The Effect of Visual Cues on Cognitive Load Depending on Self-Regulation in Video-Based Learning

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ABSTRACT

Recently, online learning has been increasingly used due to its advantages that allow people to study anytime and anywhere. Learners, on the other hand, are separated from the instructor in video-based learning, which makes learners difficult to maintain their motivation until the end of the activity. Therefore, it is required to provide instructional treatment so that learners keep their motivation and be immersed in learning. Visual cues, lowering cognitive load, are known a putative way in which learners can distinguish essential information from irrelevant one. The aim of this study is to explore the effect of visual cues on cognitive load depending on the level of self-regulation. The result shows that self-regulation lower cognitive load in the non-visual-cue group as time series, but self-regulation doesn't have an effect on cognitive load in the visual-cue group. This indicates learners in the non-visual-cue group experience difficulty to keep their motivation so that they are hard to put mental effort into the learning. This study suggests that the pupil dilation which reflects cognitive load can be predicted by behavior log which indicates self-regulation. Therefore, it is necessary to enhance learners' cognitive strategies, as well as the reduction of the factors causing unnecessary cognitive load.

Keywords

Visual Cues, Cognitive Load, Self-Regulation, Video-Based Learning, Learning Analytics

1. INTRODUCTION

With the development of technology, online learning has been dramatically increased and people can easily watch videos from different platforms on diverse terminals, such as desktop, tablet, phone [16]. It allows learners to study anytime and anywhere [6]. Learners, on the other hand, are separated from the instructor in video-based learning, which makes learners difficult to maintain their motivation until the end of the activity. Therefore, it is required to provide instructional treatment so that learners can keep motivation and be immersed in learning.

According to Mayer, meaningful learning requires learner to select relevant information, organize the information into coherent representation and integrate this representation into existing knowledge [11]. Multimedia instructions are effective when it is designed in accordance with how human mind works [7]. Working memory has limited capacity when dealing with novel or unorganized information, since it needs more cognitive processing [17]. Cognitive load theory (CLT) is based on the concept that people have a limited working memory and processing capacity [23]. Therefore, the ease of information processing in working memory is main interest of cognitive load theory [13].

CLT consists of three elements: intrinsic load, extraneous load, and germane load [12]. Among them, extraneous load and germane load are affected by instructional design. Extraneous load is risen when unnecessary cognitive processing is needed. Germane load is decreased when learners are not involved in deep cognitive processing, such as organizing or relating the material to prior knowledge [15]. Relatedly, using cues when designing instruction can draw learners' attention to essential elements in learning. Therefore, providing visual cues can lower extraneous load and increase germane load [8].

The relationship between cognitive load and self-regulation sheds light on when and why learners adopt their behaviors and how these behavioral changes are related with cognitive load [5]. Self-regulated learning (SRL) refers to learning with student's goal-directed self-generated thoughts, feelings, strategies, and behaviors [14]. A self-regulated learner plans, monitors, reflects, and adjusts his/her learning process metacognitively, so he/she shows self-paced learning behaviors in computer-mediated learning environment [19, 24]. Learners' regulating behaviors can be assessed as how frequently learners use the learning strategy with the Learning Management Systems (LMSs) in real learning time [4, 18]. Therefore, learners' online behaviors in an e-learning player can be used to analyze self-regulation.

In sum, two hypotheses are created. Firstly, visual cues would be a factor to promote germane load with decreasing extraneous load in time series, which is measured by pupil dilation. Secondly, self-regulation would have a moderate effect on learners' cognitive load. This study aims to explore the effect of the instructional design with visual cues in regard with learners' cognitive load depending on the level of self-regulation.

2. METHODOLOGY

2.1 Participants

Participants were recruited through online notices for a month. Since an ophthalmic disease influences the eye-tracking, participants were asked if they suffered from any of it. A total 100 undergraduate students (46 female, M = 24, SD = 1.79) took part in the study on a voluntary basis. Then they were randomly assigned to the group with or without visual cues. Among 100 participants, 23 participants were excluded from the analysis due to mechanical faults (e.g., calibration was cancelled or failed, recording was stopped). In the end, 77 participants' data were used and analyzed.

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2.2 Procedures

Table 1. Research procedures

Recruitment		Online Notices (Korean Undergraduates)
Screening		Based on Eyesight, Major, Sex
Orientation (5 min)		Explanation about Research and IRB approval, Informed Consent
Experiment (80 min)	Questionnaire (10 min)	Motivated Strategies for Learning Questionnaire (MSLQ)
	Pre-Test (25 min)	6 Multiple-choice Items (from PSAT)
	Video-Based Learning (17 min)	Learning Material for PSAT Problem Solving Strategies
	Post-Test (25 min)	6 Multiple-choice Items (from PSAT)
	Questionnaire (3 min)	The ITC-Sense of Presence Inventory (ITC-SOPI)
Interview (60 min)		Interview with Eye Movement Data

The experiment proceeded in five phases (Table 1). Before starting the experiment, each participant took a 5-minute instruction about the procedure. All the phases were carried by computer. In the first stage, participants responded to Motivated Strategies for Learning Questionnaire (MSLQ). In the second stage, with eye calibration for the eye tracking, a 25-minute pre-test were administered to assess participants' prior knowledge. In the third stage, participants watched the 17-minute video lecture. The video lectures had been designed as two versions whether providing visual cues or not. In the meantime, participants' eye movement and behavior log were recorded with the e-learning player. In the fourth stage, participants took a 25-minute post-test for measuring learning achievement. Finally, they filled out the ITC-Sense of Presence Inventory (ITC-SOPI) scale and then they were interviewed for the comparison between the eye movement and the subjective learning experience response.

2.3 Learning Materials

Learning materials for Public Service Aptitude Test (PSAT) problem solving published by online distance educational institution [26] were used after having been edited. In South Korea, PSAT was devised to test the public officer applicants how well they deal with the public service. For the purpose of this research, the 'data interpretation ability' section in PSAT was only used. This material consists of four problem solving items and total learning time is about 17 minutes.

Two versions of the learning materials were developed with visual cues or without them. Both versions of the learning materials have an illustrated document and a spoken explanation. The experimental group was provided additional colored visual cues when an instructor explains or emphasizes the learning content. That is, colored visual scribbles are added in real time by the instructor while he/she speaks. By contrast, the visual cues were not given to the control group.

2.4 Measures

2.4.1 Physiological measure of cognitive load

Pupillary response measures people's cognitive processing load as a physiological measure [25]. Especially, pupil dilation reflects capacity utilization and relates to cognitive demand [1]. Mean pupil dilation is a useful for measuring cognitive load [2, 13]. Therefore, mean pupil dilation is measured to analyze participants' mental effort and cognitive load during test and learning time. A Tobii Pro X2-30 eye-tracker and Tobii Studio software was operated at a sampling rate of 30 Hz. Pupillary response was calibrated to the environmental brightness and display luminance for controlling external noise.

2.4.2 Behavioral measures of self-regulation

In order to measure and analyze learners' self-regulating behavior, behavioral log data were collected via e-learning player automatically (figure 1). The learning-related behavior was counted to assess learners' self-regulation [3]. In this study, self-regulation is defined as the sum of frequencies corresponding to every operation to regulate learners' learning and learning environment. Therefore, the frequencies of play, pause, skip, replay, volume change, and rate change were used to analyze learners' self-regulation. The e-learning player was developed by 4CSoft and EduTech Convergence Lab in South Korea.

2.4.3 Learning achievement

Learning achievement was measured as the difference between pre-test scores and post-test scores. Pre-test and post-test were designed based on PSAT. Each test material consists of 6 multi choices items. Both pre-test and post-test were verified by PSAT subject matter expert.

2.4.4 Questionnaires

2.4.4.1 Motivated Strategies for Learning Questionnaire (MSLQ)

In order to investigate learners' motivation, MSLQ was used. MSLQ is a self-report instrument designed to assess a general cognitive view of motivation and learning strategies [20]. According to MSLQ manual, it consists of two sections: the motivation section and the learning strategies section. Among 81 questions, 10 questions about peer learning, help seeking, and specific course were excluded because they do not fit to this study. Finally, 71 questions were used after adjusting to 5-point scale.

2.4.4.2 The ITC-Sense of Presence Inventory (ITC-SOPI)

When learners perceive presence in distance learning, learners have more sense of being in and belonging in learning [22]. To find out learners' learning experience in video-based learning environment, ITC-SOPI was used. 11 of 38 questions are not appropriate in the context of video-based learning environment, so 27 questions are only used with 5-point scale.

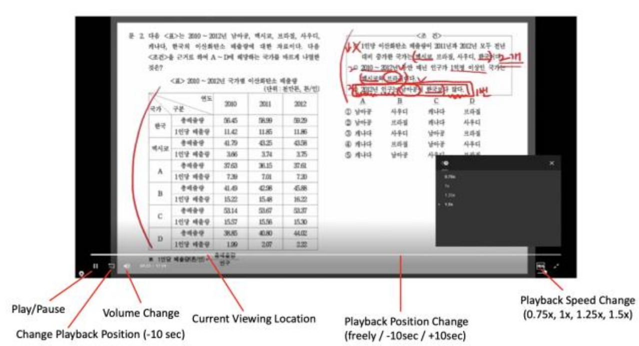

Figure 1. Example of the e-learning player

3. RESULTS

3.1 Descriptive Statistics

Table 2. Means of participants' characteristics

Variables		Mean(sd) No Cue (n=36)	Mean(sd) Cue (n=32)	χ^2 (p)	t(W) (p)
	Sex (F)	17	20	.040 (.841)	
	Major (STEM)	19	15	.236 (.627)	
	Age	23.8 (1.80)	24.2 (1.69)		-.897 (.373)
Motivation	Intrinsic Goal Orientation	3.68 (.69)	3.59 (.79)		(619) (.599)
Motivation	Extrinsic Goal Orientation	3.91 (.70)	3.68 (.74)		(700.5) (.125)
Motivation	Task value	4.14 (.56)	4.05 (.57)		.674 (.503)
Motivation	Control Beliefs	3.81 (.42)	3.80 (.47)		(580) (.965)
Motivation	Self-Efficacy	3.60 (.51)	3.38 (.62)		1.604 (.114)
Motivation	Test Anxiety	3.29 (.69)	3.26 (.74)		.152 (.880)
Learning Strategies	Rehearsal	3.94 (.56)	4.00 (.60)		-.445 (.658)
Learning Strategies	Elaboration	3.98 (.52)	3.94 (.42)		(639.5) (.435)
Learning Strategies	Organization	3.98 (.66)	3.96 (.81)		(590.5) (.863)
Learning Strategies	Critical Thinking	3.54 (.61)	3.51 (.66)		.212 (.832)
Learning Strategies	Metacognitive Self-regulation	3.56 (.39)	3.50 (.51)		.535 (.595)
Learning Strategies	Time and Study Environment	3.50 (.58)	3.49 (.71)		.098 (.927)
Learning Strategies	Effort Regulation	3.44 (.66)	3.35 (.71)		.517 (.607)

STEM: Sciences, Technology, Engineering, or Mathematics.

Total 68 participants' data were used in analysis after 9 outliers of either pupil dilation or behavioral log had been excluded. There is a difference in the participants' pre-test scores (Wilcoxon rank sum test: U = .883, $p < .01$). Except for this, all the other differences are not found (p_{all} = n.s., see Table 2). Regarding the pre-test scores difference between two groups, the level of prior knowledge should be considered when interpreting the results.

Because the pupil dilation is affected by time goes, the data should be analyzed as time series [21]. Section division for data analysis was implemented based on four problem solving items at the 17-minute video learning. The mean and standard deviation of pupil dilation in each section were analyzed between groups (No Cue: M_{Total} = .11(.12), M_1 = .16(.12), M_2 = .13(.12), M_3 = .08(.12), M_4 = .06(.15); Cue: M_{Total} = .13(.14), M_1 = .16(.16), M_2 = .16(.14), M_3 = .10(.15), M_4 = .10(.15), see Table 3).

Table 3. Means of dependent variables

Variables	Mean(sd) No Cue (n=36)	Mean(sd) Cue (n=32)	t(W) (p)
Total Pupil Dilation	.11 (.12)	.13 (.14)	-.656 (.51)
Pupil Dilation in 1st section	.16 (.12)	.16 (.16)	.004 (.997)
Pupil Dilation in 2nd section	.13 (.12)	.16 (.14)	-.874 (.385)
Pupil Dilation in 3rd section	.08 (.12)	.10 (.15)	(475) (.218)
Pupil Dilation in 4th section	.06 (.15)	.10 (.15)	-.873 (.386)
Behavior Frequency	18.2 (22.0)	18.8 (20.8)	(518) (.479)
Pre-test Scores	4.03 (.88)	3.47 (.95)	**(760) (<.05*)**
Post-test Scores	4.89 (1.04)	4.47 (1.19)	(685) (.165)
Improvement in Test Scores (= posttest - pretest)	0.86 (1.25)	1.00 (1.61)	(540) (.655)
Learning Presence	3.05 (.55)	3.16 (.52)	.813 (.419)

3.2 Pupillary Responses

3.2.1 Pupil dilation in time series

Average pupil dilation is gradually decreased as learning sections proceeded (F(3, 268) = .5.834, p = .001, see figure 2). The pupil size of all participants in 1st section is higher than those of participants in both 3rd and 4th sections (Tukey's post hoc: 1st vs 3rd, $p < .05$; 1st vs 4th, $p < .01$). Similarly, this tendency is shown between 2nd and 4th sections ($p < .05$). This indicates when the sections proceed, the overall pupil size is decreased.

3.2.2 The Effect of Visual Cues on Pupil dilation in time series

The result shows that pupil dilation of the group without visual cues in 1st section is higher than those of participants in both 3rd and 4th sections (Kruskal-Walis test: H(3) = 14.203, p < .01; Nemenyi post hoc: 1st vs 3rd, $p < .05$; 1st vs 4th, $p < .05$, figure 3). This indicates that pupil dilation of the group without visual cues is statistically decreased as time goes by. However, this tendency is not shown in the group with visual cues (F(3, 124) = 1.824, n.s.).

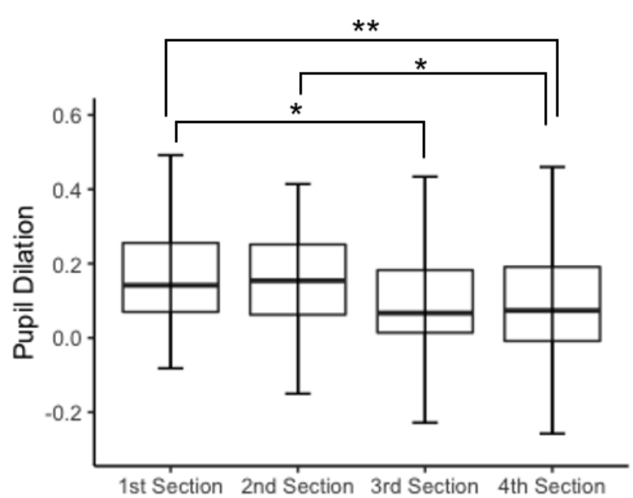

Figure 2. Pupil dilation in time series (*, <.05; **, <.01; error bar, SEM)

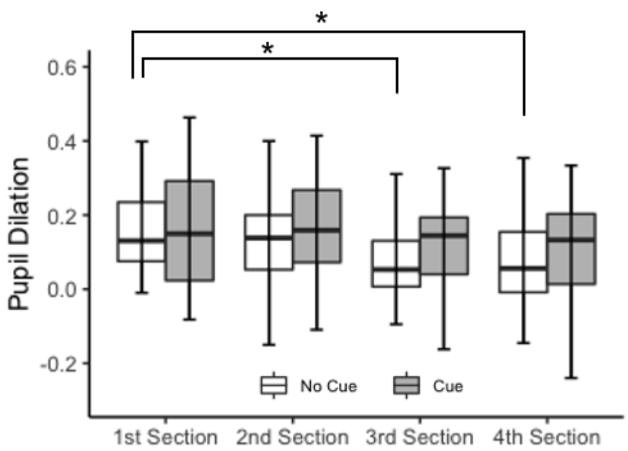

Figure 3. The effect of visual cues on pupil dilation in times series (*, <.05; error bar, SEM)

3.2.3 The Effect of Visual Cues on Pupil dilation in time series depending on self-regulation

Multiple linear regression was conducted to test the effect of visual cues on cognitive load depending on self-regulation. Results indicate that the frequencies of self-regulated behavior predict pupil dilation in the non-visual cue group in time series (R^2 = .137, adjusted R^2 = .112, p < .001, see Table 4). Especially, pupil dilation in 3rd section (B = -.082, β = -.263, SE = .030, p = .007) and 4th section (B = -.101, β = -.324, SE = .030, p = .001) are predicted in the non-visual cue group. Behavior frequency is also explained in the non-visual cue group (B = .002, β =.221, SE = .001, p = .006). On the other hand, the frequencies of self-regulated behavior do not predict pupil dilation in the visual-cue group in time series (R^2 = .043, adjusted R^2 = .012, n.s.).

4. DISCUSSION

Effective instructional design is crucial to maintain learners' motivation and promote cognitive processing in video-based learning. When an ineffective learning material is provided to learners, learners have to effort to distinguish key elements from irrelevant information. Being distracted by irrelevant information causes extraneous cognitive load. Based on the CLT and SRL, cueing was used to investigate whether it moderates learners' cognitive load depending on their self-regulatory capacity.

Table 4. Multiple linear regression analyses predicting cognitive load and self-regulation

Variables		B	β	SE	*p*
No Cue	Pupil Dilation in 1st section	.029	.000	.023	.197
	Pupil Dilation in 2nd section	-.032	-.102	.030	.290
	Pupil Dilation in 3rd section	-.082	-.263	.030	.007**
	Pupil Dilation in 4th section	-.101	-.324	.030	.001**
	Behavior Frequency	.002	.221	.001	.006**
Cue	Pupil Dilation in 1st section	.049	.000	.029	.091
	Pupil Dilation in 2nd section	-.004	-.011	.038	.921
	Pupil Dilation in 3rd section	-.060	-.170	.038	.117
	Pupil Dilation in 4th section	-.068	-.194	.038	.074
	Behavior Frequency	.000	.035	.001	.691

The present study shows pupil dilation of the non-visual-cue group statistically is decreased time goes by. By contrast, there is no statistical difference in the visual-cue group as learning sections proceeded. This implies that learners' cognitive load can be affected by visual cues in time series. Visual cues have an effect on cognitive load in time series within each group. By contrast, pupil dilation was not differed between those groups. This indicates that learners in the non-visual-cue group experience difficulty to keep their motivation and put into mental effort in learning, due to ineffective learning. Next, learners' self-regulated behavior explains cognitive load in the non-visual cue group. In the visual-cue group, learners' self-regulated behavior does not predict cognitive load. Although the interaction between self-regulation and cognitive load is not figured out, the results partially suggest that self-regulation would have the effect on cognitive load within time change by showing different tendencies between two groups.

The previous research said pupil dilation is affected by time and tiredness [9], but the visual-cue group could keep deep cognitive processing and the arousal status until the end of learning. Furthermore, reduction of extraneous cognitive load and increasement of germane cognitive load are expected when cue is provided [10]. Consistently, learners' germane cognitive load can be kept and increased when extraneous cognitive load is reduced by the effect of visual cues in this study. Therefore, instructional designers have to consider the effect of visual cues with time series in video-based learning.

This study has several limitations. The first limitation is the difficulty in classifying specific elements of cognitive load. Although, pupillary response is useful way to predict learners' cognitive load, pupil dilation has a problem that pupil dilation can be interpreted in two ways: an increase in germane cognitive load (or mental effort) or extraneous cognitive load (or allocation of attentional resources as task demands increased) [21]. In other words, pupil dilation can reflect both extraneous load and germane load in the same way.

The second limitation is that the group differences in pupil dilation are not figured out, though there are statistically significant differences in time series within each group. This may be caused by the difference of the level of the prior knowledge. Learners' prior knowledge is related to intrinsic cognitive load. This intrinsic load is hard to be affected by instructional design [12]. Considering this, the group's prior knowledge difference may offset the effect of the visual cues on the pupillary response.

Third limitation is about the analytic method of self-regulated behavior. Individual difference of behavior frequency was not controlled in this study. To minimize the variation, behavior frequency was analyzed by the sum over all sections, not by the division of each section. For more accurate measurements of self-regulation, the number of self-regulation behaviors should be analyzed within time goes.

Future research should continue to explore the effect of visual cues on cognitive load depending on self-regulation. With the combination of different measurements for assessing cognitive load, separating specific aspects of cognitive load is expected. When learners' cognitive load is divided and analyzed in each element of cognitive load, designing effective instruction is possible to improve learning effectiveness in video-based learning.

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