scores differed between conditions, even for the smallest difference between SEMANTIC and COMBINED conditions, $F(1, 31) = 41.14$, $p < 0.001$.

To further determine the validity of our stimuli, we conducted the fifth pretest on sentence congruency related to our phrasal structure, in order to make sure that the transitive verbs could indeed be used in the BEI constructions, and that the counterpart nouns used in the SYNTACTIC condition really did not make sense in such structures. The phrasal segments (e.g., "... ", BEI...carefully wipe) were rated on a 5-point scale by another group of 34 participants regarding how plausible it was to use the phrasal segments to construct a congruent sentence (ranging from 1 = extremely implausible to 5 = fully plausible). A repeated measures ANOVA revealed a significant main effect of condition, $F(1, 33) = 2119.30$, $p < .001$. Post-hoc Bonferroni comparisons showed that the mean score of the noun in SYNTACTIC and COMBINED (mean = 1.97, SD = 0.11) was significantly lower than that of the transitive verbs in CORRECT and SEMANTIC (mean = 4.57, SD = 0.08).

Materials. Each participant read 160 critical sentences, with 40 in each condition. Word frequencies and strokes of critical words and Patient NPs were well matched across conditions ($p > .1$). In addition, 220 filler items were used to prevent participants from developing test-taking strategies. Eighty were correct BEI sentences with two NPs varied in their animacy status. These sentences were included to equate the numbers of the correct and incorrect BEI sentences overall and to offset the inanimate-animate configuration used in the critical sentences. The remaining 140 fillers were of different syntactic structures, including the BA construction, simple SVO sentences, topicalization, and complex clauses.

Four lists were created using a Latin Square design. In each list, 160 critical sentences and 220 fillers were pseudo-randomized, such that no more than 4 BEI sentences and no more than two critical sentences of the same condition appeared consecutively.

Procedure

Participants sat approximately 100 cm away from a CRT computer screen in a dim and sound-

mastoids. The vertical electro-oculogram (VEOG) was recorded from electrodes placed above the right eye. The horizontal EOG (HEOG) was recorded from electrodes placed at the outer cantus of left eye. Electrode impedance was kept below 5 kΩ. The biosignals were amplified with a band pass from 0.016 to 100 Hz and digitized on-line with a sampling frequency of 500 Hz. ERPs were additionally filtered for plots with 20Hz low pass. The ocular artifacts were corrected automatically, with both VEOG and HEOG as common reference and blink detection by algorithms implemented in Brain Vision Analyzer. The original ERP data and the data produced during the analysis can be found in Harvard Dataverse Database (doi: 10.7910/DVN/28781).

ERP analysis

ERPs were computed for each sentence type, electrode site, and participant. Sentences contaminated by excessive movement artifacts (mean voltage exceeding ±100 μV) or incorrectly judged were excluded before averaging. The overall trials rejection rate was 11.3% across all 24 participants and conditions. The mean rejection rate for each condition was 13.3% (SD = 0.14) for CORRECT, 12.3% for SEMANTIC (SD = 0.14), 9.2% (SD = 0.09) for SYNTACTIC and 10.5% (SD = 0.14) for COMBINED.

Analyses were based on the critical verbs in the critical sentences. Since the critical words were preceded by different words in different conditions (see Table 1), we used a post stimulus-onset baseline covering 100 ms post critical-word-onset, following Friederici et al. [22]. Subsequent analyses were based on 800 ms-epochs post onset of the critical words. Two time windows were chosen on the basis of visual inspection and previous studies [15,25]: (1) 300–500 ms time window for possible N400 effects; (2) 500–800 ms for possible P600 effects. A repeated measures analyses of variance (ANOVAs) were conducted on the average ERP amplitudes in the two time windows with following within-subjects factors: semantic consistency (SEM+, SEM-), syntactic category (SYN+, SYN-), hemisphere (left, middle and right) and region (anterior, central and posterior). Crossing the factors of hemisphere and region produced nine regions of interest (ROI), each with 6, 4, or 2 electrodes, including left anterior (F1, F3, F5, FC1, FC3, FC5), left central (C1, C3, C5, CP1, CP3, CP5), left posterior (P1, P3, P5, PO3), middle anterior (FZ, FCZ), middle central (CZ, CPZ), middle posterior (PZ, POZ), right anterior (F2, F4, F6, FC2, FC4, FC6), right central (C2, C4, C6, CP2, CP4, CP6) and right posterior (P2, P4, P6, PO4). Mean amplitudes were averaged over electrodes in each ROI for statistical purpose. Comparisons were planned for each ROI if interactions reached significance. The Greenhouse-Geisser correction was applied when the evaluated effects had more than one degree of freedom in the numerator. For planned comparisons, the probability levels were Bonferroni-adjusted.

Results

Behavior results

The overall response accuracy rate was 91.6% across all four conditions: 87.7% for the correct sentences (SD = 0.1); 89.2% for the semantic anomaly condition (SD = 0.1); 93.8% for the syntactic-category anomaly condition (SD = 0.09); 96% for the combined anomalies (SD = 0.06). A repeated-measures ANOVA with semantic consistency and word category as two within-participant factors showed only a significant main effect of syntactic category, $F(1, 23) = 14.59$, $p < 0.01$, with the accuracy higher for sentences in the SYNTACTIC and COMBINED conditions than for sentences in the CORRECT and SEMANTIC conditions. We did not measure RTs in this study, following Friederici et al. [22] and Zhang et al. [26]. RTs were not informative

in the current study as they were recorded long after the presentation of each sentence. In general, behavioral results showed that participants were attentive to the task.

ERP data

As shown in Fig 1 and Fig 2, in the 300–500 ms time window, compared with the CORRECT sentences, anomalous sentences in all the other three conditions (SYNTACTIC, SEMANTIC and COMBINED) elicited larger negativities (N400 effects). These effects had somewhat different distributions over the scalp (Fig 2), with the effect for SYNTACTIC predominantly on the left hemisphere and the effect for COMBINED over the whole scalp. In the time window of 500–800 ms, compared with the CORRECT sentences, sentences in the SYNTACTIC and COMBINED conditions elicited larger positivities (P600) in the centro-posterior areas whereas the effect for the SEMANTIC conditions was more left-lateralized. Statistical analyses confirmed these observations.

The 300–500 ms time window. A repeated-measures ANOVA revealed a main effect of semantic consistency, $F(1, 23) = 20.2$, $p < 0.01$, suggesting that sentences in the SEMANTIC and COMBINED conditions evoked a larger N400 than sentences in the CORRECT and

SYNTACTIC conditions. This effect did not interact with syntactic category, F(1, 23) = 0.341, p > 0.1, but interacted with hemisphere and region, F(4, 92) = 4.167, p < 0.01, indicating that the size of the main effect of semantic consistency varied over different scalp areas (Figure 2). Importantly, the main effect of syntactic category also reached significance, F(1, 23) = 16.41, p <

and SYNTACTIC conditions did not reach significance, F(1, 23) = 1.17, p = 0.1, although it did interact with hemisphere and region, F(4, 92) = 2.46, p = 0.05. Detailed analyses for ROIs showed that the N400 effect was stronger for the SEMANTIC condition than for the SYNTACTIC condition in middle posterior, right central and right posterior areas (0.05 or 0.05 < p < 0.1). Importantly, the N400 effect for the COMBINED condition was larger than the effect for either the SEMANTIC or SYNTACTIC conditions: F(1, 23) = 3.19, 0.05 < p < 0.1, and F(1, 23) = 6.74, p < 0.05, respectively (Fig 2).

The 500–800 ms time window. A repeated-measures ANOVA revealed a significant main effect of syntactic category, F(1, 23) = 8.17, p < 0.01, with syntactically anomalous sentences in the SYNTACTIC and COMBINED conditions being more positive than sentences in the CORRECT and SEMANTIC conditions. This effect interacted with hemisphere, F(2, 46) = 3.29, p

Discussion

The main goal of this study was to test whether Chinese sentence processing was consistent with the syntax-first model by using the BEI construction, a passive structure that has not been extensively studied but is most comparable to the German passive. Overall, we found both N400 and P600 effects for sentences with semantic anomaly, with syntactic category anomaly, or with combined anomalies. Our results replicate and extend findings from previous Chinese ERP studies that used different structures [24–27] and present a solid piece of evidence against the syntax-first model.

The present findings demonstrate the importance of probing processing differences from a cross-linguistic perspective. By using passive sentences, we ruled out the potential confound o sentence structure in the previous ERP studies on Chinese. As stated in the introduction, evidence supporting the syntax-first model comes mainly from German passive structures [15,16,22]. However, existing ERP results in Chinese that conflict with this model could be attributed to the idiosyncrasies of the Chinese language. By using the Chinese BEI structure that closely resembles the German passive structure, we obtained a pattern of effects that supports existing ERP work on the BA construction and offers converging evidence that semantic processing in Chinese does not need to be licensed by syntax.

After controlling for structural differences between the two languages, what is the real rea-

(although these words were not presented). Federmeier and Kutas [36] also demonstrated that words that were expected with respect to sentential context but were from the same semantic category as the expected words elicit reduced N400 responses, compared with words that were expected and were from different categories. This finding was interpreted as reflecting the impact of context-independent long-term memory structure on sentence processing: semantic features shared between the target words and the unexpected but related words are activated by sentence context, facilitating to a certain degree the integration of the former with the context. For the present study, although the critical words and the most expected words were largely from the same category (verbs for the SEMANTIC condition) or from different categories (nouns vs. verbs for the SYNTACTIC and COMBINED conditions), they nevertheless varied over conditions in terms of semantic relatedness (Table 2). It is possible that this variation contributed to the differential N400 responses in the three anomalous conditions.

Second, compared with the correct sentences, sentences with syntactic anomaly also elicited increased N400 responses. This effect seems surprising. But both comprehensibility ratings and the rating of semantic relatedness between the critical words and contextually-expected words (Table 2) indicated that participants had more difficulties in integrating the critical nouns, which violated the expectancy of verbs at the critical position in the SYNTACTIC condition, compared with the processing of critical verbs in the CORRECT condition. The finding of increased N400 responses for the SYNTACTIC condition, as compared with the CORRECT condition, was very much consistent with the finding of increased N400 responses for the COMBINED condition, as assessed against the SYNTACTIC and SEMANTIC conditions.

The third noteworthy finding is that in the 500–800 ms time window, we observed a positivity effect for sentences with semantic anomaly in a parietal region. This effect appeared to be similar to the "semantic P600" that was reported not only for thematic role reversals [39–41], but also for the violations of semantic constraints between the verb and the object noun in a complex syntactic structure [42,43]. Jiang and Zhou [43] suggested that the appearance of the (left-lateralized) semantic P600 indicates the initiation of a coordination process for multiple semantic processes at different levels of syntactic hierarchy. When the semantic process at one level encounters difficulties, the processing system may initiate a process redeploying the processing focus from this level to the semantic process at another level, in order to mitigate the difficulty in constructing a meaningful representation. Differing from the previous studies in which the semantic P600 effects were observed at the position of object nouns, our P600 effect here was obtained on the verbs, which were also embedded in a hierarchical structure. It is plausible that such coordination was also initiated by the input of the incorrect verb which had to satisfy both the local constraints between the adverbs and the verb and the long-distance dependency between the object noun and the verb. Further studies are needed to verify our findings and to choose between different accounts of the semantic P600.

The fourth noteworthy finding in our study is the "asymmetry" between semantic and syntactic processing. During the 300-500ms time window, we found a significantly stronger N400 effect in the COMBINED condition than in the SEMANTIC condition; however, we find no difference for the P600 effect between the SYNTACTIC and COMBINED conditions. This asymmetry seems consistent with the findings of Hagoort (2003), who specifically tested the effects of combined violations in relation to the effects of single semantic and single syntactic violations in Dutch. As suggested by Hagoort (2003), semantic integration is influenced by syntactic processing, however, the assignment of syntactic structure is independent of semantic context. We are cautious about whether our study supports this conclusion, because (i) a number of studies have also shown an increased P600 in the COMBINED condition relative to the SYNTACTIC condition (Friederici et al., 2004; Wang et al., 2013) and (ii) the increased N400 effect in the COMBINED condition of our study can be largely explained by the results of

pre-tests and the negativities in the SYNTACTIC condition (see above discussion). It is possible that the interplay of syntax and semantics is asymmetric during online processing, but more work is needed in order to fully understand the underlying mechanism.

To conclude, the current study on Chinese passive sentences is consistent with studies on other Chinese structures[24–28] and demonstrates an N400 effect for sentences with both semantic anomaly and syntactic category anomaly, indicating that semantic processing persist in face of anomalous syntactic structure. Claims of syntactic category processing primacy do not apply to Chinese.

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Author Contributions

Conceived and designed the experiments: YY FW XZ. Performed the experiments: YY. Analyzed the data: YY FW. Contributed reagents/materials/analysis tools: YY XZ. Wrote the paper: YY FW XZ.

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