ON THE ROLE OF WORKING MEMORY CAPACITY AND SIGNALING IN MULTIMEDIA LEARNING

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Abstract

A variety of instructional design principles have been proposed to ease the demands on working memory during multimedia learning. However, not many studies showing the positive effects of such principles controlled variation in working memory capacity (WMC). Furthermore, findings from those studies that considered the WMC factor have been mixed, showing a varied effectiveness of some of the principles. The present study addresses this issue and presents the results of a pilot experiment which examined the effects of signaling (a multimedia design principle) and WMC on learning with a narrated slideshow. Results showed that individuals with high WMC performed better than those with low WMC on a comprehension test. No effect of signaling was observed. Compatibility of our findings with the existing literature and possible factors influencing the effectiveness of signaling are discussed.

Keywords: Multimedia learning, working memory capacity, signaling, multimedia design principles.

1 INTRODUCTION

The use of multimedia in delivering educational content has become common in a variety of educational settings. Here, multimedia refers to presentation of information that involves two modalities [1]. According to the Cognitive Theory of Multimedia Learning (CTML) [1], the objective of multimedia learning is knowledge construction which involves the following processes: selecting relevant elements in each of the information sources (selection), organizing them into coherent verbal or visual representations (organization), and integrating those representations with each other and within learners’ existing knowledge (integration) [1: p.51]. While successful learning depends on active engagement of learners with these processes, designing optimal instructional material is also important in order to reduce learners’ cognitive load which arises as a result of capacity constraints in the human information processing system [1]. Given these characterizations, it makes sense that multimedia instructional research considers both learner characteristics such as variation in working memory capacity and effectiveness of design techniques such as signaling (definition provided below). However, empirical research that addressed both issues is limited. The present study reports the result of a pilot study that addressed these two issues in one study.

1.1 The effects of signaling in multimedia learning

Signaling (or cueing) refers to the insertion of cues (e.g., arrows, color-coding) within multimedia material. It helps increase visual saliency and guides the learner’s attention to cued elements [2: p.282] (see also van Gog [3] for a review). Signaling is especially important for the initial stages of the multimedia learning processes, i.e., selecting relevant verbal and visual images [3] (see also de Koning et al. [4] for a review on an issue of learning stages affected by signaling). For example, by minimizing unnecessary visual searches, signaling helps learners with finding linked elements from the visual and auditory stimuli [5].

While exceptions exist (e.g., see the results of a survey by Mayer et al. [2]), research concerning the use of signaling has shown its overall effectiveness during multimedia learning. Mautone et al. [6] tested the effects of a variety of cues (text-based, typological or visual such as arrows, color, and icons) that were inserted to different types of presentation materials (written and spoken texts as well as narrated animation). They found that signaling improved participants’ learning outcomes assessed on a transfer test. Jamet et al. [7] examined the use of two types of cues in a narrated illustration. The cues were: color-coding and so-called ‘step-by-step presentation’ in which narration-mentioning areas in a diagram were highlighted in color one by one (p.137). They found an ‘additive’ effect of these cues on participants’ performance on a retention task; that is, using two signaling cues produced higher learning outcomes than using one of the cues. They also reported that color-coding was positively associated with participants’ perceptions towards ease of learning. Their participants felt that color-
coded presentation helped memorization and focusing on the relevant information. However, not all cues seem to be equally effective. By surveying 28 experimental studies, Mayer et al. [2] reported that cues such as ‘spreading’ color produced a stronger effect than cues such as arrows (p.296). Most recently, Richter et al. [5] conducted a meta-analysis of 27 empirical studies and found an overall small-to-medium positive effect of signaling.

Whether learners can or cannot control the pace of presentation (so-called learner-paced vs. system-paced presentation) seems to affect the effectiveness of signaling. Tabbers et al. [8] found a positive effect of color-coding on a retention task when participants were allowed to view an instructional website at their own pace for up to 70 minutes. In contrast, Lin et al. [9] failed to observe a signaling effect. In their study, the presentation was learner-paced with no time limit. The scores on the concept and process retention tests did not differ between the cued and no-cued materials. However, they found that benefits of signaling emerged in a different measure: participants in the cued condition spent less time on learning than participants in the no-cued condition. The authors argued that signaling improves efficiency of learning. More recently, Jamet et al. [10] tested the use of arrows in a learner-paced environment and found evidence for both the effectiveness and efficiency of signaling on learning. The participants in the cued group performed better on a retention task and spent less time on reviewing between presentation slides.

Use of an eye tracking technique allows researchers to investigate how people process cued material and helps in understanding the source of a signaling effect. Ozcelik et al. [11] conducted an eye-tracking study examining the effects of color-coding on learning with static illustrations. A signaling effect was observed on transfer and matching tests. Eye movement data showed that the cued condition produced significantly longer total fixation time and made a higher number of fixations on the relevant information. In addition, during the visual search task, which measured the time the participants spent successfully finding relevant information, the cued material elicited shorter search time. Taken together, the authors concluded that signaling guides the learner’s attention effectively and therefore improves not only the effectiveness but also the efficiency of locating important information (cf., see de Koning et al. [12] who found perceptual advantages of signaling with no effect on learning outcomes.)

To summarize, the literature has shown that signaling is an effective design technique to direct learners’ attention to the relevant parts of multimedia material and consequently facilitate learning. However, research findings have also revealed some variables that may influence its effectiveness. Those variables include: the type of cues, the pace of presentation, and the type of learning-outcome measures (e.g., recall, retention or transfer tests). In addition, it has been shown that signaling can facilitate learners’ perceptual processing of the learning material (as manifested in total fixation time and the number of fixations made). However, as suggested by Ozcelik et al. [11], perceptual advantages do not necessarily guarantee successful learning (as manifested in learning outcome measures).

1.2 The effect of working memory capacity on multimedia learning

Working memory (WM) is a cognitive system involved in a variety of cognitive tasks (e.g., understanding language and problem solving); it provides the mechanism and cognitive resources needed to process and temporarily store information (e.g., [13], [14]). WM has a limited capacity, known as working memory capacity (WMC), and it varies among individuals. The reading span task [15] is the first memory span task that was designed to measure individuals’ WMC. Since then various span tasks have been devised (e.g., [16]) and extensive research has investigated the relationship between individuals’ WMC and their performance on various cognitive tasks. Overwhelming evidence suggests that people with high WMC perform better than people with low WMC (e.g., reading and language comprehension: [15], [17], [18]; problem solving: [19]; see also Miyake [14] for a review).

In the field of multimedia learning, evidence on the issue of WMC and multimedia performance is very limited (see Schuler et al. [20] for an extensive review). Given that major multimedia learning theories place WM and its limited capacity at the core of their theoretical claims [1], [21], it would seem to make sense that additional research is needed to test the effectiveness of multimedia design techniques (e.g., signaling) by considering individual differences in WMC.

Available evidence on this issue has been mixed. Batka et al. [22] examined the effects of WMC with three multimedia design techniques (contiguity, redundancy, and modality). Results showed that the effects of these techniques depend on participants’ WMC. While learners with low WMC benefitted from the techniques, the same techniques negatively affected the learning of individuals with high
WMC. Sanchez et al. [23] used an eye tracking technique and investigated the influence of irrelevant pictures embedded in the multimedia material. They found that the use of irrelevant pictures impeded the learning of low-WMC, while it did not affect high-WMC learners. This observation was further supported by their eye movement data that revealed that learners with high-WMC spent less time on looking at irrelevant pictures. Based on an attention-control view of the WM, the authors attributed the absence of a negative impact on high-WMC learners to their greater ability to control attention and ignore irrelevant information (23: p.345). Lusk et al. [24] focused on the segmentation technique (i.e., dividing a continuous presentation unit into smaller segmented parts) and found another interaction pattern. Segmentation had no impact on high-WMC learners (i.e., they performed equally well during both segmented and non-segmented presentations). But it improved low-WMC learners significantly to the extent that their performance showed no different from that of high-WMC learners. The authors argued that by considering learner characteristic such as WMC, use of multimedia techniques could be used more effectively targeting particular learner groups without negatively affecting others.

Research focusing on the relationship between WMC and signaling is also limited, and the findings are as diverse as those with other design techniques. Skuballa et al. [25] conducted an eye tracking study and compared three signaling conditions: spotlights, pre-learning verbal instructions, and ‘no support’ which was a control condition. Unexpectedly, the ‘no support’ condition yielded the best performance for both high- and low-WMC groups. Furthermore, the two WMC groups responded differently to the spotlight and verbal instruction cues. High-WMC did well with verbal instruction, while spotlights impeded their learning. In contrast, low-WMC learners did well with the spotlight technique, while they suffered from verbal instructions. The results of this study are similar to Batka et al. [22] in that both studies showed that the use of certain cues could produce an adverse effect on the learning of high-WMC individuals. To the best of our knowledge, Doolittle et al. [26: Experiment 2] was the only study that observed the WMC effect without the influence of signaling (the use of keyword and spotlight). High-WMC group outperformed the low-WMC group. Neither the main effect of signaling nor the interaction of WMC and signaling was significant. Additional evidence similar to this pattern was reported by Doolittle and colleagues [26: Experiment 1], [27], who examined WMC with other multimedia design principles.

1.3 Predictions

The present study aimed to test the following predications. First, learners with high-WMC are predicted to perform better on a comprehension test than learners with low-WMC (Prediction 1). We have previously outlined the advantageous effects of high WMC found in multimedia research; additionally there exists substantial evidence outside multimedia learning research that showed this tendency. Second, signaling is predicted to have a positive impact on the learning outcomes across the participants (Prediction 2). Substantial evidence suggests that signaling helps guide the learner’s attention to cued elements and facilitates multimedia learning. Third, the effect of signaling is mediated by WMC (Prediction 3). More specifically, the benefit of signaling is predicted to be greater for low-WMC learners than for high-WMC learners (Prediction 4). For one reason, unlike the spotlight cues used in Skuballa et al. [25], the color-coding cues used in our study do not block the processing of any part of the learning material. Therefore, both WMC groups should benefit from the use of color-coding. Nonetheless, following the explanations offered by Sanchez et al. [23], high-WMC learners who have a superior attention-control capacity can perhaps process the multimedia material efficiently without the support of signaling. On the other hand, low-WMC learners who are poor at controlling their attention may find multimedia material difficult to process and therefore fully utilize an external support provided in the form of color-coding.

2 METHOD

2.1 Participants

Fifty-two undergraduates (29 males, 20 females) in the department of systems information science at a university in the northern island of Japan were paid to participate in the experiment. All of them were native speakers of Japanese with normal or corrected to normal vision.
2.2 Materials

2.2.1 Operation Span task

Participant's WMC was measured by a version of the automated operation span task (AOspan: [28]) developed by Millisecond Software, LLC and made available to run on Inquisit 5 software [29]. Because the original script was written in English, all of the instructional texts and feedback during the span task were translated into Japanese by the authors. Font design attributes, font size, and the position of the instructional texts on the display were adjusted to make them fit the 24-inch iMac display used for the experiment.

In the AOspan task, participants were first instructed to perform a three-step sequence on the computer: (a) solve a simple math problem (e.g., \((8\times9)-8=?\)), (b) decide whether a given answer (e.g., 9) for the math problem is true or false, and (c) memorize a letter (i.e., an alphabet) that appears on the screen. After this sequence was repeated 3 to 7 times, participants were then presented with a 12-letter matrix and asked to recall all of the letters in the order of appearance, which they were supposed to have memorized during the first sequence. The task contained a practice session followed by a test session consisting of a total of 15 test trials. The program calculates and reports an AOspan score (ranged between 0 and 75) for each participant based on the absolute Ospan scoring method, which is basically the sum of all perfectly recalled sets.

2.2.2 Multimedia instructional material

A presentation slideshow explaining the formation of memory in human brain was created as multimedia instructional material. It consisted of narration, recorded by one of the authors' voice, and black and white static illustrations of the nervous system. Parts of the nervous system in the illustration were captioned in Japanese. Two sets of the slideshow were created: a cued version and a no-cued version. The two versions were identical except that in the cued version, a narration-mentioning part was highlighted in red. The color turned back to black and white after the narration transitioned to other information. Note, in one slide the narration spoke about two adjacent parts of the nervous system; in that case, a different color (blue) was used to make the part visually distinguishable from the adjacent part (in red). The presentation was divided into four sections with each section starting with a title slide and a short introduction. The presentation was system-paced lasting for about 8 minutes.

2.2.3 Prior knowledge questionnaire

To assess participants' prior knowledge about the instructional material, a paper-and-pencil questionnaire (similar to the pre-test used in Jamet et al. [7]) was created. It consisted of three questions. Question 1 asked the participants to name any brain regions and their functions that they know. Question 2 asked them to indicate the approximate location of those regions (which they had written in Q1) on the provided blank diagram with the shape of the brain. Question 3 was an open-ended question which asked participants to write down anything that they know about memory and human brain. As for scoring, among a total of 20 brain areas and functions that were mentioned in the presentation, one point was awarded for each of the areas or functions participants wrote in Q1 and Q3. Because indicating the location of brain areas on a sheet of paper turned out to be difficult for some participants, responses for Q2 were not used for the analysis.

2.2.4 Comprehension test

To assess learning outcomes a 5-part comprehension test was created: (a) a diagram completion task (6 questions, 2 points each), (b) a multiple-choice function retention task (3 questions, 1 point each), (c) an open-ended process description task (1 question, 5 point), (d) a multiple-choice vocabulary retention task (4 questions, 1 point each), and (e) a fill-in-the-blank process retention task (4 questions, 2 points each). The maximum score on the test was 32 points. For part (c), the authors developed a rubric for scoring. First, the two authors independently marked the answers of several randomly selected participants and compared the points awarded for each participant. Any cases of disagreement were resolved by discussion until agreement was reached. Once the rubric was finalized, one of the authors marked the rest of the participants' answers.

2.2.5 Post-learning questionnaire

A questionnaire was created to evaluate the presentation used in this study. Participants were asked to rate six items on a 6-point scale: (a) difficulty of the explanation (1: felt very difficult to 6: felt very
easy), (b) length of the presentation (1: felt very long to 6: felt very short), (c) pace of the explanation
(1: felt very fast to 6: felt very slow), (d) general interest in the presentation topic (1: not interested at
all to 6: very interested), (e) frequency of using narrated presentations for self-study (1: do not use at
all to 6: use every time), and (f) amount of prior-knowledge on the presentation topic (1: did not know
at all to 6: knew a lot). The last item, amount of prior knowledge on the presentation topic, was
included in order to compare with the prior knowledge questionnaire which was given prior to the
learning session.

Because self-report measures such as these questions may influence learning outcomes (e.g., those
participants who find the presentation very easy-to-understand may gain higher scores in the
comprehension test), we used the results of this questionnaire as control variables to ensure that there
is no group difference among the four experimental conditions.

2.3 Procedure

The experiment was conducted in a single session in which participants were tested individually. The
experiment consisted of four tasks which were administered in the following order: (a) the AOspan
task, (b) the prior-knowledge test, (c) the multimedia learning task (i.e., viewing the presentation), (d)
the comprehension test, and (e) the post-learning questionnaire. The AOspan task and the learning
task were conducted on a desktop computer (24-inch iMac) with a connected headset, while other
tasks were performed paper-and-pencil. Based on the score on the AOspan task, the experimenter
tentatively determined the participant’s WMC group (high or low), and then randomly assigned him or
her to one of the signaling conditions (cued or no-cued) for the learning task. For two participants who
indicated their color-blindness on the demographic form, the experimenter assigned them to the non-
cued condition. The entire experiment took about one hour.

3 RESULTS

Three participants’ data were removed from analysis as either their prior knowledge or comprehension
test Z scores were beyond |2.58| (i.e., 99% confidence interval). Thus, the results reported below were
based on the data from a total of 49 participants.

The participants were designated into either the low- or high-WMC group based on their AOspan
scores using an extreme-groups design [30]. Those individuals who scored in the upper 40% of the
sample’s distribution were identified as high-WMC and those who scored in the lower 40% were
identified as low-WMC. Data from 9 participants who belonged to the neither group were excluded
from the main analysis. Table 1 provides descriptive statistics of the two WMC groups. The difference
between those two groups was significant ($t(38) = -11.72, p < .001$).

<table>
<thead>
<tr>
<th>WMC groups</th>
<th>N</th>
<th>M</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-WMC</td>
<td>20</td>
<td>23.85</td>
<td>5.08</td>
<td>12</td>
<td>29</td>
</tr>
<tr>
<td>High-WMC</td>
<td>20</td>
<td>47.55</td>
<td>7.48</td>
<td>38</td>
<td>68</td>
</tr>
</tbody>
</table>

Descriptive statistics per condition for all of the experimental data are provided in Table 2.

3.1 Control variables – ratings on the post-learning questionnaire

A two (low-WMC, high-WMC) by two (color, no-color) between-subjects analysis of variance (ANOVA)
was performed for each of the ratings obtained in the post-learning questionnaire. This was to ensure
that there were no group differences with respect to these control variables. None of the effects (the
main effect of WMC, the main effect of signaling, and the interaction of WMC and signaling) was
significant (all $ps > .05$) for all of the variables.
Table 2. Descriptive statistics for this experiment.

<table>
<thead>
<tr>
<th></th>
<th>Low-WMC Color (n = 10)</th>
<th>Low-WMC No-color (n = 10)</th>
<th>High-WMC Color (n = 10)</th>
<th>High-WMC No-color (n = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Prior knowledge</td>
<td>2.10</td>
<td>1.73</td>
<td>3.50</td>
<td>1.43</td>
</tr>
<tr>
<td>Comprehension test (%)</td>
<td>73.13</td>
<td>10.23</td>
<td>79.38</td>
<td>12.08</td>
</tr>
<tr>
<td>Q1 (1: very difficult - 6: very easy)</td>
<td>4.70</td>
<td>1.16</td>
<td>5.40</td>
<td>0.52</td>
</tr>
<tr>
<td>Q2 (1: very long - 6: very short)</td>
<td>3.40</td>
<td>0.97</td>
<td>3.70</td>
<td>0.48</td>
</tr>
<tr>
<td>Q3 (1: very fast - 6: very slow)</td>
<td>4.10</td>
<td>0.57</td>
<td>4.10</td>
<td>0.74</td>
</tr>
<tr>
<td>Q4 (1: no interest at all - 6: very interested)</td>
<td>4.10</td>
<td>1.45</td>
<td>3.80</td>
<td>1.14</td>
</tr>
<tr>
<td>Q5 (1: not using at all - 6: use every time)</td>
<td>2.10</td>
<td>0.99</td>
<td>1.80</td>
<td>1.23</td>
</tr>
<tr>
<td>Q6 (1: had no knowledge - 6: knew a lot)</td>
<td>2.40</td>
<td>0.84</td>
<td>2.50</td>
<td>1.35</td>
</tr>
</tbody>
</table>

Q1: Difficulty of explanation; Q2: Length of the presentation; Q3: Pace of explanation; Q4: General interests in the presentation topic; Q5: Frequency of using narrated presentations in self-study; Q6: Prior knowledge on the presentation topic.

3.2 Control variable – scores on the prior knowledge questionnaire

A 2 x 2 ANOVA was performed in order to examine group difference with respect to prior knowledge on the learning material. There was no main effect of either WMC ($F(1,36) = 1.24; p = .273, \eta^2_p = .033$) or signaling ($F < 1$). Unexpectedly, however, there was a significant interaction between WMC and signaling ($F(1,36) = 7.14; p = .011, \eta^2_p = .166$). Simple main effects analysis showed that among those who were assigned to the cued condition, the prior-knowledge score of low-WMC individuals was significantly lower than that of the high-WMC counterparts ($F(1,18) = 6.42; p = .021, \eta^2_p = .263$). There was no difference between low- and high-WMC participants in the no-color condition ($F(1,18) = 1.37; p = .256, \eta^2_p = .071$).

It is unlikely that the interaction reflects a general difference in the amount of knowledge between low-WMC and high-WMC individuals. No significant correlation was found between prior knowledge and WMC ($r = .12, n = 49, p = .421$). Because difference in prior knowledge can influence learning outcomes (see Kalyuga [31] for a review), this variable was further examined in the multiple regression analysis that was conducted to complement the results of ANOVA, the main analysis.

3.3 Effects of WMC and signaling on comprehension performance

A 2 x 2 ANOVA with WMC (high, low) and signaling (cued, non-cued) was conducted to test the influence of WMC and signaling on learning outcomes. The result revealed a marginal main effect of WMC ($F(1, 36) = 3.53, p = .069, \eta^2_p = .089$); high-WMC learners scored higher than low-WMC learners in the comprehension test. The main effect of signaling was not significant ($F < 1$). There was no significant interaction between WMC and signaling ($F(1, 36) = 2.79, p = .104, \eta^2_p = .072$). Overall, these results indicate that high-WMC individuals learned better from multimedia material than low-WMC individuals regardless of the presence of a color-coding cue. It should be noted that the magnitude of the WMC effect is best captured by the effect size ($\eta^2_p = .089$), since statistical significance is highly dependent on sample size, which is small in the present study.

Categorizing continuous variables (e.g., WMC scores) into two extreme groups leads to loss of statistical power and smaller sample size [20], [30]. In addition, the magnitude of WMC’s unique contribution to the learning outcomes was not clear because of a potential influence of prior knowledge. In order to resolve these issues and to test the ability of WMC to predict learning...
outcomes, a hierarchical multiple regression analysis was conducted. Based on the preliminary analyses, two predictor variables were selected: participants’ score on the prior knowledge questionnaire and ratings on Q1 (participants’ perceived difficulty of the explanation) on the post-learning questionnaire. The correlations between each of those variables and participants’ scores on the comprehension test were moderate (prior knowledge: $r_s = .26, p = .074$; ratings on Q1: $r_s = .29, p = .046$).

First, prior knowledge scores and Q1 ratings were entered into the first block of hierarchical regression analysis. The regression model was not significant ($F(2,46) = 2.40, p = .102$), which only explained 9.4% of variance in the comprehension score. While prior knowledge made a marginal contribution to this model ($\beta = .24, p = .091$), Q1 ratings were not a significant predictor ($\beta = .17, p = .223$). Introducing WMC at the second stage of the regression analysis significantly improved the model ($F(3,45) = 3.00, p = .04$) accounting for 17% of variance in the comprehension test score. The change of $R^2$ due to the addition of WMC was marginally significant ($R^2$ change = .07, $p = .054$). In this final model, neither prior knowledge ($\beta = .21, p = .138$) nor Q1 ratings ($\beta = .22, p = .119$) were significant, while WMC was the only (marginally) significant predictor ($\beta = .28, p = .054$). Overall, the results of regression analysis showed that participants’ WMC predicts the learning outcomes even after other potentially influencing variables (e.g., prior knowledge and participants’ perceived difficulty of the explanation) were controlled.

4 DISCUSSION

The present study investigated whether WMC and signaling (color-coding) influence the understanding of multimedia material created with narration and static illustration. Learning outcomes of the two groups of participants (high and low WMC) were assessed through a comprehension test. Results showed that high-WMC participants performed better than low-WMC participants. Prediction 1 was supported. Our result is consistent with previous work reported by Doolittle & his colleagues [26], [27]. The result is also in line with ‘classic’ findings existing outside multimedia literature that has shown strong association between people’s WMC and their performance on a wide range of cognitive tasks (e.g., [15], [17]).

While theories of WM differ with respect to what WMC represents, one of the views that postulates WMC as a measure of attention control has been incorporated into several multimedia research findings (e.g., [23], [26], [27]). According to this model (e.g., [32], [33]), WMC reflects one’s ability to control attention that is needed to stay focused on the objective of an on-going task while not being distracted by interferences and irrelevant information. With this view, our findings (i.e., an advantage of high-WMC learners over low-WMC learners) can be explained by a superior attention-controlling ability of high-WMC learners who can select important information and make auditory-visual correspondences efficiently in the presence of other (visual and auditory) distractors present in the learning material.

Our study failed to find an effect of signaling. Comprehension performance did not differ between the cued and no-cued groups. This pattern was the same for both of the WMC groups. Predictions 2, 3 and 4 were not supported. As Mayer admitted [1], [2], some of the multimedia design principles may not apply under certain circumstances (see also Richter et al. [5] for further discussion on this issue). However, given the overall significant effect of signaling found in a meta-analysis of 47 studies [5], the lack of a signaling effect was unexpected.

One factor that has been suggested as influencing the applicability of a signaling effect is the degree of complexity of the learning material [34], [35] (c.f. see Richter et al. [5] for counter evidence). Jeung et al. [34] explained the complexity by the amount of visual search that is needed to locate matching elements. They argued that when visual search requirements are low, cues offer no benefits and thus a situation with no cues is in fact superior (p.342). In our study, the diagram (i.e., an illustration of a human brain showing different brain regions) that we used was relatively simple and perhaps was a too familiar image to our university students. Viewing a familiar image repeatedly throughout the learning session may have made the visual search process predictable and too easy, making signaling ineffective.

Interestingly, the evaluation scores on the learning material given by our participants were relatively high. For example, it appeared that our participants found the narration relatively easy (the mean rating for ‘the difficulty of narration’ was 4.8 on a 6-point scale with 6 the easiest). They also seemed to have thought that the presentation was a little slow (the mean rating for ‘the pace of presentation’
was 4.2 on a 6-point scale with 6 very slow). Furthermore, our participants did relatively well on the post-learning comprehension test (the overall mean was 79%). These results suggest that our learning material was not challenging enough for color-coding to be beneficial. As Skuballa et al. [25] stated, less-challenging learning material may discourage learners to actively process the material, and consequently, extra support via signaling cues becomes redundant (p. 846).

We acknowledge that the present study has several limitations, and therefore the results need to be interpreted with caution. First, the present study used only one measure of WMC (the operation span). Ideally, composite scores of multiple span tests should be used in order to accurately measure the memory capacity that is involved in the cognitive tasks a study is investigating [20], [30]. Second, our study used a ‘wider’ range of span scores (i.e., the upper and lower 40% of the overall distribution) to determine participants’ WMC groups. To avoid potential mis-grouping of the ‘middle-range’ scores, a narrower range (the upper and lower quartiles) should be used [20], [30]. Third, we would need a bigger sample to increase statistical power and to ensure a sufficient range of variance among participants [20: p.396]. Finally, prior knowledge of the learning material needs to be controlled in order to rule out the possibility of its influencing the learning outcomes.

5 CONCLUSION

The present study has shown that individual differences in WMC play a role in the learning of multimedia content that consists of narration and static illustrations. Consistent with previous findings in the literature, learners’ performance on the comprehension test revealed an advantage of high-WMC learners over low-WMC learners. Inconsistent with overall empirical support for the effectiveness of signaling, the present study found no evidence that color-coding cues facilitated multimedia learning. Before the final conclusion can be drawn on this issue, however, further studies are needed to examine how the degree of complexity of the learning material affects the effectiveness of signaling. Finally, given the growing evidence in support of the role of WMC in multimedia learning, the design of future multimedia instruction should take WMC variation into consideration in order to accommodate the needs of specific learner groups and enhance their multimedia learning experience.

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REFERENCES


