A reading model of young EFL learners regarding attention, cognitive-load and auditory-assistance

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Abstract

Audio-assisted reading (reading-while-listening) was commonly used as a pedagogical method in English (L2) learning. Numerous studies had reported its efficacy in English (L2) reading. Its efficacy in reading comprehension has been inconclusive due to the lack of studies on the relationship among attention, cognitive load and L2 reading comprehension, with the possibility that the synchronous auditory input lessens attention to the visual input. We present a study of 41 Mandarin-speaking 8-year-old children reading English texts in three modes in a between-participants design. Data of cognitive load, comprehension scores and attention were fitted to a formal mathematical model, which confirmed that influences on L2 reading comprehension could be captured by interactions between attention and cognitive load. Based on the findings, three implications regarding how to appropriately apply auditory-assistant tools to L2 reading were generated.

Introduction

Reading comprehension is an important indicator of language proficiency. Readers reading in second language (L2) are required to map the orthographical forms into the phonological presentations first, and then access their semantic meanings from their first language (L1; see Van Assche et al., 2012 for review). The first process is called decoding, which makes a large positive contribution to reading comprehension at lower grades. This Simple View of Reading (SVR) theory (Gough & Tunmer, 1986) holds that reading is a product of decoding, i.e., transforming written codes to phonological codes and eventually to meanings, and linguistic comprehension. Although studies around SVR theory suggested that decoding and listening are two different factors influencing reading comprehension, the contribution of both for reading are substantial (see Jeon & Yamashita, 2014 for review), which laid a foundation for the application of audio-assisted reading.

Nowadays, audio-assisted reading has been widely employed in regular pedagogical activities of second language learning, such as improving vocabulary learning rates (Brown et al., 2008; Webb & Chang, 2012), promoting listening comprehension (Chang, 2009, 2011; Chang & Millett, 2014; Chang et al., 2019), enhancing reading fluency (Chang & Millett, 2015; Taguchi et al., 2004), and facilitating reading comprehension (Chang & Millett, 2015). Nevertheless, its effectiveness in reading comprehension is inconclusive since related studies yielded inconsistent results, for example Diao and Sweller's study (2007), Rogowsky et al.'s study (2016) showed reading-while-listening had no superiority to silent reading, and Tragant and Vallbona's study (2018) showed that audio-assistance had a moderate effect on L2 comprehension, but Chang and Millett's work (2015) showed reading-while-listening is superior to silent reading in reading comprehension.

Many factors may rise the inconsistency of the results, such as L2-vocabulary knowledge and L2-grammar knowledge (Jeon & Yamashita, 2014). ‘Attention’ as a psycholinguistic factor was found to be of vital importance in influencing the performance of audio-assisted reading, as almost all studies reported positive results suggesting that their participants’ attention had been stimulated because of the auditory-inputs. On the contrary, cognitive load was presumed to be the major reason that prevented reading-while-listening from producing satisfied reading-comprehension performance. It was assumed that the verbal redundancy, i.e., concurrently providing learners with written and verbal contents, arose cognitive-overload in L2 reading (Diao & Sweller, 2007) and L2 listening (Moussa-Inaty et al., 2012). Based on this research background, an interesting research question has emerged, that is, why and how auditory-assistance used to facilitate L2 reading comprehension can affect cognitive load.

This study scrutinised three kinds of reading statuses and two kinds of reading patterns to build up a reliable L2 reading model, which finally forms three implications regarding how to appropriately apply auditory-assistant tools to L2 reading.

Literature review

Reading modes for English

One famous English reading model was named Dural Rout Cascaded model (DRC model) of word identification (Coltheart et al., 2001), which describes how the visual features corresponding to a printed word are used to access the word’s pronunciation and meaning. The first route to identifying the meaning of the words for native speakers is: visual input→visual feature nodes→letter nodes→orthographic input lexicons→phonological output lexicon→phoneme nodes→speech; and the second route is: visual input→visual feature nodes→letter nodes→grapheme-phoneme rule system→phoneme nodes→speech (see Fig. 1 in Reichle, 2015). No matter which route readers use, decoding the visual presentations at the phoneme level is a corner-stone process to implement the reading, suggesting that for English native readers decoding at the phoneme level is a prerequisite for successful reading, and the malfunction of the decoding process would cause a language developmental delay or some pathological changes, i.e., dyslexia (for a review, see Beaton, 2004).

Nevertheless, answering questions like whether English-as-foreign-language (EFL) readers would activate the same processing steps when they read English texts requires a cross-disciplinary research given that bilingualism is associated with brain structural alterations (for review, see García-Pentón et al., 2016). BIA+ model (Dijkstra & Van Heuven, 2002) suggests that L1 and L2 lexicons stored together, and would be activated simultaneously when L2 stimuli came in, as illustrated in Figure 1. After conducted a meta-analytic review and explored 44 experiments and studies to testify the robustness of non-selective theory in BIA+ model, Lauro and Schwartz (2017) concluded that BIA+ model supports the assumption that both L1- and L2-comprehension require readers to carry out a decoding and reconstruction process. Nevertheless, it is noteworthy that BIA+ model is limited in alphabetical L1 and alphabetical Ln, but logographical L1, such as Chinese or Japanese was not under scrutinisation.

The non-selective theory revealed by the bilingual-reading models implies that the decoding of L1 complicates the decoding of L2, and how L1's decoding complicating L2's reading is varied according to the different L1 and L2. Allen and Conklin (2017) studied the impact of the words in L2 that shared the same phonological cognates with

L1 pronunciations on the L2 reading, and showed that the L2 words which had similar phonological pronunciations with L1 words but without similar orthographical presentations would not facilitate those words' recognition. Their study concluded that the cross-linguistic similarity was constrained within the orthographical similarities between L1 and L2.

It was found that Chinese (L1) readers failed to activate the left mid- superior temporal cortex in phonological processing in English reading, demonstrating that Chinese readers processed English words in the same way they did to the Chinese characters (Cao et al., 2013; Tan et al., 2003), i.e., to directly map a whole word to its corresponding phonological combination as they read Chinese words, rather than spell the word letter by letter, because of the absence of the decoding systems of mapping graphemes to phonemes (Tan et al., 2003). And this theory was also testified by other neuro-evidence (Gao et al., 2017; Qu et al., 2019; Sun et al., 2015), suggesting that the orthographical transparency would influence the recognisation in L2 reading, i.e., the deeper the language's orthography is, the more lexical-level procedures required to process the spelling (Das et al., 2011; Jamal et al., 2012; Nelson et al., 2009).

Empirical studies of using reading-while-listening in English reading

Table 1 lists the sample studies of using reading-while-listening in EFL reading and the meta-data involved in those studies, most of which were implemented with the help of electronic devices, e.g., computers. The most significant influence of the audio-assisted reading was found in promoting auditory skills, such as developing learners' auditory discrimination, and forming the pronunciation mapping. Few studies reported the negative influence on auditory performance by using reading-while-listening. Although most studies focused on college students, there still existed some studies covering teenagers and primary school students, showing that the positive effects of audio-assistance cover a long developmental span.

Studies showed that reading-while-listening promoted learners' form-meaning relationship (Malone, 2018; Osada, 2001). The effect-transfer path originated from its effectiveness in word recognition, e.g., Stenton (2012) analysed the feedback data from a computer-assisted-language-learning (CALL) tool: SWAN, and concluded that 10% of the users scored higher in lexical recognition test when reading was synchronised with visual- and auditory input, and Malone's (2018) study suggested that audio-assistance stimulated a deep processing of L2 form. Then, the benefits of lexical recognition can be transferred to vocabulary memorisation (Brown et al., 2008; Webb & Chang, 2012) and reading fluency (Chang & Millett, 2015; Taguchi et al., 2004). Finally, the influence of audio-assistance can be transferred to reading comprehension (Chang & Millett, 2015; Granena et al., 2015; Tragant & Vallbona, 2018).

However, the effects of reading-while-listening that were finally transferred to reading comprehension were not always successful. The reason that generates the inconsistency of the results comes from many aspects, among which, 'attention' was reported as one of the major reasons that impacted the comprehension results, suggesting that reading-while-listening yields different attention patterns. For example, Chang et al.'s study (2015) summarised four possible reasons to explain the efficacy of audio-assisted reading, among which the attention attracted by the audio was the most important one. Diao et al.'s (2007) study implied that reading-while-listening incurred cognitive overload which jeopardised the attention devoted to the reading tasks. In addition to the above ones, four high-evidence factors, which are correlated to L2-reading: L2 decoding, L2 vocabulary knowledge, L2 grammar knowledge, L1 reading comprehension (Jeon & Yamashita, 2014), were also considered as possible elements that influence the results.

Cognitive-load and Working memory in L2 reading

Cognitive-load in learning science is described as a multidimensional construct that represents the load that a learner carries when performing a particular learning task (Sweller, 2004). Although it was assumed that the verbal redundancy arose cognitive-overload in L2 reading (Diao & Sweller, 2007) and listening (Moussa-Inaty et al., 2012), there were some exceptions, e.g., Chang et.al., (2011) suggested in their work that the dual-channel input lowered the extraneous load for the low-proficiency learners, which in consequence led to improved listening comprehension. In Lee and Mayer's study (2018), they found that the redundancy effect disappeared, in which the researchers explained the reason as their participants put more attention efforts on the reading tasks, and the improved concentration promoted learners' tolerability to the cognitive-loads. The conflicts about 'cognitive-load' and 'attention' suggested that the two were mutually influenced because of the synchronised auditory input.

Given that working memory (WM) acts as a container with limited capacity to afford cognitive processes that are necessary in L2 processing (Ellis, 2005; Sweller, 2004), it is considered as one of the facets that comprise the cognitive-load structure. Numerous studies reported that WM outcome is highly correlated with the overall English language competence, as well as with reading, listening, speaking and the use of English (vocabulary and grammar) (Kormos & Safar, 2008). For example, Malone (2018) concluded in his study that WM outcomes correlated with vocabulary outcomes from reading for form recognition; and Yang et al. (2019) found that students with sophisticated L2 skills (including reading ability) were also with good WM outcomes. However, WM was not independently considered as a highly correlated factor in Jeon and Yamashita' study (2014) as it involved many other cognitive processes. Reversely, as a necessary resource in processing online L2 tasks, WM can be used to quantify the cognitive-load carried by readers when they implement a task with WM constraint (Ellis, 2005).

Method

Experimental design

To investigate the changing of the cognitive load caused by technique-enhanced (TE) assistance, we designed three groups to simulate three kinds of reading modes: reading with audio-assistance, reading with visual-assistance, and silent reading, among which audio-assisted reading was in a reading-while-listening form, visual-assisted reading was in the form of visual-enhancement (color), and silent reading was in the form of usual reading. Reading modes were conclusively named as technique-enhanced (TE) assistance mode.

This experiment employed a $3 \times 3 \times 2$ design with the variables of reading pattern (sequential reading; task-driven reading), length of the text (3; 4; 5), and TE-assistance mode (audio-assisted; visual-assisted; none). An alpha level of .05 was used for all statistical tests. Reading patterns were designed to simulate two kinds of intrinsic cognitive-loads readers have to carry when they are reading. The first pattern is sequential reading, which requires readers to carry a comparatively less cognitive load when they process a reading task; the second pattern is task-driven pattern, which requires readers to read comprehension questions first, and then conduct the following reading which is highly question-oriented. According to Cognitive Load Theory, readers' intention of generating information from reading contents in the task-driven pattern is stronger than that from the sequential reading as readers in the former pattern need to integrate the problems required to be solved into the reading process. Thus, readers reading in the task-driven pattern carry heavier cognitive loads than those they carry in the sequential reading.

In this study, external factors had been carefully controlled for. The words inferred in the experiment were those that had been learned by learners and at the same time were repeatedly exposed to the learners, the sentences followed the basic 'Subject-Verb-Object (SVO)' structure. Although sentences in one text were made-up sentences which had never ever appeared in the participants' reading books before to avoid the long-term memory influences, the sentences comprised with the words that readers showed no recognition difficulties in their last semester's final examination.

This experiment simulated WM's occupation by testing participants with different-length texts, the longer the texts are, the more information required to be recalled by the participants in the reading comprehension tests, and the heavier the cognitive-loads the readers carry.

Participants

Forty-one Mandarin-speaking students aged 8 (mean=8.51, sd=0.44) participated in the experiment. All participants were at grade-3 at an experimental primary school in Chengdu, Sichuan Province. They were recruited from the same school, but not from the same class. All participants had little L2 decoding skills and had normal L1 reading comprehension aptitude, and those whose L2 reading ability exceeded the normal range or who had L1 reading disability had been excluded from the experiment. Small gifts were promised to each student as rewards for the participation. The participants (N = 41) were assigned to one of the three groups: reading with audio-assistance (N=13), reading with visual-assistance (N=14), and reading silently (N=14). The assignment of the students was guided by their recent comprehension performances, to make sure that the reading aptitude of the participants in each group followed a normal distribution. The clustering method guaranteed the consistency between the sample composition in this study and the general composition of the students in a teaching class, and the average aptitudes showed no significant difference among three groups.

Materials

Students in the different TE-assisted group would be tested with 3-, 4-, and 5-sentence texts and two different reading patterns, and the speed of audio- and visual-assistance was set to around 60 wpm (consistent with the participants' average reading speed). The texts that were used in the reading tasks can be found in Table 2.

Eye-movement tracking

An eye-tracker (a Tobii T120 running python packages) was employed to monitor students' attention distribution while they received interventions. In our experiment, participants were required to watch videos displayed on the screen of an eye-tracker. Figure 2 illustrates that the contents on a screen would be divided into two areas: the interest area and the other area. Given that the contents had different lengths, the eye-gaze dwell time on interest area and that on the other area were manually computed according to the raw data.

The percentage of dwell time (PDT) on the interest area is calculated according to the formula: $PDT = \frac{D_{interest}}{D}$, where $D_{interest}$ is the summation of the eye-gaze fixation (>300ms) on the interest area, and the D is the total summation of the eye-gaze fixation including eye-gaze fixation on the other area.

Procedure

Students participated in this reading experiment were asked to read the texts displayed on an eye-tracking monitor, and the texts and related meta-information were listed in Table 2. Students in the different groups were tested with the same texts. In visual-assistance group, participants were exposed to a text within a time window, and the words in the text would be sequentially enhanced in red to guide the readers' visual-attention trajectory, as shown in Figure 3. Participants in the audio-assistance group were exposed to a same text but accompanied with oral-reading instead of the visual-hints. Both visual-hints and the oral-reading were in same speed which is around 60 wpm. Participants in silent reading group would also be exposed to a same text except there were no hints. Participants in 3 groups would be exposed to the texts in a same time window.

Participants in three groups would be required to implement reading tasks in sequential-pattern and in task-driven pattern, respectively. When students were asked to sequentially read the text, the text would be firstly exposed to the participants within a limited time window, then, the participants were asked to choose the right answers for three questions about the text from candidate answers. When students were asked to read the text in a task-driven pattern, the questions would be firstly exposed to the participants, then, students read the text within a limited time window, after that, students would be required to go into the question-answer process.

Results

Text comprehension performance

The evaluation of the reading comprehension performance was implemented by a test comprised of choice questions. Students were required to do a test involved three related choice questions about a reading text, if the answer was correct, the corresponding score was 1, otherwise it would be logged as 0. Thus, the score range of a participant in each reading task would be [0, 3] as each text corresponded to three related comprehension questions. The raw data of the participants' reading performance was displayed in Table 3.

The results from a MANOVA were displayed in Table 4, revealing significant main effects for text length on text comprehension. Comprehension scores were higher when readers were presented with 3-(M=2.56; d=.99) or 4-sentence text (M=2.36; d=.71) compared to the 5-sentence text (M=1.76). There also a significant effect for Reading pattern×Text length interaction, indicating that although the discrepancy of comprehension performance decreased sharply when the text length reached 5, the readers' comprehension performance significantly better when they read 5-sentence text in task-driven reading pattern (M=1.77-1.93; d=0-.4) than they read the same length text in sequential reading pattern (M=1.57-1.77; d=0-.4), participants particularly performed better when they were silently reading a 5-sentence text in a task-driven pattern (M=1.93; d=.4) than they were silently reading a text with a same length in a sequential reading pattern (M=1.57; d=.4).

Eye movement data

The area of a reading content was divided into two parts: interest area and other area, see Figure 3. Thus, the percent dwell time on the interest area (PDT), which represents the proportion of time that readers spent looking at there, was used to calculate the influences that different TE-assistance modes, text lengths and the reading patterns could make on the attention-control effort[1]. The raw data of PDT was displayed in Table 3, and the influence of the variables on the visual attention was displayed in Table 5.

It could be found in Table 4 and Table 5 that the audio-assisted reading significantly decreased visual-attention effort (PDT, M=.920) compared to silent reading (M=.959, d=.25) and visual-assisted reading (M=.963, d=.6). Moreover, the length of the text also showed a significant effect for the PDT, the visual-attention effort of 5-sentence text reading (*M*=.931) was significantly less than the PDT in 3-sentence text reading (M=.961, *d*=.17) and in 4 sentence text reading (*M*=.952, *d*=.27).

Eye-movement-data based model for audio-assisted L2 (English) reading

Variables referred in the model

The major purpose of constructing the model of reading-while-listening is to find out a reasonable relationship among the changed attention because of the TE-assistance, the changed comprehension performance and the different cognitive-load level. Therefore, the changed attention is defined as ΔE, and the changed comprehension performance is defined as ΔC, and the different cognitive-load level is defined based on the interaction of text-length and reading pattern, and is defined in an increasing order, i.e., level_1 corresponds to lightest load, and level_6 corresponds to heaviest load. The detailed descriptions of the variables are showed in Table 6. Most variables' values could be computed based on the raw data except ΔE, because the experiment was designed in three comparison groups which suggested that participants within an experimental group only had one kind PDT, e.g., reading-while-listening group only had the PDT collected from auditory-assisted reading, and didn't have PDT of silent reading to compute ΔE. To solve this problem, this paper employed a mathematical skill called Biharmonic spline interpolation to estimate the missed values, and the details can be found in the next section.

Biharmonic spline interpolation based on Green's function for silent reading

Biharmonic spline interpolation is a commonly used method to estimate the missing values by constructing a smooth surface based on the empirical data. The major steps of acquiring the value is: (1) biharmonic spline interpolating *e* = *f(l,c)* based on Green function for silent reading in a specific reading pattern, where *l* is the length of the text, *c* is the comprehension score, and *e* is the visual-attention effort which equals to PDT in silent reading; (2) Reading the *e* value by given a *(l, c)* pair regarding audio- or visual- assisted reading modes, and form a vector *E'*; (3) computing *ΔE=E'-E* to infer the visual-attention discrepancies between the PDT of TE-assistances and the PDT of silent reading, where *E* is the true PDT values of a certain kind of TE-assistance. Figure 4 illustrates the *E'* surface generated by biharmonic spline interpolation based on Green's function (Sandwell, 1987).

The PDTs of silent reading in two reading patterns are used as the baselines to infer the missed PDT values, thus, biharmonic spline interpolation is used to generate a surface for the visual-attention effort (E') of silent reading, and $\Delta E = E' - E$. Suppose the attention effort surface has n known points, and a point k is described as $\mathrm{x}_k = (l_k,\ c_k,\ e_k)$, $L = [l_1, l_2, \ldots l_n]$ is a vector of *n* possible values of the text length, $C = [c_1, c_2, \ldots c_n]$ is a vector of the participants' average comprehension score of silent reading *l*-sentence text in a specific reading pattern, and $PDT_{silent} = [e_1, e_2, \ldots e_n]$. $E' = [\ e'_1, e'_2, \ldots\ e'_n]$ is the assumed visual-attention effort of reading *l*-sentence text, $E' = E + \Delta E$. In silent reading mode, $\Delta E = [0 \ldots 0]$, and $E = PDT_{silent}$. In other reading modes, ΔE is estimated according to the interpolation results of E'. Each entry d_{ij} in an $n \times n$ Green's function, matrix *G* is computed as in (Deng & Tang, 2011):

$$d_{ij} = \left[\ln\left(\left|\mathrm{x}_i, \mathrm{x}_j\right|\right) - 1\right]\left|\mathrm{x}_i, \mathrm{x}_j\right|^2$$

Then, computes the weight matrix *W*:

$$W = G^{-1} PDT_{silent}$$

Secondly, suppose $E = [e_1, e_2, \dots e_n]$ is the PDT vector of TE-assisted reading, and $C' = [\ c'_1, c'_2, \dots\ \ c'_n]$ is a vector comprised of the comprehension scores got by participants with the help of TE. Then computes the G_p vector for each point $\mathrm{x}'_k = (l'_k,\ c'_k)$ based on Green's function as follows:

$$\mathrm{G}_p = [d_{01}\ d_{02}\ \ \dots\ \ d_{0k}\ ]$$

Where $d_{0j}\ = [\ln(|\mathrm{x}'_k, \mathrm{x}_j|) - 1]|\mathrm{x}'_k, \mathrm{x}_j|^2$.

And the estimation of the attention effort under the condition of $(l'_k,\ c'_k)$ can be calculated by the following formula[2]:

$$E' = \mathrm{G}_p W$$

Finally, estimates the attention-discrepancy due to the TE-assistances,

$$\Delta E_{TE-mode}^{(l'_k, c'_k)} = e'_k - e_k$$

Fitting △Cs, △Es and cognitive load

Figure 5 (a) plots the average △C by the △E of reading-while-listening, showing how △C depends upon the visual-attention effort that were influenced because of the auditory-inputs. △E accounted for approximately 58% of the variance in △C, with increased loss of visual-attention resulting in decreased △C. Figure 5(b) plots the average △C by the ΔE of visual-assisted reading, showing that the △E because of the visual-enhancement had no linear correlation with the △C.

Figure 6(a) plots the discrepancy between the readers' comprehension performance of reading-while-listening and the performance of silent reading as a function of the cognitive-load. As shown, a quadratic polynomial function (blue) accounted for 78% of the variance of △C. We used a quadratic polynomial model instead of linear model fit because the descending gradients of the △C fit quadratic polynomial model better, but considered the cognitive-load limitation, the effect range of the quadratic polynomial model was limited within the left side of the para-curve. Figure 6(a) also plots the ΔCs ($0.0278 \Delta E^2 - 0.2428 \Delta E + 0.4665$) fitted by ΔE (in red dot line) as a function of the cognitive-load, showing that the quadratic polynomial function accounted for 44% of the variance of ΔC.

Figure 6(b) plots the discrepancy between the readers' comprehension performance of visual-assisted reading and the performance of silent reading (ΔC) as a function of cognitive-load. It shows that the cognitive-load accounted for approximately 78% of the variance in ΔC.

Figure 7 plots the loss of visual-attention because of the auditory-input by the cognitive load, showing how ΔE depends upon cognitive load. In Figure 7, cognitive-load level accounted for about 44% of the variance of ΔE, and the loss of the visual-attention would decrease as a result of the increased cognitive-load, but the increased loss of the visual-attention is inevitable along with the increasing of the cognitive-load given that human has a cognitive-load carrying limitation.

An applicable reading model for young Chinese L2 readers of using auditory-assistance (AAER)

The results listed above revealed that reading-while-listening generated a totally different attention pattern compared to readings with pure visual-inputs. It could be found that the auditory-inputs would not directly affect the reading comprehension results; therefore, the conclusion that reading-while-listening is superior to or inferior to the silent reading could not be drawn according to our experimental results. However, reading-while-listening caused the loss of the visual-attention, and the loss of the visual-attention negatively influenced the anticipation of the comprehension performance (the

ΔE contributes about 58% negative impacts on ΔC in a linear way), implying that a satisfied comprehension result of reading-while-listening requires the limited visual-loss. Moreover, the loss of the visual-attention was not only decided by the auditory-inputs, but also partly decided by the cognitive-loads (Cognitive-load accounted for about 44% of the variance in the visual-attention-loss caused by auditory-inputs). Therefore, the framework of English reading assumption (AAER) for the young Chinese readers of using auditory-assistances could be described as Figure 8 shows.

Figure 8 demonstrates the construction of the cognitive load according to the 'Cognitive Load Theory' (Sweller, 2004), in which intrinsic cognitive load is decided by the inherent complexity of the learning material and cannot be altered by instructional activities; extraneous cognitive load is determined by the instructional design, and would be imposed if the learners are engaged into unnecessary cognitive activities due to the instructional design. It is presumed that, in L2 reading tasks, the complexity of the learning material is determined by 3 major factors that influence L2 reading (Jeon and Yamashita, 2014); and in this study, the extraneous cognitive load is determined by text length and reading pattern which can be adjusted in the instructional design. AAER assumes that the synchronised auditory-input would not impose the extraneous cognitive load, and two proofs support this argument:

(1) audio-assistance showed no significant influence on the reduced comprehension, and its significant influence was only found on the visual-attention-loss (ΔE).

(2) The extraneous cognitive load accounted for 78% of the variance in the ΔC in reading-while-listening and accounted for about 44% of the variance in the visual-attention-loss (ΔE) caused by auditory-inputs, but reversely, the ΔE caused by auditory-inputs could not explain the increasing of the extraneous cognitive load.

AAER illustrates two factors that affect the efficacy of applying reading-while-listening in L2 reading comprehension, the first one is the overall cognitive load that is carried by readers, the second one is the visual-attention-loss (ΔE) caused by auditory-inputs and the cognitive load.

Discussion

This work tried to reveal the influence that the synchronised auditory-input exerted on young Chinese students' attention when they read English texts by controlling for the possible external variables, and the relationship between the attention formed by reading-while-listening and the reading comprehension performance. The raw data resulted from the experiment was too complex to directly draw the conclusions. Thus, according to the heuristics discovered by the MANOVA analysis, we built up a computational model, named AAER, to simulate the assumption regarding visual-attention, cognitive load, and comprehension performance in L2 reading comprehension. Next, we will discuss the empirical studies in this unified framework.

Chang and Milett (2015) suggested in their work that one of the major reasons that could make a significant improvement in reading comprehension in AR (audio-reality) group is that "audio-assisted reading helps keep students on task," suggesting that reading-while-listening promotes attention. Nevertheless, they didn't indicate that the attention is visual-attention, although visual-attention is the necessary condition of L2 reading (Schmidt, 1990). The experiment results suggested that the increased visual-attention with the help of the visual-guidance showed no impact on the ΔC, while the visual-attention-loss (ΔE) because of reading-while-listening accounted 58% of the expected increasing of the comprehension (ΔC). Therefore, it could be presumed that the promoted attention in Chang and Milett (2015)' study is neither visual-attention nor auditory-attention, but the limited loss of the visual-attention. Actually, the large visual-attention-loss implied that part of the visual attention was replaced by auditory attention

(Tragant & Vallbona, 2018), which is a process requiring more cognitive resources and a process much more difficult than visual reading (Vandergrift & Baker, 2015).

Diao's study (2007) suggested that because of the imposed extraneous cognitive loads due to the auditory inputs, reading-while-listening was inferior to silent reading in reading comprehension. However, AAER model is opposed to this assumption, and suggests that although the overall cognitive load comprised of intrinsic cognitive-load and extraneous cognitive-load is the fundamental factor that affects the comprehension performance, the auditory-inputs would not incur extraneous cognitive-load (the reason had been elaborated in the last section). Therefore, it could be inferred that the poor reading-comprehension performance in Diao's work was caused by the large visual-attention-loss and the high inherent extraneous-cognitive-load. AAER model illustrates that the intrinsic-cognitive-load of a reading-while-listening task is comprised of 3 factors which are supposed to highly correlate with L2 reading performance, and the extraneous cognitive-load is decided by the different text lengths and reading patterns. In Diao's work, the core information required participants to recall were 6-12 sentences, which approached the limitation of working memory. It could be presumed that the inherent extraneous-cognitive-load that the participants carried in Diao's work was high, which consequently had a high probability of resulting in large visual-attention-loss and poor reading-comprehension performance.

In addition to the high extraneous-cognitive-load, it is presumed that, the unmatched auditory input was the second reason to cause large visual-attention-loss in Diao's study. It could be found in Diao's work that the audio speed is 76 wpm, while the speed in Chang's work (2015) was higher than 100 wpm. However, the participants in Diaos' work were English majored college students while the participants in Chang's work were 15-year-old secondary-school students. Obviously, the participants in Diao's work should be more skilful on decoding than those in Chang's work, and thus, the matched auditory speed for Diao's participants should be much higher than 76 wpm. Therefore, it could be expected that the unmatched speed of the auditory inputs might urge readers to implement the comprehension task by using asynchronised visual- and auditory attention, which inevitably caused large loss of visual-attention, i.e., the unmatched speed of the audio input impedes readers' natural and automised way of reading (Gerbier et al., 2018). Generally speaking, the condition in Diao's study is much like the negative ΔCs made by reading-while-listening at the high cognitive-levels (level_4 to level_6) in this study, see Figure 6 (a).

In contrast to Diao's work, Chang and Milett's prominent results of readers' listening fluency (C.-S. Chang, 2009, 2011; C.-S. Chang & Millett, 2014; C.-S. Chang et al., 2019) suggested that their learners' proficient L2 decoding skill lowers the readers' intrinsic cognitive-load. Moreover, the tests in Chang's study were not implemented in a recall form, which implied that the using of the readers' working memory in the study was adjustable; therefore, the extraneous cognitive-load carried by the participants in the study might be also comparatively low. Given that the intrinsic-cognitive-load and extraneous-cognitive-load in Chang's study were both at low level, the situation in the work is similar to the positive ΔCs made by reading-while-listening at the low cognitive levels (level_1 to level_3) in this study, see Figure 6 (a).

AAER demonstrates that there are two vital factors that decide the reduced or increased comprehension because of reading-while-listening in contrast to silent reading: cognitive load and visual attention-loss (ΔE), where ΔE is also affected by the cognitive load. However, it is noteworthy that, the limited loss of the visual attention is the necessary condition for satisfied English-reading-comprehension, but not the sufficient condition, i.e., the satisfied English-reading-comprehension requires the limited visual-attention-loss as a prerequisite, but the limited visual-attention-loss is not the deciding factor of good reading-comprehension. That is why most studies of using reading-while-listening in native language reading reported ineffectiveness, e.g., (Gerbier et al., 2018; Rogowsky et al., 2016), because, for most English native speakers, the visual-attention-loss control has reached its ceiling in an earlier developmental period, unless those native speakers have brain-impairments (Gough & Tunmer, 1986).

Implications

Based on the conclusions made above, three pedagogical implications are proposed. First, the audio-speed used in reading-while-listening should match the readers' reading fluency; otherwise, the reading-while-listening may enlarge the visual-attention-loss. It is suggested that a reading fluency test can be applied by teachers in evaluating students' current reading rate, e.g., to design or use materials in accordance with *Speed readings for ESL learners*[3]. However, it is noteworthy that, even the passages in the simplest version (*Speed readings for ESL learners: BNC 300*) are inappropriate for the students in our experiment as their vocabulary size and their grammatical- and syntactical knowledge are insufficient to cope with those passages. Thus, it is recommended for teachers who confront similar situation as us to make up sentences that are in line with learners' prior knowledge and to generate passages with fewer words to test their reading fluency.

This process would be a repeated process, as the passages used in each trial must be different to avoid the influence from readers' memorisation. Usually, teachers are capable of gradually reducing the syntactical and lexical difficulty to make readers reach a satisfying reading comprehension threshold which is defined as about 70% in

Speed readings for ESL learners, although comprehension accuracy is not a concerned factor of top priority in reading fluency.

Secondly, the reading-while-listening is suggested be applied in a less cognitive-load pattern to avoid abnormal visual-attention-loss. The low intrinsic cognitive-load refers to the easy L2-decoding, low-difficulty L2-lexical knowledge and grammatical knowledge. The aforementioned comprehension threshold which is used in evaluating readers' reading fluency can also be used to decide whether the reading context is affordable by readers. According to the results revealed by our experiment, reading-while-listening only boosted readers' reading when their reading comprehension accuracy were above 80%. If a reader can reach more than about 80% accuracy on comprehension without turning back to the passage, it is implied that the passage length, the lexical and grammatical knowledge reflected in the reading material are in line with learners' L2 skills and knowledge. The sentence structures, words, as well as the logistic relations embedded in the passage are low cognitive-load. Therefore, it is recommended that the discourse used in reading-while-listening training should be easier than the passages that success in testing readers' reading fluency.

However, the low intrinsic cognitive-load is adaptable, as indicated by Thomas et al. (2019) that the repeated training of the core skills in cognition can make those L2 skills work quickly enough to occupy as less cognitive resources as possible, implying that the developed L2 skills would improve learners' intrinsic cognitive-load tolerance. Low extraneous cognitive-load refers to sequential reading pattern, with shorter L2-texts and instructional designs requiring lower WM occupation. Thus, it is recommended to regularly conduct reading fluency test for monitoring the development of readers' reading speed. If readers' performance on reading comprehension in the reading fluency test has reached 80% or even higher accuracy with less reading time, it implies that the reading material used in the reading-while-listening should be upgraded to adapt readers' improved reading speed.

Finally, the synchronisation of the visual- and auditory attention is suggested to be trained with a rhymed context as it was pointed by many studies that the recognition of phonemes in rhymes is easier for young L2 learners, e.g., see (Wade-Woolley & Geva, 2000). Rhymed context can be helpful in synchronising readers' visual- and auditory pace, which in consequence strengthens the logistic correlations among sentences. Take a discourse used in our experiment for example, when readers read the second sentence of "Kipper bought a balloon, Biff bought a spade," they can make reasonable anticipations about the coming words as the second sentence has a same rhythm pace with the first one.

Limitations

We acknowledge several study limitations. First of all, this study designed an experiment to generate an EFL reading model, which testified the attention-related assumptions according to the results of the existing empirical studies. The PDT in this paper was much higher than that in the normal experiments (>0.93), indicating that most students had already put most of their attention-efforts on the reading tasks. Actually, in real reading contexts, it is hard for readers to continually retain such high-levelled concentration.

As a consequence, AAER is unsuitable to discuss the efficacy of reading-while-listening when the readers' attention-efforts are inadequate. Because the low attention-effort implies that there may exist other factors that cause the loss of the visual attention, such as less motivation, fatigue or insufficient learning interest. Thus, only when the PDT is higher enough to exclude those interference factors, the loss of the visual attention can be explained by AAER model. Otherwise, under a less motivated situation, it is very hard to decide whether the loss of the visual attention is caused by the cognitive-load, or is caused by readers' negative attitude. Therefore, AAER model also could not be used to evaluate whether reading-while-listening could or could not promote readers' motivation or reading interests, as AAER model is based on the prerequisite that readers have been fully inspired of the reading interests.

Secondly, the model was built based on the behavioural data, which cannot solve the questions like what exactly has changed readers' cognitive processing pattern along with the increasing of the cognitive-load. Thus, AAER should be further examined by brain-function related experiments. Thirdly, the current study only employed 8-years-old children as the participants, more subjects from different age groups should be recruited into the experiment.

Future Research

Our now and future work focus on tackling the last two limitations mentioned above. We are monitoring learners' brain images accompanied with the changed cognitive-load by using functional near-infrared spectroscopy (fNIRS) as the experimental device. In our ongoing work, we aim at building two computational models, and those computational models will use data collected from experiment. The first one takes visual-attention-loss as the goal function, fNIRS data, while reading pattern and reading modes are parameters of the model. This model is expected to reveal whether or how cognitive-load can trigger the different brain functions, which as a result may cause the loss of the visual attention. The second model takes the reading comprehension as the goal function, fNIRS data, reading pattern and reading modes as explanatory parameters. Until now, we have recruited about 20 college students to participate in the ongoing experiment, and the experiment referred to in this study will be replicated and complemented (would not use interpolation). We firstly will evaluate those participants' reading fluency via passages extracted from *Speed readings for ESL learners: 3000 BNC*. The fNIRS device will be used when learners implement the reading tasks in different modes and patterns.

We are expecting to integrate neuro-evidence with behavioural evidence to further demonstrate the validity and reliability of AAER model. Our assumption is that the abnormal loss of the visual attention will be accompanied with the significant changing of the cognitive processing, which as a consequence will be illustrated as different brain-function images. If the assumption is testified, the fNIRS experiment will be applied to participants from different age groups to further optimise the AAER model for EFL readers. Then, AAER will be more transparent, and its validity will be guaranteed by the improved accuracy, while its reliability will be guaranteed by the reproducibility of the brain-function activation.

Acknowledgements

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1. Despite 'effort' was originally defined as the physical movement of the human which inhibited scanning in the SEEV model (Horrey et al., 2006), many other studies (e.g.,Gollan & Ferscha, 2016) re-interpreted it as the participants' effort to attend or engage in a particular task.
2. The estimation of the attention effort value e'_k could be got by invoking griddata ('v4') method in matlab.
3. *Speed readings for ESL learners* is a reading fluency training program contains the method of testing readers' reading fluency. *Speed readings for ESL learners* includes a serials of reading contexts to adapt to EFL learners' different word size. *Speed readings for ESL learners* serial is developed by School of Linguistics and Applied Language Studies, Victoria University of Wellington. Take *Speed readings for ESL learners: 500 BNC* for instance, this program is designed for kids and contains twenty 300-word passages, each

with eight comprehension questions. The passages are written within the British National Corpus 500 (BNC 500) most frequently used words of English. Accuracy in answering the questions is not the main consideration. The fastest time with about 70% accuracy is defined as the least time that a reader is required on reading a 300-words passage. Therefore, student's current reading fluency rate, i.e., the wpm, can be calculated by "300/ fastest time with about 70% accuracy (minutes)." More details about how to conduct such a reading fluency test can be found in https://www.victoria.ac.nz/__data/assets/pdf_file/0006/1754457/500-BNC-SRs-for-ESL-Learners.pdf.

References

Allen, D., & Conklin, K. (2017). Naturalistic reading in the L2 and the impact of word frequency and cross-linguistic similarity. *Journal of the Ochanomizu University English Society*, *7*(3), 41-57.

Beaton, A. A. (2004). *Dyslexia, reading, and the brain*. Psychology Press.

Brown, R., Waring, B., & Donkaewbua, S. (2008). Incidental vocabulary acquisition from reading, reading-while-listening, and listening to stories. *Reading in a Foreign Language*, *20*, 136-163.

Cao, F., Vu, M., Chan, L., Ho, D., Lawrence, J. M., Harris, L. N., & Perfetti, C. A. (2013). Writing affects the brain network of reading in Chinese: A functional magnetic resonance imaging study. *Human brain mapping*, *34*(7), 1670–1684.

Chang, C.-C., Tseng, K.-H., & Tseng, J.-S. (2011). Is single or dual channel with different English proficiencies better for English listening comprehension, cognitive load and attitude in ubiquitous learning environment? . *Computers & Education*, *57*(4), 2313–2321.

Chang, C.-S. (2009). Gains to L2 listeners from reading while listening versus listening only in comprehending short stories. *System*, *37*, 652-663.

Chang, C.-S. (2011). The effect of reading while listening to audiobooks: listening fluency and vocabulary gain. *Asian Journal of English Language Teaching*, *19*, 43-64.

Chang, C.-S., & Millett, S. (2014). Effect of extensive listening on developing L2 listening fluency: some hard evidence. *ELT Journal*, *68*(1), 31-40.

Chang, C.-S., & Millett, S. (2015). Improving reading rates and comprehension through audio-assisted extensive reading for beginner learners. *System*, *52*, 91-102.

Chang, C.-S., Millett, S., & Renandya, W. A. (2019). Developing Listening Fluency through Supported Extensive Listening Practice. *RELC Journal*, *50*(3), 422–438.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: a dual route cascaded model of visual word recognition and reading aloud. *Psychological Review*, 108. 204–256.

Das, T., Padakannaya, P., Pugh, K. R., & Singh, N. C. (2011). Neuroimaging reveals dual routes to reading in simultaneous proficient readers of two orthographies. *NeuroImage*, *54*(2), 1476–1487.

Deng, X., & Tang, Z. (2011). Moving Surface Spline Interpolation Based on Green's Function. *Mathematical geosciences*, *43*(6), 663–680.

Diao, Y., & Sweller, J. (2007). Redundancy in foreign language reading comprehension instruction: Concurrent written and spoken presentations. *Learning and Instruction*, *17*, 78-88.

Dijkstra, T., & Van Heuven, W. J. (2002). The architecture of the bilingual word recognition system: From identification to decision. *Bilingualism: Language and cognition*, *5*(3), 175-197.

Ellis, N. C. (2005). At the interface: Dynamic interactions of explicit and implicit language knowledge. *Studies in Second Language Acquisition*, *27*(2), 305-352.

Gao, Y., Sun, Y., Lu, C., Ding, G., Guo, T., Malins, J. G., . . . Liu, L. (2017). Dynamic spatial organization of the occipito-temporal word form area for second language processing. *Neuropsychologia*, *103*, 20-28.

García-Pentón, L., Garcia, Y. F., Costello, B., Duñabeitia, J. A., & Carrieras, M. (2016). The neuroanatomy of bilingualism: How to turn a hazy view into a the full picture. *Language, Cognition and Neuroscience*, 303-327.

Gerbier, E., Bailly, G., & Bosse, M. L. (2018). Audio–visual synchronization in reading while listening to texts: Effects on visual behavior and verbal learning. *Computer Speech & Language, 47*, 74-92.

Gollan, B., & Ferscha, A. (2016). *SEEV-Effort - Is it Enough to Model Human Attentional Behavior in Public Display Settings* The Eighth International Conference on Future Computational Technologies and Applications (FUTURE COMPUTING 2016), Rome, Italy.

Gough, P. B., & Tunmer, W. E. (1986). Decoding, reading, and reading disability. *Remedial and special education*, *7*(1), 6-10.

Granena, G., Muñoz, C., & Tragant, E. (2015). L1 reading factors in extensive L2 reading-while-listening instruction. *System*, *55*, 86–99.

Horrey, W. J., Wickens, C. D., & Consalus, K. P. (2006). Modeling drivers' visual attention allocation while interacting with in-vehicle technologies. *Journal of Experimental Psychology: Applied*, *12*(2), 67-78.

Jamal, N. I., Piche, A. W., Napoliello, E. M., Perfetti, C. A., & Eden, G. F. (2012). Neural basis of single-word reading in Spanish-English bilinguals. *Human brain mapping*, *33*(1), 235–245.

Jeon, E. H., & Yamashita, J. (2014). L2 reading comprehension and its correlates: A meta‐analysis. *Language Learning*, *64*(1), 160-212.

Kormos, J., & Safar, A. (2008). Phonological Short-Term Memory, Working Memory and Foreign Language Performance in Intensive Language Learning. *Bilingualism Language & Cognition*, *11*(2), 261-271.

Lauro, J., & Schwartz, A. I. (2017). Bilingual non-selective lexical access in sentence contexts: A meta-analytic review. *Journal of Memory and Language*, *92*, 217-233.

Lee, H., & Mayer, R. E. (2018). Fostering learning from instructional video in a second language. *Applied Cognitive Psychology*, *32*(5), 648-654.

Malone, J. (2018). Incidental vocabulary learning in SLA: Effects of frequency, aural enhancement, and working memory. *Studies in Second Language Acquisition*, *40*(3), 651-675.

Moussa-Inaty, J., Ayres, P., & Sweller, J. (2012). Improving Listening Skills in English as a Foreign Language by Reading Rather than Listening: A Cognitive Load Perspective. *Applied Cognitive Psychology*, *26*(3), 391-402.

Nelson, J. R., Liu, Y., Fiez, J., & Perfetti, C. A. (2009). Assimilation and accommodation patterns inventral occipitotemporalcortex inlearning a second writing system. *Human brain mapping*, *30*(3), 810–820.

Osada, N. (2001). What strategy do less proficient learners employ in listening comprehension? A reappraisal of bottom-up and top-down processing. *Journal of the Pan-Pacific Association of Applied Linguistics*, *5*, 73e90.

Qu, J., Zhang, L., Chen, C., Xie, P., Li, H., Liu, X., & Mei, L. (2019). Cross-Language Pattern Similarity in the Bilateral Fusiform Cortex Is Associated with Reading Proficiency in Second Language. *Neuroscience*, *410*, 254-263.

Reichle, E. D. (2015). Computational Models of Reading: A Primer. *Language and*

Linguistics Compass, *9*(7), 271–284.

Rogowsky, B. A., Calhoun, B. M., & Tallal, P. (2016). Does Modality Matter? The Effects of Reading, Listening, and Dual Modality on Comprehension. *SAGE Open*(9), 1-9.

Schmidt, R. W. (1990). The role of consciousness in second language learning1. *Applied linguistics*, *11*(2), 129-158.

Serrano, R., & Pellicersanchez, A. (2019). Young L2 learners' online processing of information in a graded reader during reading-only and reading-while-listening conditions: A study of eye-movements. *Applied Linguistics Review*.

Stenton, A. (2012). Can simultaneous reading and listening improve speech perception and production? An examination of recent feedback on the SWANS authoring system. *Procedia -Social and Behavioral Sciences*, *34*, 219-225.

Sun, Y., Peng, D., Ding, G., Qi, T., Desroches, A. S., & Liu, L. (2015). The dynamic nature of assimilation and accommodation procedures in the brains of Chinese-English and English-Chinese bilinguals. *Human brain mapping*, *36*(10), 4144-4157.

Sweller, J. (2004). Instructional Design Consequences of an Analogy between Evolution by Natural Selection and Human Cognitive Architecture. *Instructional Science*, *32*, 9-31.

Taguchi, E., Takayasu-Maass, M., & Gorsuch, G. (2004). Developing reading fluency in EFL: how assisted repeated reading and extensive reading affect fluency development. *Reading in a Foreign Language*, *16*, 70-96.

Tan, L. H., Spinks, J. A., Feng, C. M., Siok, W. T., Perfetti, C. A., Xiong, J., . . . Gao, J. H. (2003). Neural systems of second language reading are shaped by native language. *Human brain mapping*, *18*(3), 158-166.

Thomas, M. S. C., Ansari, D., & Knowland, V. C. P. (2019). Annual Research Review: Educational neuroscience: progress and prospects. *J Child Psychol Psychiatr*, *60*, 477-492.

Tragant, E., & Vallbona, A. (2018). Reading while listening to learn: young EFL learners' perceptions. *ELT Journal*, *72*(4), 395–404.

Van Assche, E., Duyck, W., & Hartsuiker, R. J. (2012). Bilingual word recognition in a sentence context. *Frontiers in psychology*, *3*, 174.

Vandergrift, L., & Baker, S. (2015). Learner Variables in Second Language Listening Comprehension: An Exploratory Path Analysis. *Language Learning*, *65*(2), 390-416.

Wade-Woolley, L., & Geva, E. (2000). Processing novel phonemic contrasts in the acquisition of L2 word reading. *Scientific Studies of Reading*, *4*(4), 295-311.

Webb, S., & Chang, C.-S. (2012). Vocabulary learning through assisted and unassisted repeated reading. *Canadian Modern Language Review*, *68*(3), 267-290.

Yang, J., Thomas, M. S. C., Qi, X. F., & Liu, X. (2019). Using an ANN-based computational model to simulate and evaluate Chinese students' individualized cognitive abilities important in their English acquisition. *Computer Assisted Language Learning, 32*(4), 366-397.

Table 1. The meta-data of the empirical studies

Effect facet		Study	Participants		L1	Speech speed(wpm)
			Level	age		
Improving listening fluency and comprehension		(Chang, 2009)	College students	18-19	Chinese	125-139
		(Chang, 2011)	Secondary school students	15-16	Chinese	-
		(Chang & Millett, 2014)	College students	-	Chinese	around 100
		(Chang et al., 2019)	College students	18-25	Chinese	102-143
Improving reading fluency		(Chang & Millett, 2015)	Secondary school students	15-16	Chinese	around 100
		(Taguchi et al., 2004)	College students	18	Japanese	around 100
Improving vocabulary learning rates		(Brown et al., 2008)	College students	18-21	Japanese	93
		(Webb & Chang, 2012)	Secondary school students	15-16	Chinese	-
Reading comprehension	Negative effect	(Diao & Sweller, 2007)	College students (English major)	18-20	Chinese	76
	Moderate effect	(Serrano & Pellicersanchez, 2019)	Primary school children	10–11	Spain	-
	positive effect	(Tragant & Vallbona, 2018)	Primary school children	10-11	Spain	-
	Significant positive effect	(Chang & Millett, 2015)	Secondary school students	15-16	Chinese	around 100

Table 2. Reading texts used in the experiment

Reading pattern	Speed	Text length	Text
Task-driven reading	about 60 words per minute (wpm)	3	Mum and Dad went shopping, Kipper bought a balloon, Biff bought a spade.
		4	Mom looks silly, Mom wants a present. Kipper gives Mom two books, and Mom is very happy.
		5	Mom has a toy rabbit, Dad has a white cat. Floppy barks at Dad, Kipper looks at the rabbit, I play with the cat.
Sequential reading	about 60 words per minute (wpm)	3	Floppy is a bad dog, he barks at Mom, and he eats Mom's egg.
		4	Mom has a pair of boots, Mom wants new shoes. Dad gives mom two books, and Mom is sad.
		5	Kipper is reading a book, Dad wants him to play. Kipper plays with Floppy, Floppy wants to go outside, Kipper asks Floppy to stay at home.

Table 3. Participants' reading performance and PDT of two reading patterns and different text lengths, respectively

	TE-assisted mode					
	Audio-assisted		Visual-assisted		Silent	
	Comprehension score	PDT	Comprehension score	PDT	Comprehension score	PDT
Sequential						
3-sentence	2.500	.921	2.429	.961	2.214	.971
4-sentence	2.692	.905	2.500	.973	2.429	.971
5-sentence	1.769	.903	1.714	.960	1.571	.942
Task-driven						
3-sentence	2.636	.955	2.714	.975	2.857	.973
4-sentence	2.154	.949	2.077	.948	2.286	.962
5-sentence	1.769	.887	1.786	.958	1.929	.933

Table 4. MANOVA results for variables from experiment

Source	Comprehension score				
	MSE	F	d	Sig	η^2
TE-assistance mode (TE)	.054	.084	2	.919	.001
Reading pattern (R)	.113	.176	1	.675	.001
Text length (L)	14.033	21.943	2	.000**	.164
TE x R	.953	1.491	2	.227	.013
TE x L	.039	.062	4	.993	.001
R x L	2.763	4.320	2	.014*	.037
TE x R x L	.010	.016	4	.999	.000

Note. Variability in comprehension score was the summation of three question scores about one text reading. **Sig.*<.05, ***Sig.*<.01, η^2=.01 (small effect); η^2=.06 (medium effect); η^2=.14 (large effect).

Table 5. The MANOVA analysis of the variables' influence to PDT

	PDT				
Source	MSE	F	D	Sig	η^2
TE-assistance mode (TE)	.043	10.523	2	.000**	.086
Reading pattern (R)	.001	.183	1	.669	.001
Text length (L)	.018	4.368	2	.014*	.038
TE×R	.004	1.036	2	.357	.009
TE×L	.003	.659	4	.621	.012
R×L	.003	.814	2	.444	.007
TE×R×L	.003	.786	4	.535	.014

Note. **Sig*.<.05, ***Sig*.<.01, η^2=.01 (small effect); η^2=.06 (medium effect); η^2=.14 (large effect).

Table 6. Variables referred in computational model

Variable	Graph label	Computation	Description
∆E	∆E	$\Delta E = e' - e$, where e' is the assumed visual-attention, and e is the true PDT collected from the experiment	The lost visual attention because of the auditory-assistance or visual-assistance compared to the PDT of silent reading
∆C	∆C	$\Delta C = \overline{C_{TE}} - \overline{C_{silent}}$, where $\overline{C\_TE}$ is the average comprehension performance of audio-assisted or visual-assisted reading, and $\overline{C_{silent}}$ is the average comprehension performance of silent reading	∆C is used to describe the discrepancy between the comprehension performance of TE-assisted reading and the comprehension performance of silent reading; ∆C is computed for audio-assisted reading and visual-assisted reading on different cognitive-load level, respectively.
Cognitive load	Sequential-3	3-sentence text ×sequential reading	Level_1
	Sequential-4	4-sentence text ×sequential reading	Level_2
	Sequential-5	5-sentence text ×sequential reading	Level_3
	Task-driven-3	3-sentence text ×task-driven reading	Level_4
	Task-driven-4	4-sentence text ×task-driven reading	Level_5
	Task-driven-5	5-sentence text ×task-driven reading	Level_6

Figure 1. The BIA+ model (Dijkstra & Van Heuven, 2002)

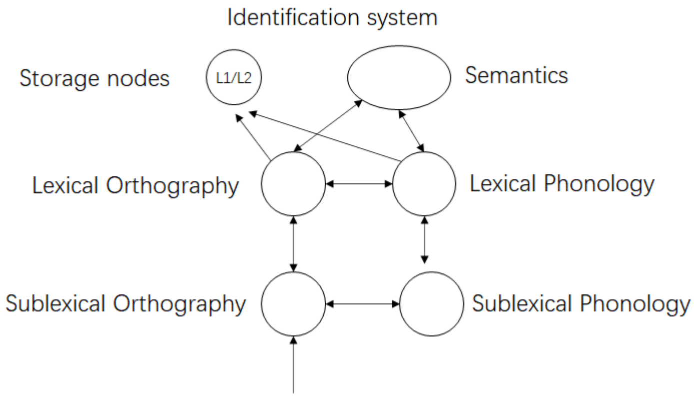


Figure 2. An illustration of the dividing of the interest area and other area

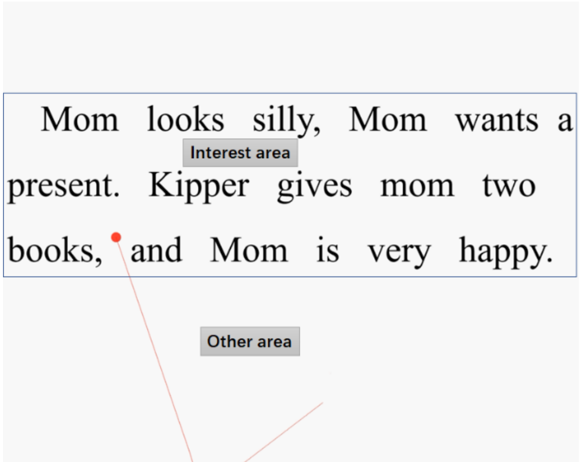


Figure 3. Visual-enhancement used in visual-assisted reading

Mum and Dad went shopping,
Kipper bought a balloon, Biff
bought a spade.

Figure 4. PDT (E') surfaces of interpolating the (sentence length, comprehension score, and PDT) data sets of silent reading in two reading patterns

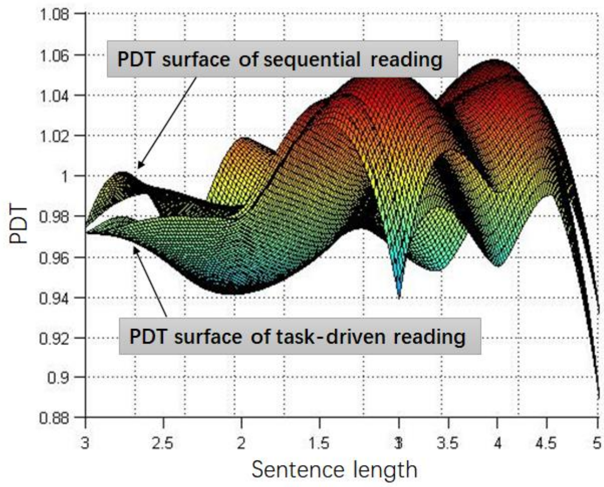
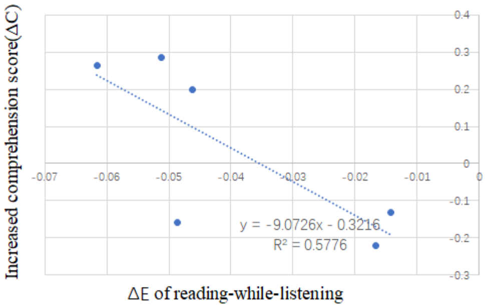
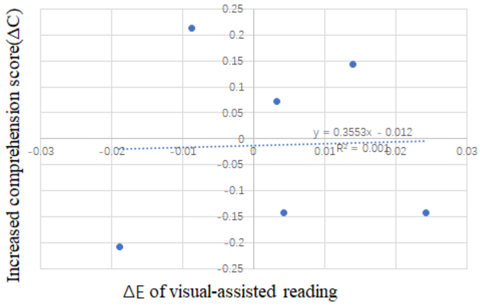


Figure 5. (a) ΔC by ΔE of reading-while-listening; (b) ΔC by ΔE of visual-assisted reading

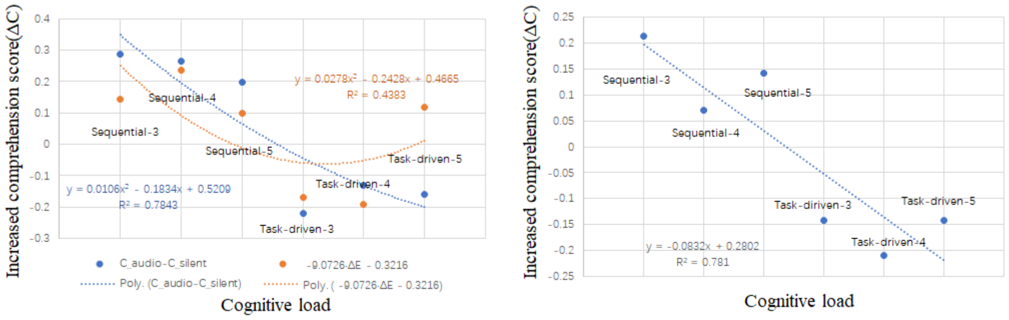


(a)



(b)

Figure 6. (a) Real ΔC and simulated ΔC of reading-while-listening by cognitive-load; (b) real ΔC of visual-assisted reading by cognitive-load



(a) (b)

Figure 7. ΔE of reading-while-listening by cognitive-load level

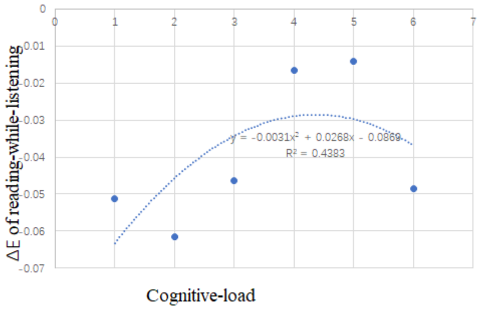


Figure 8. AAER: An reading model for Chinese L2 readers at lower grades