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Original Article

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The Influence of Visual Quality and Sentence Difficulty on Sentence Context Effects in Reading Speed

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In the present study, we investigated how sentence context effects were affected by the visual quality and sentence difficulty in reading Korean sentences. Participants read sentences or randomly ordered words (non-sentences) in good or poor visual quality and in high or low difficulty. Sentence context effects were measured as the ratio of the speed of reading sentences to the speed of non-sentences. The results from the experiment showed that sentence context effects increased in poor visual quality compared to good visual quality, and increased in low difficulty compared to high difficulty. More importantly, there was an interaction between visual quality and sentence difficulty. Sentence context effects increased in poor visual quality compared to good visual quality at both difficulty levels, but the magnitude of the increase was greater in low difficulty than high difficulty. These results suggest that sentence context may make a greater contribution in the reading of visually degraded sentences, and that this contribution may be amplified when the sentences are easier.

Keywords: sentence context effect, visual quality, sentence difficulty, reading speed, reading

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Reading is a process that begins with the analysis of visual stimuli and progresses towards comprehension. Reading is influenced not only by visual factors such as print size, spacing, and contrast but also by linguistic factors such as text difficulty (Legge, & Bigelow, 2011; Ohnishi et al., 2020; Sass, Legge, & Lee, 2006; Yu, Cheung, Legge, & Chung, 2007). Context, one of these factors, has been studied mainly in two ways. One approach involves manipulating context based on the predictability of a word following a given sentence (Amenta, Hasenäcker, Crepaldi, & Marelli, 2023; Steen-Baker et al., 2017). In this case, the impact of context is examined by observing target word recognition or fixation durations of target words between high- and low-predictability conditions. Another approach involves comparing grammatically correct sentences with randomly ordered words to investigate the influence of sentence context (Chung, Mansfield, & Legge, 1998; Sass et al., 2006). This study focused on the overall context of sentences rather than the predictability of individual

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words. Therefore, the latter method was used to examine the effects of sentence context on reading.

It is a well-established phenomenon that sentence context facilitates reading speed (Fine, Hazel, Latham, & Rubin, 1999; Fine & Peli, 1996; Latham & Whitaker, 1996; Legge, Hooven, Klitz, Mansfield, & Tjan, 2002; Sass et al., 2006). Reading speeds were found to be between 2.6 times and 2.9 times faster for sentences than for randomly ordered words (Latham & Whitaker, 1996; Fine et al., 1999). Similar results are observed using the Rapid Serial Visual Presentation (RSVP) technique, which presents one word on the screen at a time to reduce the need for eye movements. Compared to randomly ordered words, sentences could provide the semantic and syntactic information. It is assumed that using this information increase the predictability of subsequent words or content, thereby enhancing processing speed (Massol, Mirault, & Grainger, 2021; Morris, 2006; Snell & Grainger, 2017).

How will context effects appear in visually degraded reading compared to normal reading? Some studies suggest that, in visually degraded reading, context effects may increase as readers rely more on contextual information to compensate for the lack of visual information (e.g., Lee, 2004; Stanovich & West, 1983). For example, Stanovich and West (1983) observed that context effects increased when the visual quality of words was degraded, such as when the target word had low brightness or contained asterisks between letters. They argued that greater weight could be given to the information for top-down processing when the visual input is unreliable or perceived ineffectively. Lee (2004) compared word recognition when the preceding phrase predicted the target word well or predicted it poorly. The target word was displayed in good or poor visual quality. In both lexical judgment and naming latencies, Lee found that context effects (difference between high and low predictability) increased in poor visual quality compared to good visual quality. These results suggest that context can make a greater contribution in reading with degraded visual quality.

Contrary to the above position, however, there are some studies suggesting that context effects may be reduced or unaffected in visually degraded reading situations. For example, Chung et al. (1998) reported that sentence context effects were reduced when reading sentences in peripheral vision compared to reading sentences in central vision[1]. Legge, Ross, Luebker, and LaMay (1989) reported that groups with normal vision and low vision showed similar magnitudes of context effects, with both groups reading sentences 15 to 30 percent faster than random lists of words. Considering the inconsistencies in previous studies, it seems necessary to obtain more experimental evidence to understand the role of context in visually degraded reading situations.

The sentence difficulty is another important factor affecting the reading process. Easy sentences are read faster than difficult sentences. In the study of Young and Bowers (1995), fifth-grade children were asked to read aloud three stories with second-, third-, and fifth-grade levels, respectively. The children read difficult stories more slowly than easy stories. Rayner and Duffy (1986) asked college students to read sentences at their normal reading speed. The students read the sentences containing low-frequency words more slowly than the sentences containing high-frequency words.

The sentence difficulty can also change how information is extracted from surrounding region during reading. For example, Henderson and Ferreira (1990) examined how parafoveal (the area between 1 and 5 degrees from the fixation point) processing was influenced by the difficulty of foveal (the area within 1 degree of the fixation point) processing while reading sentences. The level of difficulty was manipulated at word frequency or syntactic level. It was found that the extraction of parafoveal information was harder as the difficulty of foveal processing increased.

As just described, the sentence difficulty can affect the reading process by altering reading speed or making the extraction of surrounding information more difficult or easier. However, it is not yet clearly understood how

1) In the visual field, visual acuity is found to decrease in peripheral vision, which is more than 5 degrees away from the center, compared to central vision, which is within 1 degree of the fixation point (Larson & Loschky, 2009).

sentence difficulty will affect context effects during reading. Moreover, there has been little research on the question of how visual quality and sentence difficulty interact with each other to affect context effects during reading. We aimed to address the issues of these two variables together.

In the present study, we investigated how sentence context effects were affected by the visual quality and sentence difficulty during reading aloud. Measuring reading speed are a commonly used method to examine the impact of various factors on reading (Legge, & Bigelow, 2011; Ohnishi et al., 2020; Sass et al., 2006; Yu et al., 2007). Reading speed is a measure that effectively reflects the influence of visual factors and is also significantly related to reading comprehension (Carretti, Toffalini, Saponaro, Viola, & Cornoldi, 2020; Duchnicky & Kolers, 1983). While reading speed during silent reading can be estimated from eye movement data or measured through self-report, this method makes it difficult to insure that the text is being read accurately (Rubin, 2013). The RSVP technique, which excludes eye movements, allows for the measurement of reading speed while minimizing individual differences related to eye movements. In this method, the words of a sentence appear one by one in the same position, and the participant reads each word aloud and presses a key to display the next word. The time taken to read each word is used to calculate the sentence reading speed (Song & Lee, 2010). However, it does not allow peripheral preview and thus differs from natural reading situation. In this study, reading speed was measured while reading aloud because it allows the experimenter to better monitor the participant's reading performance (Brysbaert, 2019).

We focused on three questions. First, how are sentence context effects affected by the visual quality of sentences? We were interested in whether context effects would increase, as found by Stanovich and West (1983) and Lee (2004), when reading visually degraded sentences compared to visually clear sentences. Second, how are sentence context effects affected by the sentence difficulty? We were interested to see whether context effects would increase in low-difficulty sentences compared to high-difficulty sentences. It is possible that contextual information is better processed in sentences with low difficulty because more resources can be allocated to it. In contrast, sentences with high difficulty may require more resources for processing words or syntax, leaving fewer resources for context. If so, it is expected that sentence context effects would increase in low-difficulty sentences compared to high-difficulty sentences. Third, and most interestingly, how are sentence context effects affected by the interaction of visual quality and sentence difficulty? If sentence context can make a greater contribution in reading with poor visual quality and be better processed in sentences with lower difficulty, then it is expected that the influence of visual quality on sentence context effects would be amplified in low-difficulty sentences compared to high-difficulty sentences.

Method

Participants

Forty-six undergraduate students participated in the experiment. They were all native Korean speakers with normal vision.

Apparatus

Experimental procedures were created in E-Prime and controlled on a personal computer. The stimuli were presented on a 17-inch monitor and the distance between the participant and the monitor was 50 cm.

Materials and Design

We used Korean sentences as stimuli. There were three variables. First, the stimulus type was a sentence or a non-sentence (words within a sentence were randomly ordered). Second, the stimulus was presented in good or poor visual quality. Third, the level of sentence difficulty was high or low.

The stimuli were prepared as follows. Initially, 80 sentences were selected from the university textbooks (high-difficulty candidates), and 80 sentences were

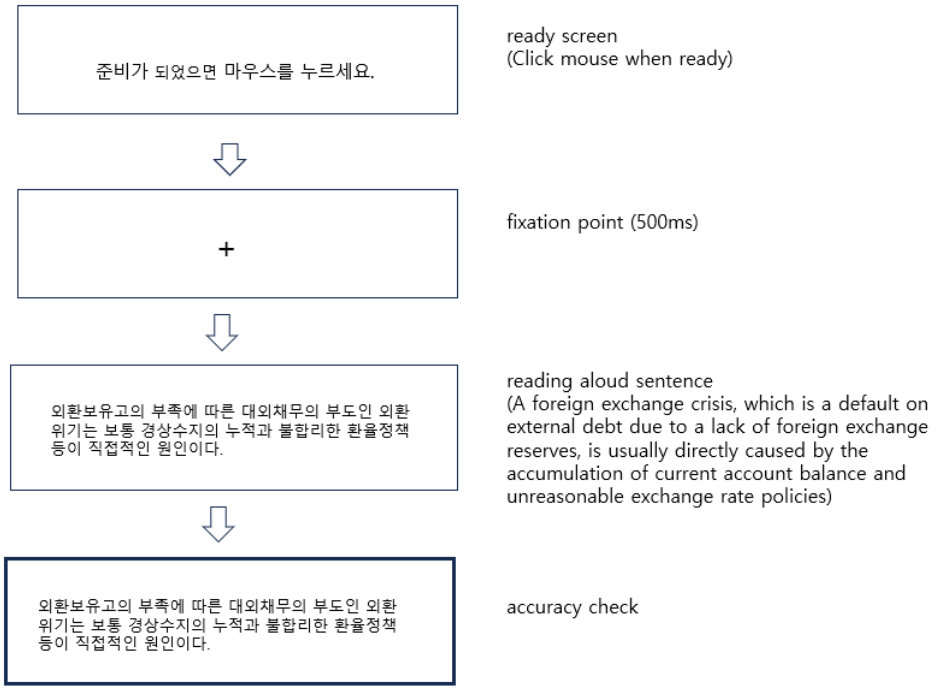

Figure 1. Procedure of a trial

selected from the textbooks for the first year of middle school and newspapers (low-difficulty candidates). For each sentence, the number of words/characters and the average frequency of words were examined. Based on this information, 56 sentences with low average frequencies and 52 sentences with high average frequencies were selected as high- and low-difficulty sentences. Then, 3 undergraduate students read aloud these sentences as quickly and accurately as possible. Based on their reading speed data, we selected the final 40 high-difficulty sentences in order of slow reading speed, and 40 low-difficulty sentences in order of fast reading speed. Sentence difficulty was primarily manipulated through differences in word frequency within the sentences. Syntactic complexity was indirectly controlled through related variables such as the number of words in a sentence and sentence length. High- and low-difficulty sentences were matched in the number of words (14 vs. 15) and characters (64 vs. 61), with the exception of the average word frequency (1980 vs. 9459). Word frequency data was referenced from Yonsei Institute of Language and Information Studies (1998).

We manipulated stimulus type (sentences vs. non-sentences), difficulty (high vs. low), and visual quality (good vs. poor) as within-participants variables. For each difficulty level, 40 corresponding non-sentences were prepared by randomly rearranging the word order of 40 sentences. To ensure each stimulus was presented only once across stimulus type and visual quality conditions, the 40 high-difficulty and 40 low-difficulty stimuli were divided into four groups of 10. Each group was assigned to one of four conditions. For example, if Group 1 stimuli were assigned to the sentence-good quality condition, Group 2 stimuli were assigned to the sentence-poor quality condition, Group 3 stimuli to the non-sentence-good quality condition, and Group 4 stimuli to the non-sentence-poor quality condition. The order of assignment was counterbalanced across conditions to create four lists. Thus, if Group 1 stimuli were presented in the sentence-good quality condition in List 1, they were presented in the sentence-poor quality condition in List 2, the non-sentence-good quality condition in List 3, and the non-sentence-poor quality condition in List 4. The participants read only one list.

The four lists were presented to the participants in turns, and the stimuli within a list were presented in different random order. Participants read half of the stimuli in good visual quality and the other half in poor

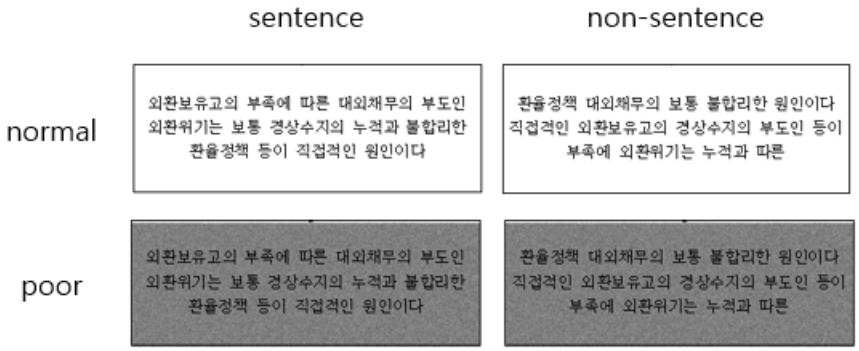

Figure 2. Examples of experimental stimuli

visual quality. In good visual quality, the stimuli were displayed in black on a white background without any disturbing visual noise. In poor visual quality, 70% random noise was created on a background using Paint Shop Pro. In the case of skilled readers, reading performance does not significantly deteriorate until the visual quality is reduced considerably (Legge, Rubin, & Luebker, 1987). Therefore, the noise level was determined through consensus among the researchers of this study to a point where the visual quality was sufficiently degraded while still allowing for letter recognition. The stimuli were presented in a font size of 15.

Procedure

The experiment was conducted individually. After the participant read the instruction, the experimenter explained the experimental procedure once again. The participant conducted 6 practice trials and then 80 main trials. The sequence of a trial is as follows. First, the ready screen appeared with a message ("If you are ready, click the mouse" written in Korean). When the participant clicked the mouse, a fixation point ('+') appeared in the center of the monitor screen for 500ms, followed by the stimulus (sentence or non-sentence) in one of two visual qualities. The stimulus was presented across three lines within a range of 30cm wide x 3cm high on the center of the screen. The participant read aloud the stimulus as quickly and accurately as possible. Immediately after the participant finished reading, the experimenter, seated in front of a separate monitor connected to the experimental computer, pressed the spacebar. A screen then appeared where the experimenter could enter the number of words the participants misread. Referring to the sentence displayed on the screen, the experimenter entered the number of incorrectly read words (a border was displayed on the screen to distinguish it from the previous one). Once the experimenter finished the input, the ready screen for the next trial appeared (Figure 1). The experiment took about 30 minutes.

Results

The reading speed was calculated in words per minute (WPM) based on the participants' performance. WPM refers to the number of words accurately read per minute. This was determined by subtracting the number of incorrectly read words from the total number of words read in each sentence, then dividing by the time taken to read each sentence and converting it to a per-minute rate. A higher the WPM score indicates faster the reading speed, as it indicates more words read per minute. The sentence context effect, the primary focus of this study, was calculated as the ratio of the reading speed in the sentence condition to the reading speed of the non-sentence condition. Linear mixed-effects models were used to analyze the results of reading speed and the sentence context effect.

Reading speed

Table 1 presents reading speed as a function of visual quality, stimulus type, and sentence difficulty. The results

Table 1. Reading speed (WPM) as a function of visual quality, stimulus type, and sentence difficulty

visual quality	stimulus type	sentence difficulty	Mean (SD)
good	sentence	high	95.03 (11.18)
	sentence	low	124.19 (13.18)
	random words	high	85.05 (10.54)
	random words	low	101.51 (13.33)
poor	sentence	high	77.84 (11.58)
	sentence	low	105.95 (14.35)
	random words	high	67.62 (10.10)
	random words	low	77.28 (11.92)

of the linear mixed-effects model analysis for reading speed showed that the effects of visual quality (β = 24.40, $p < .001$), sentence context (β = 28.68, $p < .001$), and sentence difficulty (β = −9.64, $p < .001$) were all significant. Interactions between visual quality and sentence context (β = −6.16, $p < .001$), visual quality and sentence difficulty (β = −6.62, $p < .001$), and sentence context and sentence difficulty (β = −18.31, $p < .001$) were all significant, as well as the interaction among visual quality, sentence context, and sentence difficulty (β = 5.61, $p < .001$). These interactions were further examined in detail in the subsequent sentence context effect analysis.

Sentence context effect

Sentence context effects were measured as the ratio of the speed of reading sentences to the speed of non-sentences. This ratio is a commonly used method to measure the effect of sentence context in reading research (e.g., Fine et al., 1999). Calculating the sentence context effect as a ratio has the advantage of providing relative values for each participant and condition, thereby being less influenced by the absolute reading times compared to using absolute difference. Ratio values greater than 1 indicate the presence of sentence context effects. Figure 3 presents sentence context effects as a function of visual quality and sentence difficulty.

The results of the linear mixed-effects model analysis for the sentence context effect showed that the effects of visual quality (β = −0.15, $p < .001$) and sentence difficulty (β = −0.23, $p < .001$) were both significant. Additionally, the interaction between visual quality and sentence difficulty (β = 0.12, $p < .001$) was also

Table 2. Result of linear mixed effect model analysis for reading speed (WPM)

predictor	Estimate(β)	SE	t-value	p
(Intercept)	77.39	2.20	35.12	< .001
quality	24.40	0.72	33.85	**< .001*** **
context	28.68	2.07	13.82	**< .001*** **
difficulty	−9.64	2.07	−4.65	**< .001*** **
quality:context	−6.16	1.02	−6.05	**< .001*** **
quality:difficulty	−6.62	1.02	−6.49	**< .001*** **
context:difficulty	−18.31	2.93	−.6.24	**< .001*** **
quality:context:difficulty	5.61	1.44	3.89	**< .001*** **

Table 3. Result of linear mixed effect model analysis for sentence context effect (ratio)

predictor	Estimate(β)	SE	t-value	p
(Intercept)	1.38	0.01	100.34	< .001
quality	−0.15	0.02	−8.18	**< .001*** **
difficulty	−0.23	0.02	−12.22	**< .001*** **
quality:difficulty	0.12	0.03	4.42	**< .001*** **

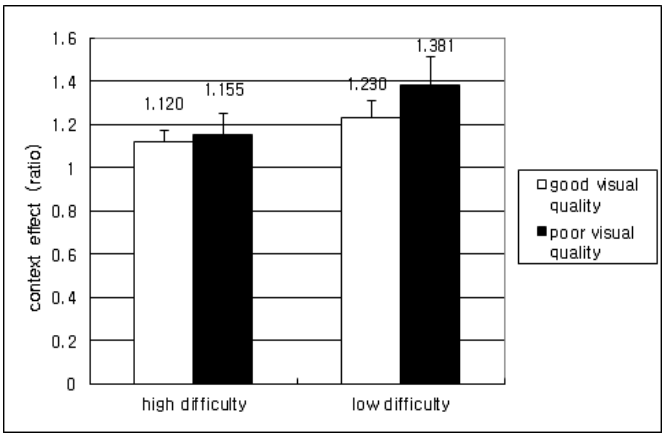

Figure 3. Sentence context effects as a function of visual quality and sentence difficulty

significant. Sentence context effects increased in poor visual quality relative to good visual quality and in low-difficulty sentences relative to high-difficulty sentences. Notably, the magnitude of the increase in sentence context effects according to visual quality was greater in the low-difficulty sentences than in the high-difficulty sentences.

Discussion

In the present study, we investigated how sentence context effects were affected by the visual quality and sentence difficulty during reading. The main results are as follows: First, sentence context effects increased in poor visual quality compared to good visual quality. Second, sentence context effects increased in low difficulty compared to high difficulty. Third, there was an interaction between visual quality and sentence difficulty. The increase in sentence context effects in poor visual quality relative to good visual quality was greater in low difficulty than high difficulty.

Although it seems generally agreed that context can help reading performance in normal reading (Rayner, 1998, for review), there is no consensus regarding the effect of sentence context in visually degraded reading situations. Previous studies have suggested that context effects may increase, decrease, or remain unaffected in reading with degraded visual quality. In the present study, sentence context effects increased when the sentences were visually degraded relative to normal. This is consistent with the view that contextual information can make a greater contribution in visually degraded reading as readers rely more on contextual information to compensate for the lack of visual information (Lee, 2004; Stanovich & West, 1983).

Sentence context might compensate for the lack of visual information by facilitating word identification (Binder, Chace, & Manning, 2007). A well-known phenomenon related to this is the sentence superiority effect, which shows that word identification is more accurate when words are presented in grammatically correct sentences compared to when they are presented in scrambled sentences (Massol et al.,, 2021; Snell & Grainger, 2017). It is suggested that sentence context not only offers constraints on syntactic categories of subsequent words through parallel processing of the multiple words comprising the sentence but also provides semantic influences that facilitate word identification. Similarly, in the present study, the sentence context provided by the presented sentences might have facilitated word processing by offering semantic and syntactic information about the following words. This contextual assistance may have been particularly pronounced when visual quality was poor and word recognition was more challenging (Bullimore & Bailey, 1995; Lee, 2004; Stanovich & West, 1983).

In the present study, we observed that sentence context effects increased in low difficulty compared to high difficulty. Previous studies have suggested that sentence difficulty can influence the effective range of reading. Surrounding information could be extracted more easily when reading low-difficulty sentences than when reading high-difficulty sentences (Henderson & Ferreira, 1990). The saccadic length, defined as the distance the eye travels from one fixation point to the next, is usually between 6.8 and 6.9 letters in reading biology or physics texts, but it increases up to 9.2 letters when reading light novels (Rayner & Pollatsek, 1989). This suggests that when reading more difficult text, the amount of information processed in a single fixation is smaller. The increased difficulty in processing high-difficulty sentences

compared to low-difficulty sentences may have led to less effective formation of sentence context, ultimately resulting in a diminished sentence context effect.

Morris (2006) posited that multiple mechanisms might underlie the effects of sentence context. According to this perspective, sentence context can enhance word processing by predicting subsequent words or by generating intra-lexical priming through word-to-word associations. Furthermore, it was proposed that context could facilitate the processing of subsequent words by constructing discourse-level representations through the combination of words. If the observed sentence context effects are indeed a result of these mechanisms, then high-difficulty sentences, composed of low-frequency words, might exhibit slower processing speeds, leading to relatively reduced intra-lexical priming compared to low-difficulty sentences with high-frequency words. Additionally, this reduced processing speed could hinder the efficient formation of discourse-level representations, which are necessary for facilitating the processing of subsequent words.

The most interesting finding in the present study is the interaction of visual quality and sentence difficulty on sentence context effects. The increase in sentence context effect in poor visual quality relative to good visual quality was greater in low difficulty than in high difficulty. Although sentence context may play a greater role in reading with degraded visual quality, how effectively sentence context is used may be dependent on the level of sentence difficulty. As evidenced by the increased sentence context effect in low difficulty compared to high difficulty in the present study, sentence context can be used more effectively in sentences with lower difficulty. Therefore, while degraded visual quality may lead to increased sentence context effects at both difficulty levels, the increase could be amplified in low-difficulty sentences compared to high-difficulty sentences. Again, these findings indicate that the impact of sentence context becomes more pronounced under poor visual quality. Additionally, for sentence context effects to appear effectively, it is essential that the context is efficiently established through primary processing, as seen in low-difficulty sentences.

In this study, reading speed was measured while participants read aloud, which involves the articulation process. This may have led to different results compared to silent reading. However, both silent reading and reading aloud involve processes related to phonological decoding, morphological decoding, and semantic decoding (Smyrnakis, Andreadakis, Rina, Boufachrentin, & Aslanides, 2021). Furthermore, various reading-related factors, such as sentence difficulty, visual quality, and context, have been observed to have similar effects on both types of reading (Handerson & Ferreira, 1990; Legge, & Bigelow, 2011; Ohnishi et al., 2020; Sass et al., 2006; Steen-Baker et al., 2017; Warrington, McGowan, Paterson, & White, 2018; Yu et al., 2007). Nevertheless, to gain a more comprehensive understanding of these dynamics, future research should investigate context effects using various reading methods, including silent reading.

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시각질과 문장 난이도가 읽기 속도에서 문장맥락효과에 미치는 영향

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본 연구에서는 한국어 문장 읽기에서 시각질과 문장 난이도가 문장맥락효과에 미치는 영향을 알아보았다. 참가자들은 시각질 변인(정상, 빈약)과 난이도 변인(고난이도, 저난이도)을 조합한 네 가지 실험 조건에서 문장을 읽거나 무선 단어열을 읽었다. 문장맥락효과는 문장의 읽기속도(분당 정확하게 읽은 어절 수)와 무선단어열의 읽기속도의 비로 측정되었다. 두 실험의 결과, 문장맥락효과는 정상 시각질보다 빈약한 시각질에서, 고난이도보다 저난이도에서 증가했다. 더욱 주목할 결과로, 시각질과 난이도 간 상호작용이 관찰되었다. 문장맥락효과는 두 난이도 조건 모두에서 정상 시각질보다 빈약한 시각질에서 증가하였는데, 이러한 증가 폭은 고난이도보다 저난이도 조건에서 더 크게 나타났다. 본 연구 결과는 시각적으로 제한된 읽기 상황에서 문장 맥락 정보의 역할이 증가하며, 이러한 증가 폭은 문장의 난이도가 낮을 때 더 커진다는 것을 시사한다.

주제어: 문장맥락효과, 시각질, 문장 난이도, 읽기속도, 읽기