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RESEARCH ARTICLE

Comparing Cognitive Processes in Math Problem Solving Between Comics and Text: An fNIRS and Eye-tracking Study

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ABSTRACT

This study aimed to determine if there are differences in students' mathematical problem-solving processes based on the method of problem presentation, using cognitive neuroscience as a basis. It particularly analyzed the differences between comics and text, which are variously used in textbooks. Elementary students in grades 5 and 6 solved two types of math problems presented in comics and text, and their eye movements and brain activity were measured using an eye tracker and fNIRS device. When the same problems were presented in both comics and text, neuroimaging results showed higher brain activation during comic-based problem-solving, though this difference was not statistically significant. Analysis of eye-tracking data revealed that the comic group had longer fixation durations compared to the text group, while the number of fixations was similar between the groups. These findings oppose concerns that educational comics might hinder active cognitive processes or distract students' attention. Based on these results, this study proposes strategies for using educational comics in mathematical problem-solving.

Key words: Math comics, fNIRS, eye-tracking, math problem-solving, neuroimaging

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Introduction

In the early 2000s, educational comic series significantly flourished in South Korea, and nowadays, one can easily find comics in textbooks as well. In mathematics textbooks and other mathematical learning materials, comics are presented for various purposes. Comics offer an intriguing method of presenting information, capable of reducing student stress and enhancing engagement (Tilley & Weiner, 2016). However, recent studies suggest that using comics in learning can distract students and lower their academic performance (Choi & Park, 2012). These results are often contradictory across different studies, and due to the variability in research environments, it is challenging to draw clear conclusions. Parents and teachers continue to present educational comics to students, harboring both skepticism and expectations.

The first skepticism about educational comics is that the various elements presented in comics can distract students more than text. It is still unclear what cognitive processes learners use to understand content presented through comics, hence there is a need to infer the cognitive processes involved in solving math problems presented in comics using brain activity and eye-tracking data.

Moreover, one of the anticipated advantages of comics in learning is their benefit for memory or recall (Mayer, 2002), yet studies comparing text to comics (e.g., Choi & Park, 2012) show conflicting results on recall levels for the same tasks. By examining the math problem-solving process presented in both text and comics through academic achievement, brain activity data, eye-tracking, and recall results, this study aims to derive implications for the application of educational comics in math learning.

Theoretical Background

Cognitive Processing in Comics

Comics are a medium that combines text, images, and narrative, characteristically conveyed through characters' actions and speech bubbles. According to the dual-coding theory, verbal and pictorial information in comics are processed as separate representations (Dong et al., 2019). Based on this theory, the brain stores these representations differently, which can enhance memory and recall of information (Clark & Paivio, 1991). In terms of learning, this use of multiple representations is known as multimedia learning (Mayer, R. E., 2002), which is reported to trigger various cognitive processes that aid in understanding concepts and enhancing memory. However, studies using comics show mixed effects. Choi & Park (2012) reported that a group that studied with comics performed lower in academic achievement compared to a group that read the same content in text form, suggesting that comics might distract attention.

In this study, attention is aimed to be examined through brain activity and eye-tracking data, and differences in task recall according to the medium are to be explored through post-experiment surveys.

Functions of the Prefrontal Cortex

The prefrontal cortex, located at the front of the brain behind the forehead, is responsible for numerous vital functions, including executive functions, working memory, and attention. In relation to comics, it is involved in visual processing and mental imaging, and plays a role in integrating visual elements and contextual clues with mathematical content in comic-based math problem-solving. It also participates in emotional processing depending on the content of the comics. On the other hand, math problems presented in text mainly focus on linguistic information processing and problem-solving using mathematical information (U. Frith., 2001; R. Saxe et al., 2009). The fNIRS device, NIRSIT Lite (OBELAB inc.), used in this study, measures oxygen saturation in brain blood flow, allowing non-invasive observation of prefrontal cortex activity. By observing the activity in the prefrontal cortex, we aim to explore differences in attention between the two types of tasks.

Eye Movements and Cognitive Processes

Eye-tracking technology, based on the eye-mind assumption (Just & Carpenter, 1980), allows observation of visual fixations and changes, providing insights into how learners acquire and process information during learning. Eye-tracking is increasingly used in educational research to illuminate learning processes (Liu & Chuang, 2011; Shin & Choi, 2013) and to understand the cognitive processes involved in learning through various media (e.g., Rummer et al., 2010; Schmidt-Weigand et al., 2010). Eye-tracking technology enables analysis of learner attention from data on gaze fixation and movement within areas of interest, one measure of which is the Percentage of Viewing Time (PVT). This value, the ratio of total gaze time to the total time slides were presented, is considered in many studies as an indicator of attention focus (Yang et al, 2013).

Eye tracking technology can be effectively utilized by researchers to investigate learners' cognitive processes by tracking their eye movements (Hyönä, 2010; Mayer, 2010). In particular, the total fixation duration and the number of fixations on text or image areas can be used as indicators of the level of attention allocated by learners to those areas (Desjarlais, M., 2017), which can provide insights into learners' cognitive load (van Gog et al., 2009).

Methods

Participants

The participants consisted of 27 elementary school students (14 males and 13 females) from two schools in Gyeonggi-do and Daejeon who consented to participate in the experiment. Initially, 32 students participated, but 5 were excluded due to poor vision, which affected the accuracy of eye-tracking data, and left-handed dominance. None of the students had psychiatric or neurological disorders.

Procedure

Task

The task was presented in two formats: comic and text. At the outset, participants were briefed on the experimental procedure and precautions, followed by two pre-test questions. These pre-test questions, involving arithmetic operations and pattern recognition presented numerically, were included to check for homogeneity in brain activity between the two groups. The main task involved solving two problems presented in both comic and text formats under given scenarios. The tasks given in comic form consisted of 16 panels per task. The text-based tasks were presented on a single screen, including essential elements necessary for problem-solving and a narrative expressed in the comics, also provided in text. The information and context provided were the same for both types of problems. The problems were adapted and modified from "Math Thief," one of the most popular math educational comics in Korea, focusing on content covered in the regular curriculum. There was a one-minute rest before starting the experiment, and a 30-second rest period between each problem.

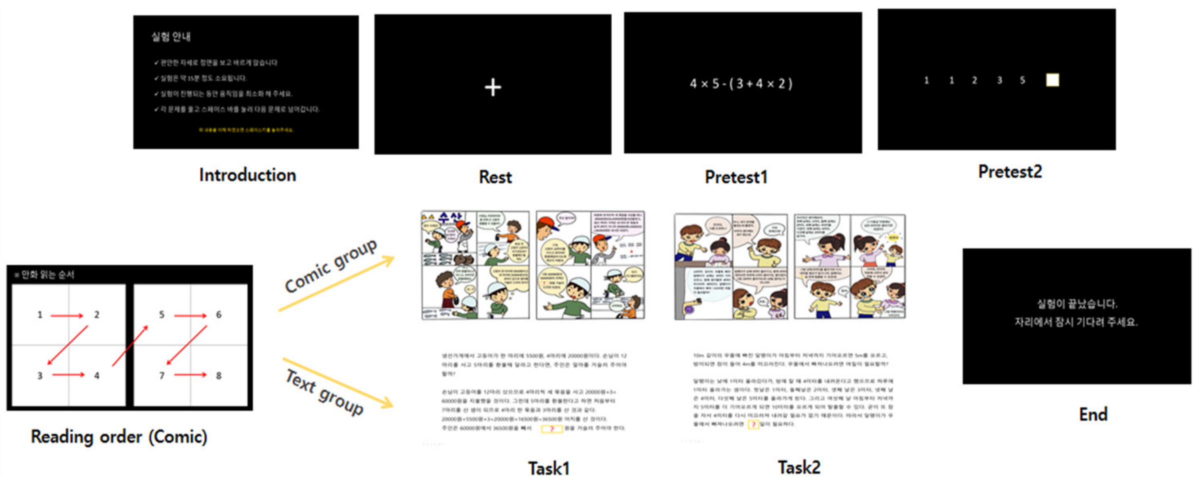


Fig. 1. Task procedure

Experiment

To ensure accurate measurements of brain activity, students were instructed not to engage in excessive physical or cognitive activities within 30 minutes prior to the start of the experiment. Participants were divided into two groups: the comic group (14 participants) and the text group (13 participants). They wore OBELAB's NIRSIT_LITE_KIDS and Tobii Glasses2 models, and solved tasks presented on a computer for about 15 minutes. To capture brain activity related to accurate problem-solving, no notes were taken, and participants were instructed to read and understand the problems with their eyes while maintaining as fixed a posture as possible before answering. After completing the tasks, a survey on task recall was conducted in a separate space. Since fNIRS uses near-infrared light, measurements were taken in environments without direct sunlight to avoid interference from direct light sources. Participants were also instructed to minimize movement during the tasks to ensure accurate data collection.

Fig. 2. Wearing the devices and performing the task

Data Collection and Analysis

The data collected through the experiment consisted of brain activity and eye movements during task performance, as well as survey results on task recall after the experiment.

Brain activity data analyzed the oxygenated hemoglobin saturation (HbO). Brain signals with a Signal-to-Noise Ratio (SNR) below 30 were excluded from the analysis. The HbO levels collected from both groups were compared statistically using the Mann-Whitney U test, as equal variances were not assumed between groups. The data were visualized using the brain map provided by OBELAB.

Eye movement data were excluded from analysis if the accuracy was below 80%. The study compared the average duration and number of whole fixations between groups during the tasks.

The survey on task recall was conducted immediately after the experiment, where participants were asked to freely write down as much information as they could remember about the task, with no time limit imposed.

Results

Brain Activity Analysis

Table 1. Comparison of HbO results between comic and text groups

Statistical Test	Group Comparison	N	U/W St atistic	p-value	Mean Rank
Mann-Whitney U Test	Comic	14	U = 76.5	0.481	15.04
	Text	13			12.88

Table 1 compares the HbO concentrations in the prefrontal cortex between the comic group and the text group. The results of the Mann-Whitney U test indicate that there is no significant difference in brain activation between the two groups (at a 95% significance level).

The presented Fig 3. represent the group averages of oxygenated hemoglobin (HbO) activation maps during task resolution for the comic and text groups. While no statistically significant differences were observed between the two groups based on the averages across 15 channels, numerically higher activation levels were observed in the comic group.

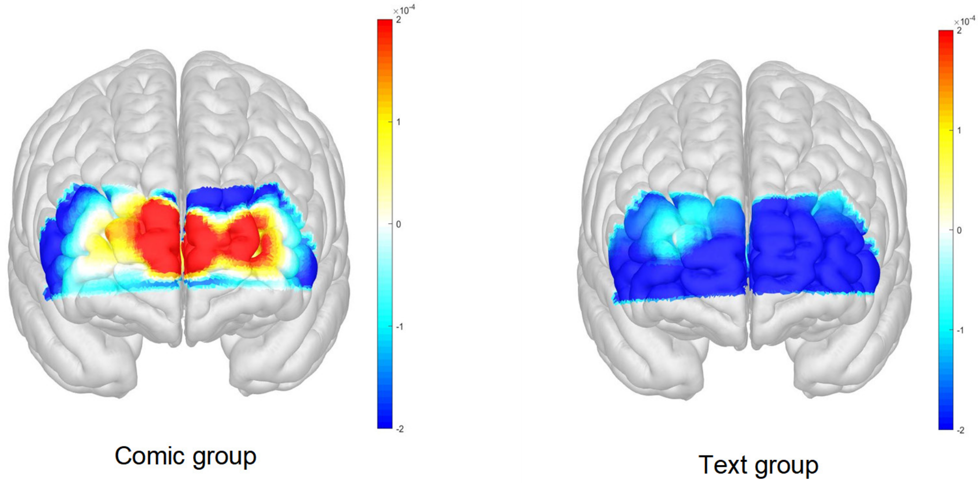


Fig. 3. Prefrontal cortex activation in the comic group(left) and the text group(right)

These results suggest that processing visual and textual information together in comics may induce a higher cognitive load compared to using text alone.

The central part of the figures, where differences between the two groups are pronounced, corresponds to the prefrontal dorsolateral prefrontal cortex, involved in strategizing, planning, and decision-making in complex situations. This area is also associated with empathy towards others and is interpreted as being related to the emotional processing prominent in comics.

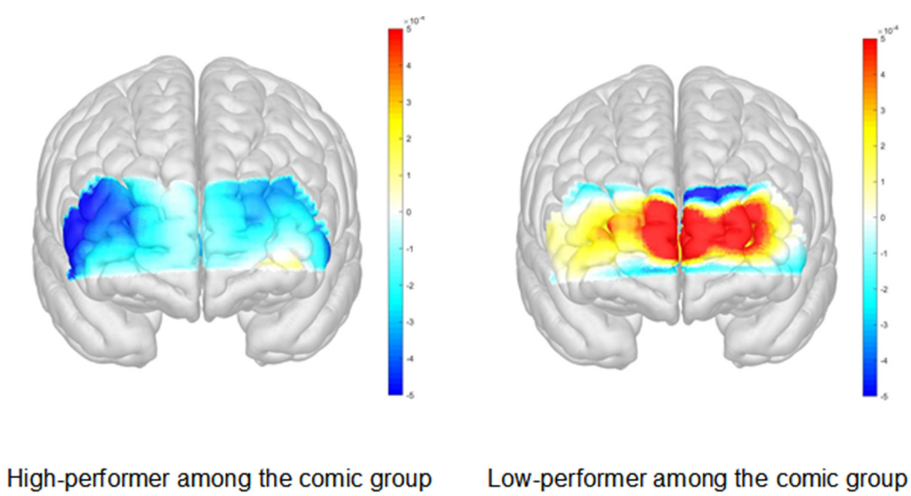


Fig. 4. Brain activation based on performance in the comic group

Analysis of the HbO activation maps revealed that the lower-achieving group (those who did not answer correctly) exhibited higher activation compared to the higher-achieving group (those who answered correctly). This pattern was consistent across both the comic and text groups. Since the differences are not statistically proven, caution is advised in the interpretation, these findings suggest that learners experience a higher cognitive load when attempting to solve challenging problems, regardless of the medium.

Eye-tracking Data Analysis

Table 2. Comparison of PVT between comic and text groups

Statistical Test	Group Comparison	N	Mean Gaze Fixation Ratio	U/W Sta tistic	p-value	Mean Rank
Man n-Whitney U Test	Comic	14	0.51	U = 46	0.029*	17.21
	Text	13	0.36			10.54

*p<.05

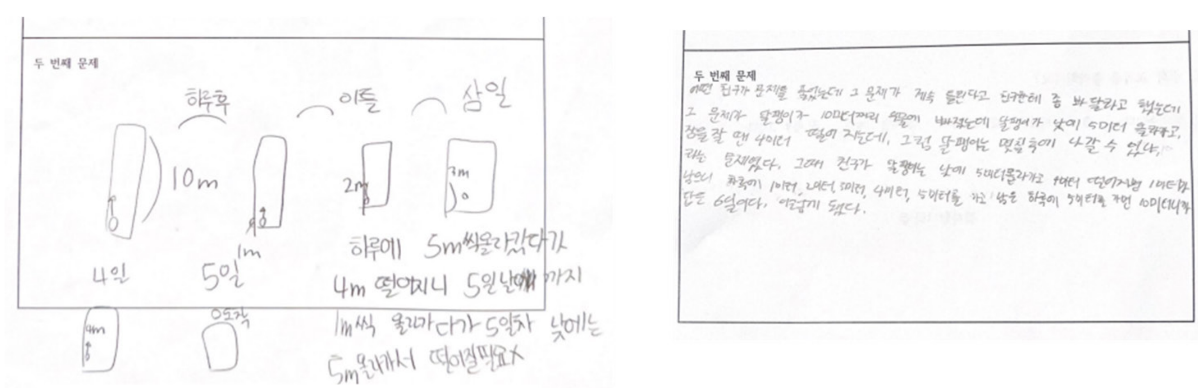
An examination of PVT(the gaze fixation ratios), which can indicate levels of attention, showed that the comic group had significantly higher fixation ratios compared to the text group(Table 2). In the comic group, as shown in Fig. 5, it was observed that most of the gaze remained on the speech bubbles. These results suggest that viewers look at one place longer when viewing comics, which can be interpreted as learners paying attention with interest and engagement. This may also be related to the higher brain activation observed in the comic group.

Fig. 5. An example of eye-tracking during a comic task

Recall of the Task

Fig. 6. Task Recall level by Media

Upon examining recall of the task, as depicted in Fig. 6, the text group showed higher levels of memory recall. Recall was categorized into three levels: Level A, where the content recalled was sufficient to solve the problem; Level B, where the content recalled could not solve the problem but captured most of the narrative flow; and Level C, where only a small amount of information was recalled. More than half of the participants in the text group demonstrated Level A recall, indicating a generally higher level of recall compared to the comic group.



An example of recall in the comic group

An example of recall in the text group

Fig. 7. Examples of task recall

In terms of how content was recalled, the comic group used a more diverse range of methods (Fig. 7). Unlike the text group, where all but one participant used only text (including numbers), the comic group exhibited a variety of expressions including drawings, diagrammatic representations, comics, and text. Additionally, the comic group uniquely expressed feelings such as 'I wonder why that happened' and 'I might have made the same mistake,' which were not observed in the text group. Detailed descriptions of scenarios, such as 'the child who got the answer wrong came running to ask,' were also noted in the comic group.

Discussion

Comparing the results of this study with previous research yields the following insights:

Firstly, no statistical differences in prefrontal cortex activation were observed between the groups when math problems were presented using comics versus text. This differs from prior studies suggesting that educational comics might distract attention (Choi & Park, 2012). Moreover, numerically, the comic group showed higher activation, consistent with research indicating that comics require a more diverse set of cognitive processes and pathways due to the integration of text, images, and narrative. This aligns with findings from Kwon (2009), who noted that comics utilize different brain regions compared to traditional math problems, particularly involving more of the right hemisphere. However, the anticipated effects of educational comics in reducing stress and cognitive load (Frank & Christine, 1987; Pyun & Kim, 2011) were not observed during the math problem-solving tasks in this study.

Upon examining eye movements, the fixation duration was longer in the comic group. Considering there was no difference in the total time spent solving problems between the groups, and the number of fixations was similar, this suggests greater attention was paid to the comics. This supports previous findings that comics can stimulate curiosity and interest, enhancing concentration (Kozma, 1991; Larkin & Simon, 1987).

Conversely, the text group showed a higher overall amount of recall information, contradicting the dual-coding theory-based assertion that using two representations should benefit memory and recall (Mayer, R. E., 2002). This result suggests that in the context of solving mathematical problems, comics are not more advantageous than text in terms of remembering the problems.

Both the brain activation and eye-tracking results indicated that the level of attention in the comic group was not inferior to that in the text group. This variability in outcomes among studies involving educational comics could be attributed to the unique aspect of 'math problem-solving' addressed in this research.

These findings suggest that using educational comic materials in mathematics can help improve students' interest, attention, and ability to utilize diverse representations. However, traditional text-based materials may be more effective for conveying factual information and recall. Therefore, teachers need to choose appropriate material presentation methods depending on the learning content and objectives.

Furthermore, as no significant differences were found in brain activation levels or academic achievement between comics and text in this study, teachers need not feel overly burdened about using comic materials. However, it is important to identify students' preferred material types considering individual differences and provide appropriate scaffolding accordingly. Teachers themselves also need to actively explore and research ways to utilize comic materials for educational purposes.

Conclusion

Based on the results and discussion, the conclusions of this study are as follows:

Firstly, in terms of attention, there is no difference between presenting math problems in text or comics. The commonly feared disadvantage of educational comics, namely 'distraction,' was not observed in brain measurement and eye-tracking data during math problem-solving. Instead, numerically higher brain activation suggests that functions such as information processing, problem-solving, and empathy in the prefrontal cortex are sufficiently occurring in educational comics compared to text.

Secondly, if the objective is to alleviate cognitive load, presenting math problems in comics is not appropriate. Although studies involving educational comics have expected to reduce cognitive load and stress in students with lower achievement, this study did not reduce cognitive load in the lower-achieving group during math problem-solving. This observation was common in both the text and comic groups, indicating that the stress-relieving effects of educational comics may not manifest well in problem-solving contexts, unlike in situations involving motivation and explanation of principles described in prior research.

Thirdly, using text is more effective when precise recall of the task is necessary. The text group showed higher levels of recall. In contrast, the comic group exhibited diverse representations of problems and detailed memories and empathy regarding the context.

In summary, this study provides empirical counterevidence to some concerns raised about educational comics and offers implications for the unique educational potential and utilization of comic materials in mathematics.

However, it is important to note that this study has limitations. The number of participants was not sufficient for quantitative comparison, and the results derived from the specific context of 'solving math problems' require caution when generalizing the findings. Future research with larger sample sizes and across diverse subjects is needed to further explore the effectiveness and applicability of educational comics in learning.

Conflicts of Interest

The author(s) declared no conflicts of interest.

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