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Author Note

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Abstract

This study aimed to examine the role of executive control in the integrative reading processes as well as the learning outcomes in illustrated science text reading. Twenty-eight 4th/5th grade elementary students read two illustrated texts while their eye movements were recorded with an eye tracker. Findings were a) children's integrative eye movement is associated with their transfer outcomes, b) attention shifting is associated with learning outcomes, and c) no other working memory capacities are associated with integrative transition.

Keywords: Illustrated text, eye tracking, comprehension, science text

Introduction

Given the belief about how effective visual representations are for learning, there has been a wide adoption of images in science textbooks. However, the effectiveness of visual representations is controversial; including pictures to text does not always lead to better learning outcomes (Bartholomé & Bromme, 2009). Providing visual representations may actually increase the cognitive demand for learners (Mayer & Moreno, 1998; Paivio, 1986; Schroeder & Cenkci, 2018). When reading illustrated texts, readers need to effectively split their attention between text and images, then integrate verbal and nonverbal information in order to construct a coherent mental model. This additional cognitive demand might hamper learning by overloading the processing capacities of learners.

Studies have confirmed the role of verbal and visuospatial working memory in illustrated text reading. For example, a meta-analysis study (Höffler, 2010) found a positive relationship between spatial abilities and learning outcomes of texts with static pictures. A recent empirical study conducted by Kühl et al. (2017) also found that spatial ability acts as an enhancer when learning with static visual representations. On the other hand, Schnotz et al. (2017) found that verbal working memory contributes illustrated text reading though not as much as visuospatial working memory does. What is relatively unexplored is whether the better learning outcomes of students with high verbal and visuospatial working memory are actually derived from their integrative reading of text and pictures. It is plausible that students with high verbal and/or visuospatial working memory capacities may effectively learn science concepts without integrating visual representations. Therefore, it is important to look at readers' online processing (during reading) behaviors in addition to working memory and learning outcome.

The present study aimed to examine the relationships between central executive, online reading behaviors, and reading comprehension in fourth and fifth grade elementary students while reading science texts. This study used an eye tracking technique to observe the online reading behaviors of fourth and fifth grade elementary students while they read both illustrated and non-illustrated science texts. Three research questions have guided this study.

1. Do students' integrative eye movements make unique and direct contributions to their learning outcomes?

2. Does students' executive control make unique, direct contributions to comprehension outcomes of illustrated science texts?

3. Does students' executive control make unique and direct contributions to integrative eye movements?

Methods

Participants

Twenty-eight fourth/fifth grades students (mean age = 10.4; SD = 7.2; range: 8.92 ~ 11.08) were participated in the study. Children who had severe developmental disorders (e.g., Autism Spectrum Disorders) and/or did not have normal or corrected-to-normal vision were excluded. The normal or corrected-to-normal binocular vision (20/40 or better) was confirmed by their performance on a standard Snellen chart.

Reading Materials

The topics of the reading materials were *How Does a Steam Train Move?* and *How Does an Airplane Take Off?* The readability of each text was adjusted for fourth grade readers. Both unillustrated and illustrated conditions were developed for each topic of text. The unillustrated (i.e., text only) texts were composed of two parts: a title and a text segment. The illustrated (i.e., text with picture) texts were composed of three parts: title, a text segment, and a picture segment. The text segment was placed on the left side and the picture segment was on the right. For both topics, word count, the number of multisyllabic words, and readability were counterbalanced with one another. Children read both the illustrated and unillustrated texts. A block randomization was used to randomly assign one of the four versions in Table 1 to the participants.

Table 1
Versions of Reading Materials

Version	First text	Second text
A	Unillustrated Airplane	Illustrated Steam Train
B	Illustrated Airplane	Unillustrated Steam Train
C	Unillustrated Steam Train	Illustrated Airplane
D	Illustrated Steam Train	Unillustrated Airplane

Measures

Attention shifting was measured by the 64-card version of Wisconsin Card Sorting Test (WCST-64; Kongs, Thompson, Iverson, & Heaton, 2000). The number of perseverative errors (i.e., errors in which students apply a previous rule after receiving feedback) was used as an indicator of difficulty with attention shifting (see Kieffer et al., 2013). A computerized color Stroop task using ePrime software was used to measure students' inhibitory control. Students' response time and accuracy were automatically recorded. The difference of the response time between congruent and incongruent conditions were used for indicating students' capacity of inhibitory control.

Verbal/visuospatial working memory were measured by digit span tests and visual/sequential memory tests. Reading comprehension was assessed by the passage comprehension subtest of the Woodcock Reading Mastery Test – III (WRMT-III; Woodcock, 2011). Four open-ended questions were used to assess students' familiarity of the topics and their prior knowledge. Nine multiple-choice questions and one open-ended question were developed for each topic to assess students' learning outcomes. Half of the question items measured readers' retention knowledge, which assessed verbal recall after reading. The other half of the questions assessed readers' transfer knowledge.

Reading comprehension skill was assessed by the passage comprehension subtest of the Woodcock Reading Mastery Test – III (WRMT-III; Woodcock, 2011). This widely used measure employs a cloze task where children were asked to read short sentences and identify missing keywords for blanks in order to accurately complete the sentences. Four open-ended questions were used to assess students' familiarity of the topics and their prior knowledge. Nine multiple-choice questions and one open-ended question were developed for each topic to assess students' learning outcomes. Half of the question items measured readers' retention knowledge, which assessed verbal recall after reading. The other half of the questions assessed readers' transfer knowledge, which assessed higher levels of understanding with regard to the learning materials.

Eye Tracking and Eye Movement Indices

While students read the texts, their eye movements were recorded using an eye tracker. Participants were seated in front of a 22-inch widescreen monitor (resolution 1920x1080 [24 bits per pixel]; refresh rate 60Hz) with a viewing distance of approximately 80 centimeters between the monitor and the participant's eyes. To minimize head movement and standardize the viewing distance, participants were asked to use an adjustable chin rest and a forehead bar. Data were collected using SR Research EyeLink 1000 system (SR Research Ltd., Ontario, Canada) with a sampling rate of 1000 Hz from the right eye. The calibration and validation were deemed successful when an average error was less than 1° and a maximum error was less than 1.5°, as tested using a nine-point calibration. During the experiment, the calibration and validation were repeated after any breaks or whenever the experimenter considered it necessary. After successful calibration and validation, the reading materials were presented one by one. Children needed to solve comprehension question items after reading each topic. The question items were presented in a paper and pencil format. This study particularly observed students' integrative reading behaviors, which was defined as the total number of times the eye gaze is moved from text to picture and vice versa (Johnson & Mayer, 2012; Mason, Tornatora, & Pluchino, 2013).

Analytic Approach

To answer research question one, hierarchical regression analyses were conducted with learning outcomes as dependent variables and integrative eye movements as a predictor, while controlling for students' working memory and executive control. To answer research question two, hierarchical regression analyses were conducted with both executive control and verbal/visuospatial working memory as predictors. Learning outcomes were identified as the dependent variable while controlling for students' reading comprehension skills. To answer research question three, a multiple regression analysis was conducted with verbal working memory, visuospatial working memory, and executive control as predictors and integrative transition as a dependent variable.

Results

Associations Between Text/Picture Processing and Learning Outcomes

Table 2 shows the results from the hierarchical regression analyses for the total learning outcome (retention and transfer). The regression models tested whether integrative transition accounted for significant amounts of variance in the learning outcomes of illustrated text reading after controlling for working memory and executive control. Although Model 1 shows that working memory and executive control accounted for 35% significant variance in learning outcomes, Model 2 indicates that integrative transition did not account for significant variance of learning outcomes in the illustrated text condition.

Table 2
Hierarchical Regression Analyses for Learning Outcome

Model	*t*	*p*	*b*	*β*	R^2	ΔR^2	*F*
Model 1					0.35	0.35	6.76^{**}
Working Memory	3.01	0.006	0.13	0.49			
Executive Control	1.79	0.086	0.30	0.29			
Model 2					0.38	0.03	1.02
Working Memory	2.48	0.020	0.12	0.43			
Executive Control	2.01	0.056	0.35	0.34			
Integrative Transition	1.01	0.322	0.08	0.18			

Follow-up analyses were conducted with separate dependent variables of retention and transfer learning outcomes. As shown in Table 3, although Model 1 shows that working memory and executive control accounted for 35% of the variance, Model 2 revealed integrative transition did not account for significant variance in retention outcome. However, as shown in Table 4, for transfer outcome, integrative transition accounted for a significant 12 % of the variance, suggesting integrative transition has a unique, direct contribution on transfer learning outcomes over and above the contributions of working memory and executive control.

Table 3
Hierarchical Regression Analyses for Retention Learning Outcome

Model	*t*	*p*	*b*	*β*	R^2	ΔR^2	*F*
Model 1					0.35	0.35	6.76^{**}

Working Memory	1.99	0.058	0.04	0.32			
Executive Control	2.83	0.009	0.20	0.46			
Model 2					0.42	0.07	2.86
Working Memory	2.51	0.019	0.05	0.02			
Executive Control	2.31	0.030	0.16	0.38			
Integrative Transition	-1.69	0.104	-0.05	-0.29			

Table 4

Hierarchical Regression Analyses for Transfer Learning Outcome

Model	*t*	*p*	*b*	*β*	R^2	ΔR^2	*F*
Model 1					0.22	0.22	3.56*
Working Memory	2.49	0.02	0.10	0.44			
Executive Control	0.69	0.50	0.10	0.12			
Model 2					0.34	0.12	4.29*
Working Memory	1.79	0.09	0.07	0.32			
Executive Control	1.31	0.20	0.19	0.23			
Integrative Transition	2.07	0.05	0.13	0.38			

Associations Between Central Executive and Learning Outcomes

Regarding the association between executive control and learning outcomes, individual differences in attention shifting is only associated with learning outcomes.

Table 5

Hierarchical Regression Analyses for Illustrated Text

Model	R^2	*ΔR*2	*F*
1. Reading Comprehension	0.04	0.04	1.09
2. Working Memory	0.27	0.23	7.83**
3. Attention Shifting	0.44	0.17	7.27*
4. Inhibitory Control	0.48	0.04	1.62

Associations Between Central Executive and Text/Picture Processing

Table 6 summarizes the regression results regarding research question three. Children's integrative reading behavior was not significantly associated with working memory components.

Table 6
Results of Multiple Regression Analyses

IT					1.68	3, 24	0.20	0.17
VWM	0.6	0.586	0.14	0.12				
VSWM	1.2	0.257	0.26	0.26				
EC	-1.5	0.137	-0.67	-0.29				

Note: VWM = Verbal working memory; VSWM = Visuospatial working memory; EC = Executive control; IT = Integrative transition

Discussion

Integrative eye movement is only associated with transfer learning outcome. This result suggests that integrative reading may be more closely aligned with how children construct mental models, as well as a deeper understanding of the topics, not with surface knowledge. Being partly consistent with Mason et al. (2013), the finding is especially significant given the prevalent adoption of visuals in textbooks. Without enough processing time and integrative reading behaviors, visual representations might not help learning, especially for transfer knowledge building. Accordingly, the results may suggest that classroom teachers need to explicitly teach and model how to integrate visual representations while reading illustrated scientific texts.

Regarding the relations between executive control and learning outcomes, only attention shifting accounted for a significant variance in the learning outcomes from illustrated texts. The finding suggests that when learners read illustrated science texts, it is important for them to flexibly allocate their attention to different pieces of textual and pictorial information most relevant to the learning goals (Baadte et al., 2015). The fact that attention shifting was not related with unillustrated text comprehension, is inconsistent with the previously identified relationship between attention shifting and reading comprehension skills. As Baadte et al. pointed out, however, the role of attention shifting is highly dependent on cognitive demand of text materials. In the current study, the cognitive demand of text might have been a factor that determines the involvement of attention shifting.

This study adds to existing literature focused on the relationship among working memory, integrative reading behaviors, and learning outcomes when upper elementary students read scientific texts. This study contributes to the limited body of knowledge regarding the role of executive control in upper elementary students' learning with illustrated text and their integrative reading behaviors. Further, with the findings regarding the role of executive control, this study supplements the current Cognitive Theory of Multimedia Learning (Mayer, 2014). Finally, this study gives practical implications on the development of visual literacy interventions, as well as on how teachers can design their instruction.

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