studies demonstrate clear developmental courses from children to adults in phonological (Bonte and Blomert, 2004; Brem et al., 2006; Coch et al., 2002, 2005; Grossi et al., 2001; Licht et al., 1988

location was significant, $F(1, 24) = 28.98$, $p < 0.001$, with the anterior regions (9.14 μV) significantly more positive than the posterior regions (5.63 μV). Importantly, the interaction be-

$F(2, 48) = 7.09$, $p < 0.01$. Further tests indicated that, for children,

Fig. 3 – Difference waveforms contrasting the homophonic and the baseline conditions and contrasting the orthographic and the baseline conditions for the adult and the child participants.

posterior regions was marginally significant ($0.05<p<0.1$), although the peak amplitude showed a similar trend of increasing over the homophonic, the orthographic and the baseline conditions.

Analyses of the normalized data produced essentially the same pattern of effects. There was no main effect of participant group, F (1, 24) <1, but a main effect of condition, $F(2, 48)=7.66$, $p<0.001$. Further tests showed that the peak amplitudes for the orthographic (5.52 μV) and the homophonic (5.00 μV) conditions were significantly less positive ($p<.05$ or $p<0.01$) than for the baseline condition (6.40 μV). The main effect of anterior/posterior was significant, $F(1, 24)=28.98$, $p<0.001$. Moreover,

($p<0.01$) than the amplitude for the baseline condition (1.88 μV); the difference between the orthographic and the homophonic conditions was marginally significant ($0.05<p<0.1$). Importantly, the interaction between participant group and experimental condition was significant, $F(2, 48)=5.39$, $p<0.01$. Further tests showed that the mean amplitude in the homophonic condition was significantly more negative ($p<0.01$) for children (−3.50 μV) than for adults (−0.19 μV). Moreover, while the amplitudes in the orthographic and the homophonic conditions were more negative ($p<0.01$) than the baselines for both participant groups, showing the N400 effects, only for the child group was the amplitude in the homophonic condition (−3.50 μV) more negative ($p<0.001$) than the amplitude in the orthographic condition (−1.50 μV), indicating a larger N400 effect for the former than for the latter condition. The main effect of anterior/posterior location was significant, $F(1, 24)=32.03$, $p<0.0001$, with more negative ERP responses at anterior regions (−2.06 μV) than at posterior regions (1.43 μV). The interaction between participant group, experiment condition and anterior/posterior location was significant, $F(2, 48)=5.41$, $p<0.01$. Further test showed that the above difference between the two participant groups in the homophonic condition appeared at both anterior and posterior regions ($p<0.05$), while at the same time the child participants showed also more negativity than the adult readers for the baseline condition at anterior sites ($p<0.01$). The main effect of laterality was significant, $F(2, 48)=15.44$, $p<0.001$, with the most negative ERP responses in the midline (−1.27 μV) than at the left (0.71 μV) or right (−0.39 μV) side.

In the analysis of peak latencies, the main effect of participant group was significant, $F(1, 24)=6.51$, $p<0.05$, with the peak appeared earlier for adults (381 ms) than for children (413 ms). The main effect of experimental condition was also significant, $F(2, 48)=4.22$, $p<0.05$, indicating that, relative to the baseline (389 ms), the appearance of the peak was delayed less severely by orthographic mismatch in the homophonic condition (393 ms) than by phonological mismatch in the orthographic condition (409 ms). Importantly, the interaction between participant group and experimental condition was significant, $F(2, 48)=3.83$, $p<0.05$. Further tests showed that the peak appeared earlier for adults than for children in the baseline ($p<0.01$) and the homophonic ($p<0.05$) conditions, but not in the orthographic condition ($p>0.1$). Moreover, for adults, the peak appeared earlier for the homophonic (379 ms) and the baseline (362 ms) conditions ($p<0.05$ or 0.01) than for the orthographic condition (403 ms). The main effect of anterior/posterior location was significant, $F(1, 24)=18.53$, $p<0.001$, with the peak appeared earlier at posterior regions (387 ms) than at anterior regions (407 ms).

In addition, we used the Jackknife-based procedure (Miller et al., 1998; Ulrich and Miller, 2001) to evaluate whether the onsets and offsets of the N400 effects for the orthographic and homophonic conditions differed between the adult and the child participants. The onset and offset of the differential effects reaching significance were defined as the points equating to 60% of the peak amplitudes of the differential effects (Fig. 3), taking into account the starting points of the N400 components illustrated in Figs. 1 and 2. Thus for the child and the adult readers respectively, the onsets of the differential effects contrasting the homophonic and the baseline conditions were 302 ms and 330 ms, and the onsets of the differential effects between the orthographic and the baseline conditions were 327 ms and 363 ms. ANOVA with participant group (adults vs. children) as a between-participant factor and experimental condition (orthographic vs. homophonic) as a within-participant factor found neither a significant main effect of participant group, $F(1, 24)=1.88$, $p>0.1$, nor interaction between participant group and experimental condition, $F<1$, although the main effect of experimental condition was marginally significant, $F(1, 24)=3.11$, $0.05<p<0.1$. These findings suggested that while the differential N400 effects starts at essentially the same time points for the child and the adult readers, the effect for orthographic mismatch in the homophonic condition appeared somewhat earlier than the effect for phonological mismatch in the orthographic condition.

On the other hand, for the child and the adult readers respectively, the offsets of the differential effectl tJ-1.9(h)0(3)23.3nesdie forttd children than for adults, and the peaks of this component in the recovery process, allowing the processing system to search for a solution in a well-defined, often explicitly taught homophonic set.

To conclude, by measuring ERP responses to mismatches between orthographic or phonological input and the underlying representations in the lexicon and by comparing children with adult readers, we demonstrate that both Chinese adult readers and school children rely more on orthographic information than on phonological information to access lexical semantics in reading for meaning during sentence comprehension, but the differential effects between orthography and phonology may have different ERP manifestations in adults and children. Further, longitudinal studies are needed to confirm and extend these findings.

4. Experimental procedures

4.1. Participants

Thirteen undergraduate students (5 female and 8 male, aging between 19–24 years old) from Peking University took part in the experiment. They received 50 Chinese yuan (about 8 US dollars) for their participation. In addition, 13 fourth and fifth grade school children, with a mean age of 10 years and 6 months, participated in the study. They were screened from several primary schools in Beijing, originally as control participants for our earlier study on orthographic and phonological processing in Chinese dyslexic children (Meng et al., 2007). Raven's standard progressive matrices (IQ test), reading fluency, and vocabulary test showed that these children's IQ and reading ability were normal. Parents of all the child participants gave their informed consent for the children to participate in the experiment. The children were accompanied by their parents to the ERP laboratory. All the participants were right-handed and had normal or corrected-to-normal vision. None of the participants had a history of neurological or emotional disorders.

4.2. Stimuli

4.2.1. Stimuli and design

The experiment had three conditions: the orthographic condition; the homophonic condition; and the correct, baseline condition. In the former two conditions, the second characters (morphemes) of two-character compound words that could fit with the sentence context were replaced with characters that were orthographically similar or homophonic to the original characters, resulting in compound nonwords. All the correct or incorrect words were embedded at the end of sentences (see Table 1).

The orthographic similarity between the replacing characters and the base characters in the orthographic condition was mostly achieved by they having the same phonetic radicals (e.g., 服, /fu2/, *clothes*, 报

for the 60 pairs of the base characters and the replacing characters in the orthographic condition was 3.5 and 3.9 respectively for children and adults.

4.3. Procedure

The participants were tested individually in a sound-attenuating and electrically shielded booth. They were seated in a comfortable sofa in front of a computer monitor. Before the experiment started, the participants performed a practice block of 15 sentences and they were told to relax as much as possible without moving their heads. Sentences were presented at the center of the computer screen word-by-word. Each word was presented for 500 ms. The sentence-final critical word (non-word) was presented together with the mark of full stop. The participants had 2500 ms to make the acceptability judgment for the sentence. The experiment consisted of 8 testing blocks, with each block having 40 sentences. Sentences from different conditions and the filler sentences were randomized before being presented to the participants. The whole experiment lasted for about 2 h.

Participants were asked to judge whether sentences were semantically acceptable. In order to balance the potential “yes” and “no” responses, 100 correct and 40 semantically unacceptable sentences were added to the critical sentences. The unacceptable filler sentences had incorrect characters in the middle of sentences to prevent the participants from forming response strategies based on the position of critical words.

4.4. EEG recording and data analyses

The EEG data was recorded and analyzed by NeuroScan 4.3.1. The EGG was recorded with 32 electrodes based on the advanced International 10–20 system. The vertical electrooculogram (VEOG) was recorded from electrodes placed above and below the right eye. The horizontal EOG (HEOG) was recorded from electrodes placed 1.5 cm lateral to the left and right external canthi. The linked bilateral mastoids served as reference points and the AFz electrode on the cap served as ground. Electrode impedance was kept below 5 kΩ. The EEG was amplified (band pass 0.05–70 Hz) and digitized at a sampling rate of 500 Hz. The continuous EEG recordings were epoched off-line (−200–1000 ms). Any trail with EOG artifacts greater than ±75 mV was excluded from further analysis. The ERPs were recorded from the onset of the final word in each sentence. They were averaged separately off-line for each condition.

For the statistical analysis of the ERP effects, only trials with correct responses in the sentence acceptability judgment were analyzed. Because the preceding words before the critical targets were different between conditions, we used the ERPs in the 0–100 ms for baseline correction to control for the potential influence of the preceding words on ERP responses to the critical words. It turned out that the results had no substantial difference from the results with −200–0 ms ERPs for baseline correction, as we have reported for the child participants (Meng et al., 2007). Peak amplitudes and latencies of N100 and P200 were obtained in the 50–150 ms, and 150–300 ms time window, respectively, and the mean amplitudes of N400 were calculated for the window 300–500 ms. Peak latencies of N400 were also obtained in this time window.

In addition, to control for the typically the larger ERP amplitudes in children than for adults, the amplitude data were normalized with the formula (score − mean/SD), where score was an ERP average amplitude value (one for each condition and scalp site for each participant), mean was the mean amplitude across all the participants in a particular age group, and SD was the standard deviation of the mean amplitude (Coch et al., 2002, 2005; Holcomb et al., 1992). The data were entered into the mixed-design analyses of variance (ANOVAs), with participant group (children vs. adults) as a between-participant S263.8-61or,.8(S2-1.43:pera610.6(d)-42we)TJ0-u2 and

Coch, D., Grossi, G., Coffey-Corina, S., Holcomb, P.J., Neville, H.J., 2002. A developmental investigation of ERP auditory rhyming effects. Dev. Sci. 5, 467–489.
Coch, D., Grossi, G., Skendzel, W., Neville, H.J., 2005. ERP nonword rhyming effects in children and adults. J. Cogn. Neurosci. 17, 168–182.
Connolly, J.F., Phillips, N.A., Forbes, K.A.K., 1995. The effects of phonological and semantic features of sentence-ending words on visual event-related brain potentials. EEG. Clin. Neurophysiol. 94, 276–287.
Dambacher, M., Kliegl, R., Hofmann, M., Jacobs, A.M., 2006. Frequency and predictability effects on event-related potentials during reading. Brain Res. 1084, 89–103.