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# Does presentation size of instructional materials influence the split-attention effect?

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## Abstract

The split-attention effect posits that learning outcomes are negatively impacted when interrelated text and graphics are spatially segregated rather than cohesively integrated. This study explored how the instructional material's presentation size influences the manifestation of the split-attention effect. Based on cognitive load theory and perceptual load theory, we hypothesized that elevated information density in a compact presentation format would attenuate the advantage of integrated text and graphics, thereby diminishing the salience of the split-attention effect relative to a more expansive presentation size. University students ($n = 146$) studied a split-attention format or integrated format in either large or small presentation size. Results on retention and comprehension tests and extraneous cognitive load ratings revealed no effects of instructional format, presentation size or their interaction. The present results call for a more nuanced understanding of the split-attention effect and suggest additional research to explore its cognitive foundations.

KEYWORDS

cognitive load theory, learning, perceptual load theory, presentation size, split-attention effect

## 1 | INTRODUCTION

Learning from various external representations within the visual modality, such as a picture with its explanatory text, is a common situation in educational settings. For instance, a picture depicting a human eye with accompanying text explaining the structures is often used in an anatomy lesson. Studying from words and pictures has generally been found to be more effective for learning than studying words alone (i.e., the multimedia effect; Mayer, 2003; Mayer & Fiorella, 2021). However, research has shown that with mutually referring text and picture it is important that the text and picture(s) are presented physically close to each other to prevent split-attention. Split attention refers to the process that learners must divide their attention between two (or more) visual information sources (e.g., text and picture) and then mentally integrate the information to comprehend the learning materials. According to the split-attention effect (Ayres & Sweller, 2021; Tarmizi & Sweller, 1988; also known as the spatial contiguity principle, Mayer & Fiorella, 2021; Moreno & Mayer, 1999), less effective learning would be obtained in learning from multiple sources of information distributed in space than from the same information sources integrated as one source of information (Sweller et al., 1998, 2019). Cognitive load theory (CLT) suggestes that the processes that are needed to search and match relevant information from spatially separated text and picture impose extraneous cognitive load (i.e., unnecessary cognitive load not contributing to learning), and are therefore unproductive for learning. Because humans have a limited working memory capacity (Cowan, 2010; Miller, 1956; Sweller et al., 2019), a higher extraneous load means that there are less working memory resources left for relevant cognitive processes that are productive for learning (i.e., intrinsic cognitive load), which is not the case for integrated materials.

Meta-analyses by Ginns (2006) and Schroeder and Cenkci (2018) have confirmed the robustness of the split-attention effect across various topics and disciplines. However, recently several studies failed to replicate the effect (e.g., Cammeraat et al., 2020; Experiment 3 in Pouw et al., 2019; Zhang et al., 2022). In addition, another meta-analysis showed that most studies that included measurements of cognitive load could not confirm the assumption that learning from split-attention materials is associated with higher extraneous cognitive load than learning from integrated materials (Schroeder & Cenkci, 2019). These findings make clear that more research is needed to uncover the mechanisms underlying the split-attention effect, factors influencing this effect, and potential boundary conditions. At the early stage of research on the split-attention effect, element interactivity (the complexity of instructional materials, e.g., Cerpa et al., 1996; Chandler & Sweller, 1996; Leahy & Sweller, 2019), redundancy of the information sources (i.e., whether text or picture can be informative on their own, Chandler & Sweller, 1991), learner expertise (e.g., Kalyuga et al., 1998; Yeung, 1999), and working memory capacity (e.g., Batka & Peterson, 2005) have been studied as important factors (Ayres & Sweller, 2021). The split-attention effect tends to occur in situations where complexity of the materials is high, redundancy is low, learner expertise is low, and learner's working memory capacity is low. In the last decade, researchers have investigated other possible design factors, such as the spatial distance between two representations (Bauhoff et al., 2012; Beege et al., 2019; Cammeraat et al., 2020; Florax & Ploetzner, 2010; Pouw et al., 2019), text segmentation (Florax & Ploetzner, 2010), and signaling (Cammeraat et al., 2020; Florax & Ploetzner, 2010). Across the studies, the impact of spatial distance on the split-attention effect is inconsistent. In some cases, this effect manifests in task performance, cognitive load ratings, or both (Experiments 1 and 2 by Beege et al., 2019), while in other instances, no such impact is observed (Bauhoff et al., 2012; Cammeraat et al., 2020; Florax & Ploetzner, 2010; Pouw et al., 2019). Text segmentation resulted in a smaller split-attention effect while the presence of signaling failed to exert any influence on it.

In two recent studies (Zhang et al., 2022, 2023), another potential factor influencing the split-attention effect was identified, namely the presentation size of the instructional materials. These studies investigated the split-attention effect to determine if a self-management pointing strategy could help mitigate this effect for students learning from split-attention materials. Therefore, in both studies there were groups of university students who were instructed to use pointing strategies when learning from split-attention materials, plus two additional groups of students who learned from either a split-attention format or an integrated format of the instructional materials without using the pointing strategy. The predominant difference between these two studies is the presentation size of the instructional materials. Comparing the same instructional materials under different presentation size conditions showed a split-attention effect when studying the information from a large presentation size on paper in 297 × 575 mm (slightly bigger than A3 size paper, Zhang et al., 2023), but not for the smaller presentation size on A4 size paper (Zhang et al., 2022). Except for the sample, the other characteristics of these two studies such as study time and knowledge tests were identical. These results are suggestive for presentation size as a potential boundary condition for the split-attention effect, but these studies did not compare two presentations sizes in a single study. In the present study, we aimed to directly examine whether the split-attention effect would vary under different presentation size conditions.

## 1.1 | Influence of presentation size on cognitive load and learning

We defined the presentation size by considering the physical size of the presentation and the density of the content simultaneously. Scaling instructional materials while maintaining realistic proportions in the content involves both aspects. For example, enlarging split-attention materials containing text and picture from A4 paper size to A3 paper size, there is scaling of 141% of the length and width of the A4 paper size to reach A3 size, which means that the density of the content decreases at the same time. It is worth to note that the presentation size of instructional materials is also determined by the distance to the learner. In this study, we considered the presentation size of split-attention materials under relatively fixed distance conditions, more specifically learning from information presented on a computer screen while sitting on a chair behind a desk.

In the educational research literature, little attention has been paid to presentation size of instructional materials so far. Some studies examined how font size (e.g., Halamish, 2018; Luna et al., 2018; Yang et al., 2018) influenced learning. This idea is based on fundamental research on memory and visual perception suggesting that people tend to perceive larger stimuli as more salient, more important, and easier to remember than smaller stimuli (e.g., Pfabigan et al., 2015; Undorf et al., 2017). Interestingly, in learning settings these perceptions do not guarantee better retention performance (i.e., the font size effect, Rhodes & Castel, 2008). A few studies that investigated the effects of different small screen sizes (e.g., mobile phone) on learning also showed mixed results (De Bruijn et al., 2007; Kim & Kim, 2012; Maniar et al., 2008). At the perceptual level, a small screen size could be problematic because participants can experience difficulties in searching for the relevant information. At the cognitive level, a small screen size could impose challenges in solving complex tasks as less information can be displayed. However, the manipulation of the screen sizes in those studies did not always lead to a difference in performance. Together, prior research thus far investigated changes in size regarding the textual information or relatively small screen sizes. It is yet unclear how presentation size of instructional materials like split-attention materials—which are more complex and involve textual and pictorial information and are typically presented at larger screens-affects learning.

According to the theoretical assumptions of CLT (Sweller et al., 2019), it is reasonable to argue that presentation size can affect learner's cognitive load and learning. Both too large and too small presentation sizes could lead to unnecessary extraneous cognitive load and therefore interfere with learning. With too large presentation sizes all the information elements and spatial distances between the elements are larger (i.e., lower information density) than with smaller presentation sizes. Learners can pay attention to fewer elements within one fixation, and consequently they have to make more eye movements to process all information. This means that they have to invest more effort in visual search and integration processes. With too small presentation sizes the information is presented closer to each other (i.e., higher information density) which may help to easily connect spatially separated information. However, the higher density of the materials may make it more difficult to distinguish between information elements, requiring greater effort in visual search and potentially hindering the learning process. Perceptual load theory (Lavie, 2005; Lavie et al., 2004), a theory explaining the mechanism of selective attention, can provide support for this argument. Similar as working memory, human perception has a limited capacity (i.e., attentional resources). The availability of attentional resources is critical in determining whether or not irrelevant distractors are processed. Specifically, when the perceptual load of a task is high, attentional resources are fully engaged with the task at hand, leaving little capacity for processing irrelevant distractors. Conversely, when the perceptual load is low, attentional resources are not fully utilized, allowing for greater processing of irrelevant distractors. However, cognitive load can also impact attentional selection, in addition to the perceptual load. High cognitive load can divert attentional resources away from the task at hand, making it more difficult to selectively attend to relevant information and ignore irrelevant distractors. This occurs because less working memory resources are available to maintain task priority (Lavie et al., 2004). Therefore, for complex tasks, the closer distracting stimuli are presented to the target stimuli, the more difficult it could become to inhibit processing of the distracting stimuli, which is the case when the task is presented in a small size. In the learning process, it is important to recognize that distracting stimuli encompass any information elements that are unrelated to the current processing task. For example, paragraph A would be considered distracting if a learner is reading paragraph F when these paragraphs are addressing different topics but presented in proximity. Learners can experience higher difficulty to disengage attention from the distractors under limited cognitive control, which hinders learning as attention is then not allocated sufficiently or timely to information that is (more) relevant.

If we further take the split-attention effect into account, the influence of presentation size may contribute differently to the split-attention format and the integrated format. The only difference between the two formats is the spatial proximity between the textual and pictorial information elements, in which the distance is closer in the integrated format than in the split-attention format. Although based on the split-attention effect, an integrated format is expected to reduce extraneous cognitive load by facilitating the mental integration of textual and pictorial information, there may exist a trade-off between visual search effort and ease of mental integration at smaller presentation sizes. While the proximity of textual and pictorial information may facilitate easier mental integration, the increased information density could heighten the extraneous cognitive load due to the need to search for relevant information. This increased cognitive load could potentially offset the benefits of easier integration, thereby resulting in a complex interplay that may or may not favor the split-attention effect. Thus, the negative impact of visual search efforts at smaller presentation sizes may outweigh the positive mental integration effect of more readily integrated interrelated text and pictures. In contrast, presenting the integrated format in a large presentation size is less likely to be influenced by the negative impact of increased extraneous cognitive load associated with higher visual search because there is enough space in-between information elements. Accordingly, it can be expected that the split-attention effect is less pronounced or even may disappear with a small presentation size compared with a large presentation size.

## 1.2 | Present study

The aim of this study was to investigate whether the split-attention effect varies as a function of the presentation size of the instructional materials. Previous studies testing the split-attention effect mostly employed computer-based and paper-based learning environments. Only a few of them reported the size of the paper (e.g., Gordon et al., 2016) or the monitor (e.g., Johnson & Mayer, 2012) on which the instructional material was presented, and none of them reported the presentation size of the content. The relation between presentation size and the split-attention effect has not yet been systematically investigated. Theoretically, this investigation can extend our knowledge regarding the boundary conditions of the split-attention effect (Ayres & Sweller, 2021). Practically, considering the various learning media learners have access to nowadays (e.g., laptops/computers in different sizes), it is important to investigate how the split-attention effect is affected by factors related to its presentation such as presentation size. Moreover, in the cases that learners can freely zoom in or zoom out the instructional materials in digital environments, the investigation can also shed light on potential self-management strategies that learners can use to deal with split-attention materials (Castro-Alonso et al., 2021; Zhang et al., 2021).

We manipulated instructional format (split-attention vs. integrated) and presentation size (large vs. small) between participants in a computer-based learning environment. Participants studied a text and picture in one of four conditions and were tested for learning outcomes (i.e., retention and comprehension) and experienced cognitive load. We focused specifically on extraneous cognitive load among the two main types of cognitive load (i.e., extraneous and intrinsic cognitive load) because it is most relevant in explaining the influence of presentation size. Based on CLT, perceptual load theory, and empirical findings suggesting a potential influence of presentation size on the split-attention effect (Lavie et al., 2004; Sweller et al., 2019; Zhang et al., 2022, 2023), we hypothesized an interaction between instructional format and presentation size. Specifically, we expected that with a large presentation size learning from an integrated format would lead to higher learning outcomes and lower experienced extraneous cognitive load than learning from a split-attention format, whereas for a small presentation size learning from an integrated format would lead to equal learning outcomes and equal experienced extraneous cognitive load as learning from a split-attention format.

## 2 | METHOD

### 2.1 | Participants and design

One hundred forty-six university students (21 males, 123 females, and 2 preferred not to say) with a mean age of 20.90 years (SD = 3.02) participated in this study. Students originated from various backgrounds, with the majority being non-native English speakers (88.36%). Based on previous studies on the split-attention effect (e.g., Cierniak et al., 2009), an a priori power analysis with a power of .80 and an estimated effect size of .25 indicated that a sample size of 128 participants was required for *F*-testing between means with $\alpha = .05$. The Ethics Review Committee at Erasmus University Rotterdam provided ethical approval for the study. Participation was voluntary and participants signed an informed consent form and received either research credits or 10 Euro as rewards. An additional monetary reward (i.e., 10, 30, and 50 Euros) was given to the three participants who performed best on the subsequent tests. Participants were randomly assigned to one of the four experimental conditions: (1) split-attention format with large presentation size ($n = 35$); (2) integrated format with large presentation size ($n = 37$); (3) split-attention format with small presentation size ($n = 37$); (4) integrated format with small presentation size ($n = 37$).

### 2.2 | Materials

#### 2.2.1 | Instructional materials

The instructional materials regarding the nephron (the kidney's functional unit) were modified from Zhang et al. (2022) and originally created by Cierniak et al. (2009). The language of the materials was English. The instructional materials contained two pages (in color): (1) a short introduction page providing basic knowledge about the kidney and nephron and (2) an illustration page presenting the content of the learning task. On the illustration page, mutual-referring text and picture were presented explaining the structure and function of the nephron. The content of the illustration page was presented in either split-attention format or integrated format and in either large size (1700 × 1002 pixels; 504 × 297 mm) or small size (1100 × 648 pixels; 326 × 192 mm) on screen. We chose these two sizes because they were close to the sizes reported by Zhang et al. (2023) and Zhang et al. (2022), that is, 575 × 297 mm and 297 × 210 mm, respectively. These sizes mostly reflected the media/sizes that are commonly used for studying by learners (e.g., a 22-inch monitor or 11.6-inch monitor). The materials used in this study are shown in Figure 1.

#### 2.2.2 | Demographic information and prior knowledge

A questionnaire was used to collect demographic information about age, gender, native language, English proficiency, and prior knowledge. Participants rated their English proficiency on a 9-point scale ("1—beginner" to "9—advanced"). Prior knowledge about the nephron was measured on a 5-point scale ("0—none at all," "1—a little," "2—a moderate amount," "3—a lot," and "4—a great deal"). Following the study of Zhang et al. (2022), if a participant selected "1" or higher, they were asked to list what they knew about the topic in an open question. If answers were completely irrelevant and erroneous, the self-rating was set to 0 as a result. For the prior knowledge test, participants could receive a minimum of 0 points and a maximum of 4 points. In general participants reported sufficient English proficiency ($M = 7.73$, SD = 1.13) and had low prior knowledge about the nephron ($M = 0.29$, SD = 0.63).

#### 2.2.3 | Knowledge test

The knowledge test was also adapted from Zhang et al. (2022) and included a retention test and a comprehension test. The retention test consisted of 10 matching questions. For each question, participants were asked to select the correct term from 14 alternatives to match the indicated structure in the picture. One point was awarded for each correct answer. A maximum of 10 points could be obtained on the retention test. The comprehension test consisted of 24 multiple-choice questions which were designed in such a way that mental integration of textual and pictorial information was required to answer them correctly (e.g., "What happens after the level of urine increases in the collecting duct?"). For each question, four answer options were provided, of which only one was correct. A maximum of 24 points could be obtained on the comprehension test. The Cronbach's alphas of the retention test and comprehension test in this study were 0.78 and 0.67, respectively, showing an acceptable reliability of the tests.

#### 2.2.4 | Extraneous cognitive load ratings

As indicated in the Introduction, extraneous cognitive load was the main interest in the present study. To get an indication of learners' perception of extraneous cognitive load, we adapted the extraneous cognitive load ratings from the 13-item scale developed by Leppink et al. (2014). This scale provides specific measurements for different types of cognitive load. Among them, four items measured extraneous cognitive load (ECL, the load determined by the design and presentation of the learning task, for example, "The explanations and instructions in this learning task/test were very unclear"). For each extraneous cognitive load item, participants were asked to position the slider on the presented scale from "0, not at all the case" to "10, completely the case."

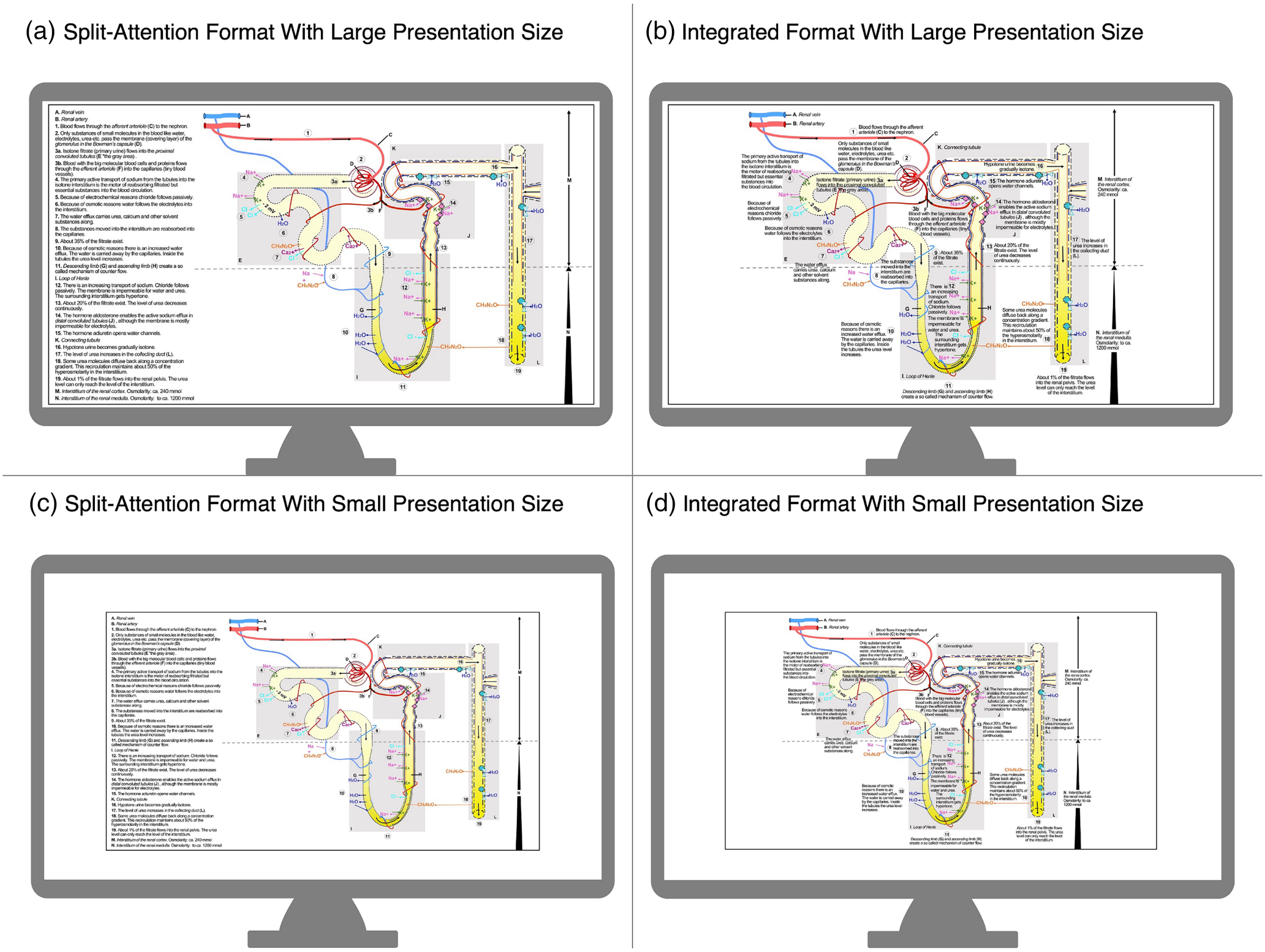


**FIGURE 1** Display of the instructional materials in this study.

### 2.2.5 | Working memory capacity

Given that learners may differ regarding their working memory capacity (WMC), which is assumed to influence the split-attention effect (Fenesi et al., 2016), we also included a measure of working memory capacity as a control variable. The advanced automated symmetry span test (SymSpan) developed by Unsworth et al. (2009) was used to measure participants' visual working memory capacity. The symmetry span test contained dual tasks: a recall task interrupted by a symmetry-judgement task. At the beginning of each trial, a series of squares was presented one by one in a 4 × 4 matrix (varying from two to five squares as the set size). Participants were asked to remember the positions and the order in which the squares were presented. After that, an 8 × 8 matrix with some squares filled in black were presented as a pattern. Participants were asked to indicate whether the presented pattern was symmetrical or not along the vertical axis. Immediately after the judgement, a 4 × 4 empty matrix was presented. Participants were required to recall the sequence of the square positions shown at the beginning of the trial by clicking on the cells of the matrix in correct order. Participants first completed a familiarization session of the task. In the formal task, each set size was used three times. For each square that was recalled in correct serial position, 1 point was assigned. A maximum score of 42 could be obtained.

## 2.3 | Procedure

The study took place at the Behavioral Lab of Erasmus University Rotterdam. Participants completed the experiment individually in separate lab room, which was equipped with a 22-inch PC monitor with a resolution of 1920 × 1200 pixels, a mouse, and a keyboard. They were sitting at a comparable distance from the screen (approximately 60 cm). The study contained four parts. In part 1, participants completed the symmetry span task in E-Prime (running version 3.0.3.82). A short break of 3 min was provided subsequently. Parts 2, 3, and 4 were presented in Qualtrics. In Part 2, participants answered the demographic questions and prior knowledge ratings. In Part 3, participants engaged in the learning task. They were first asked to study the introduction page of the kidney and nephron at their own pace. After that, they read the information about the learning phase, including the learning purpose, time restriction, and requirements. Then participants studied the illustration page in their assigned condition for 12 min. During learning, they were not allowed to take notes, move the mouse, and zoom in or zoom out on the Qualtrics page. Right after the learning phase, they filled in the cognitive load ratings regarding the learning task. Lastly, in Part 4, participants had max. 11 min for the retention test and max. 25 min for the comprehension test, after each of which they also filled in the cognitive load ratings. The whole study lasted around 65 min.

### 2.4 | Data analysis

All data were analyzed in SPSS 27. Separate one-way analyses of variance (ANOVAs) were conducted to check for differences in prior knowledge, English proficiency, and SymSpan score among the four conditions despite the randomization. In addition, correlations between these three control variables and the dependent variables were calculated (retention test score, comprehension test score, extraneous cognitive load rating for the learning task, retention test, and the comprehension test, respectively). In case of a significant difference among conditions or a significant correlation, the control variable was included in subsequent analyses as a covariate (cf., Klepsch & Seufert, 2021). Separate two-way AN(C)OVAs were conducted to test main effects of format and presentation size and the interaction effect between format and presentation size on dependent variables. We used partial eta-squared and Cohen's *d* as measures of effect size with the interpretation of small ($\eta_p^2 \sim .01$, $d \sim 0.2$), medium ($\eta_p^2 \sim .06$, $d \sim 0.5$), and large ($\eta_p^2 \sim .14$, $d \sim 0.8$) effect sizes (Cohen, 1988). Follow-up simple effects analyses with Sidak correction were conducted to measure the effects of instructional format at each level of presentation size. In addition to frequentist analyses, we performed Bayesian AN(C)OVAs using JASP (JASP Team 2023, Version 0.18.1) to obtain evidence for the main effects and interaction effects when including format and presentation size as predictors in the model (Rouder et al., 2012). We used default priors p(M) = 0.5 to compute the inclusion Bayes Factors ($BF_{\text{inclusion}}$) with the interpretation of evidence favouring the alternative hypothesis ($BF_{\text{inclusion}} > 1$) and evidence favouring the null hypothesis ($BF_{\text{inclusion}} < 1$) (Jeffreys, 1961).

## 3 | RESULTS

### 3.1 | Preliminary analyses

Table 1 shows the descriptives per condition of all demographics, scores regarding prior knowledge, English proficiency, and SymSpan score. There appeared to be no significant differences between conditions in prior knowledge, $F(3, 142) = 0.17$, $p = .918$, $\eta_p^2 = .00$. For English proficiency there was a significant difference between conditions overall, $F(3, 142) = 2.77$, $p = .044$, $\eta_p^2 = .06$, but post hoc tests did not show any significant comparisons, all $ps > .05$. There was also a significant difference between conditions on the SymSpan score, $F(3, 141) = 2.82$, $p = .041$, $\eta_p^2 = .06$. The split-attention format with large presentation size condition had a lower SymSpan score than the integrated format with small presentation size ($p = .03$). Correlational analyses indicated that prior knowledge had a significant positive relation with retention test score ($r = 0.25$, $p = .002$) and comprehension test score ($r = 0.28$, $p < .001$). English proficiency only had a significant positive relation with retention test score ($r = 0.23$, $p = .005$). SymSpan score had a significant positive relation with comprehension test score ($r = 0.21$, $p = .013$). None of the control variables significantly related to extraneous cognitive load ratings ($p > .05$). Following the inclusion criteria for covariates described in the Data Analysis section, prior knowledge, English proficiency, and SymSpan score were included as covariates regarding the effects on the retention test and comprehension test. English proficiency and SymSpan score were included as covariates regarding the effects on the cognitive load measures.

**TABLE 1** Descriptive statistics of demographics, English proficiency, prior knowledge, and SymSpan score.

| | SA-large | I-large | SA-small | I-small |
|---|---|---|---|---|
| Gender (%) | | | | |
| Male | 6 (17.10) | 4 (10.80) | 6 (16.20) | 5 (13.5) |
| Female | 28 (80.00) | 33 (89.20) | 31 (83.8) | 31 (83.8) |
| Prefer not to say | 1 (2.90) | 0 (0.00) | 0 (0.00) | 1 (2.70) |
| Native language (%) | | | | |
| English | 2 (5.71) | 3 (8.11) | 6 (16.22) | 6 (16.22) |
| Dutch | 4 (11.43) | 10 (27.03) | 13 (35.14) | 12 (32.43) |
| Other | 29 (82.86) | 24 (64.86) | 18 (48.65) | 19 (51.35) |
| Age *M* (*SD*) | 20.69 (3.11) | 20.41 (2.54) | 21.49 (3.43) | 21.03 (2.96) |
| English proficiency *M* (*SD*) | 8.03 (1.15) | 7.43 (1.12) | 7.97 (1.01) | 7.51 (1.17) |
| Prior knowledge *M* (*SD*) | 0.26 (0.56) | 0.35 (0.72) | 0.32 (0.71) | 0.24 (0.55) |
| SymSpan score *M* (*SD*) | 27.83 (7.62) | 30.89 (6.87) | 30.22 (6.73) | 32.27 (5.05) |

**TABLE 2** Means (and standard deviations) of performance of knowledge test and extraneous cognitive load ratings as a function of condition.

| | | SA-large M (SD) | I-large M (SD) | SA-small M (SD) | I-small M (SD) |
|---|---|---|---|---|---|
| Retention test | | 6.14 (2.57) | 5.27 (3.09) | 5.49 (2.80) | 5.30 (2.70) |
| Comprehension test | | 10.43 (3.15) | 10.03 (4.37) | 9.16 (4.32) | 9.89 (3.21) |
| ECL | Learning task | 3.28 (2.18) | 3.55 (2.55) | 4.34 (2.73) | 3.61 (2.60) |
| | Retention test | 1.78 (1.67) | 2.25 (2.67) | 2.07 (1.91) | 1.79 (1.59) |
| | Comprehension test | 2.41 (2.23) | 2.35 (2.41) | 2.43 (2.23) | 2.31 (1.95) |

## 3.2 | Performance on the knowledge tests and extraneous cognitive load ratings

The means and standard deviations for performance on the retention and comprehension tests and cognitive load ratings per condition are shown in Table 2.

### 3.2.1 | Retention

There were no significant main effects of instructional format, $F(1, 138) = 0.61$, $p = .437$, $\eta_p^2 = .00$, $BF_{\text{inclusion}} = 0.256$ (substantial evidence for null hypothesis), and presentation size, $F(1, 138) = 0.49$, $p = .487$, $\eta_p^2 = .00$, $BF_{\text{inclusion}} = 0.212$ (substantial evidence for null hypothesis). No significant Instructional Format × Presentation Size interaction was found either, $F(1, 138) = 0.75$, $p = .388$, $\eta_p^2 = .01$, $BF_{\text{inclusion}} = 0.333$ (anecdotal evidence for null hypothesis).

### 3.2.2 | Comprehension

There were no significant main effects of instructional format, $F(1, 138) = 0.00$, $p = .977$, $\eta_p^2 = .00$, $BF_{\text{inclusion}} = 0.182$ (substantial evidence for null hypothesis), and presentation size, $F(1, 138) = 2.40$, $p = .124$, $\eta_p^2 = .02$, $BF_{\text{inclusion}} = 0.450$ (anecdotal evidence for null hypothesis). Also no significant Instructional Format × Presentation Size interaction was found, $F(1, 138) = 1.73$, $p = .190$, $\eta_p^2 = .01$, $BF_{\text{inclusion}} = 0.510$ (anecdotal evidence for null hypothesis).[1]

### 3.2.3 | Extraneous cognitive load ratings

There was no significant main effect of instructional format on the extraneous cognitive load rating for the learning task, $F(1, 139) = 0.08$, $p = .773$, $\eta_p^2 = .00$, $BF_{\text{inclusion}} = 0.198$ (substantial evidence for null hypothesis), the retention test, $F(1, 139) = 0.06$, $p = .813$, $\eta_p^2 = .00$, $BF_{\text{inclusion}} = 0.183$ (substantial evidence for null hypothesis), and the comprehension test, $F(1, 139) = 0.27$, $p = .601$, $\eta_p^2 = .00$, $BF_{\text{inclusion}} = 0.185$ (substantial evidence for null hypothesis). There was no significant main effect of presentation size on the extraneous cognitive load rating for the learning task, $F(1, 139) = 1.48$, $p = .225$, $\eta_p^2 = .01$, $BF_{\text{inclusion}} = 0.343$ (anecdotal evidence for null hypothesis), the retention test, $F(1, 139) = 0.15$, $p = .697$, $\eta_p^2 = .00$, $BF_{\text{inclusion}} = 0.185$ (substantial evidence for null hypothesis), and the comprehension test, $F(1, 139) = 0.04$, $p = .848$, $\eta_p^2 = .00$, $BF_{\text{inclusion}} = 0.178$ (substantial evidence for null hypothesis). Also there was no significant Instructional Format × Presentation Size interaction on the extraneous cognitive load rating for the learning task, $F(1, 139) = 1.17$, $p = .281$, $\eta_p^2 = .01$, $BF_{\text{inclusion}} = 0.498$ (anecdotal evidence for null hypothesis), the retention test, $F(1, 139) = 1.05$, $p = .306$, $\eta_p^2 = .01$, $BF_{\text{inclusion}} = 0.390$ (anecdotal evidence for null hypothesis), and the comprehension test, $F(1, 139) = 0.00$, $p = .987$, $\eta_p^2 = .00$, $BF_{\text{inclusion}} = 0.251$(substantial evidence for null hypothesis).

## 4 | DISCUSSION

The aim of this study was to investigate whether the presentation size of split-attention materials would influence the split-attention effect. Based on theoretical and empirical findings (Lavie et al., 2004; Sweller et al., 2019; Zhang et al., 2022, 2023), it was hypothesized that there would be no (or a smaller) split-attention effect (reflected in equal- or lower- retention and comprehension scores) with a small presentation size because the high information density in the small-sized split-attention materials may increase extraneous cognitive load. Results showed no split-attention effect with instructional materials in a small presentation size. However, the hypothesized interaction between the instructional format and the presentation size was not confirmed as no split-attention effect was found with a large presentation size either, both regarding learning outcomes and extraneous cognitive load ratings.

Even though we used the same instructional materials and adopted similar large presentation sizes as Zhang et al. (2023), who found a split-attention effect on comprehension performance and instructional efficiency, we failed to replicate the results. Similar to the findings of Cammeraat et al. (2020), Pouw et al. (2019), and Zhang et al. (2022), our results could be seen as challenging the robustness of the split-attention effect across different studies and learning domains (Ayres & Sweller, 2021; Schroeder & Cenkci, 2018; Sweller et al., 2019). Alternatively, these discrepancies might be attributed to methodological differences between the study. This further underscores the need for additional research to uncover the cognitive processes underlying the split-attention effect. In addition, given that we did not find the split-attention effect with either a small or large presentation size, it is difficult to draw conclusions on the relation between presentation size and the split-attention effect. Further research is needed to examine the potential influence of presentation size, as it could enhance our understanding of the split-attention effect and inform both instructional design and self-management strategies. Nonetheless, some explanations for the non-significant results in the current study can be derived from methodological differences with previous studies.

Compared to Zhang et al. (2023) and Zhang et al. (2022), a major difference was that we presented the instructional materials on a computer screen instead of on paper. The change of medium could be a reason for the diverging findings with the large presentation size. The meta-analysis by Schroeder and Cenkci (2018) indicated that the split-attention effect was observed from both computer-based studies and paper-based studies, but interestingly, the paper-based studies produced larger effects than the computer-based studies. Although the underlying mechanism is unclear yet, this observation to some extent is in line with the discrepancy between the present study and the study of Zhang et al. (2023). It is possible that learners perceive instructional materials (especially in large size) differently from a computer screen and from paper (see also "media bias" in Castro-Alonso et al., 2016). For example, the physical distance between a learner and the paper-based materials is normally shorter than the distance between the learner and the computer screen. Shorter distance could make learners perceive the paper-based materials larger compared to the materials with same size presented on computer screen. Apart from the perceptual difference, learners can also engage in different meta-cognitive processes. There is evidence that people tend to expect a shallower processing on screen compared to paper (Sidi et al., 2017). Also, learners can get used to large presentation on the computer screen as this is increasingly common in practice, while the use of large paper is relatively rare, triggering higher motivation for learning. It would be necessary to test whether our study can be replicated using paper-based materials.

Following the change of medium, the presentation sizes deviated somewhat in the current study to adapt to the presentation on the computer screen despite our attempt to stay close to the size in Zhang et al. (2023) and Zhang et al. (2022). As shown in the materials section, the scaling of size from small to large in present study could be smaller than which was manifested in those two studies. Possibly, the two sizes have not been distinct enough to elicit a significant effect. Based on cognitive load theory (Sweller et al., 2019) and perceptual load theory (Lavie et al., 2004), we hypothesized that with either too large or too small presentation sizes, there may be an increased extraneous cognitive load associated with higher visual search demands that interfere with learning. However, the sizes that we used in the current study, especially the small presentation size, may not have been that small or large that they reached the point of increasing extraneous cognitive load for learners studying these materials. Furthermore, the two sizes chosen in the present study resemble frequently encountered screen sizes when studying from a computer screen. It is also possible that learners have developed individual strategies to deal with these types of presentations, which may have decreased the likelihood of finding the hypothesized effects. In short, maybe the way we manipulated the presentation size, is not the most optimal way. Future research could consider adjusting the sizes to compare, for instance, adding an even smaller presentation size and explore whether a reverse split-attention effect would be observed in the condition with the smallest presentation size.

### 4.1 | Limitations and future directions

Besides the changes of medium and sizes mentioned above, a few more minor changes have been made compared to Zhang et al. (2023) and Zhang et al. (2022) to serve our aim. Extraneous cognitive load ratings from cognitive load scales that specify different types of cognitive load (Leppink et al., 2014) were employed instead of a single-item question asking for overall cognitive load (Paas, 1992; Paas et al., 2003). Moreover, participants were asked to rest their hands on their legs or table during the learning task, while in the study of Zhang et al. (2023) and Zhang et al. (2022) participants had to sit on their hands during learning. These minor changes could have influenced the results. Thus, instead of a conceptual replication, an exact direct replication is needed.

Other than that, several future directions can be explored. First, future studies could consider the impact of time pressure. In the current study, participants were allocated 12 minutes to complete the learning task, a duration deemed suitable for learning the materials. However, as indicated by Schroeder and Cenkci (2019), if participants are given extended time, they might be able to manage the extraneous cognitive load imposed by split-attention materials. The effects of presentation size and the split-attention effect may be more pronounced under time-limited conditions, as selective attention mechanisms can be time-sensitive. Additionally, incorporating eye-tracking measures, such as speed and number of transitions, could provide valuable insights into perceptual processing (Alemdag & Cagiltay, 2018).

Second, future studies could consider the possibility that several design factors interacted together, (not) causing the split-attention effect. For example, research has shown mixed findings on whether spatial distance is a main factor causing the split-attention effect (e.g., Bauhoff et al., 2012; Cammeraat et al., 2020). It would be interesting to investigate if the influence of spatial distance is more salient with a large presentation size than when using medium and small presentation sizes given that learners have to invest more effort in processing a single source of information already with large presentation size. As another example, the study by Florax and Ploetzner (2010) showed that text segmentation and picture labeling contributed significantly to retention performance when learning from split-attention materials. The materials used in the present study employed text segmentation and picture labeling too, which may have influenced the effectiveness of presentation size and the interplay with instructional format. Apart from considering the interaction between design factors, it is also possible that there exists a core factor underlying all the design factors that relates to difficulty on visual search, such as visual complexity. It is worth to find out the mutual aspects of such potential factors to shed light on the cognitive basis of the split-attention effect.

## 4.2 | Conclusion

In conclusion, the present study did not find the split-attention effect and no effects of presentation size on learning from split-attention materials and integrated materials were found. The fact that we built on two recent studies that used the same split-attention materials but still obtained diverging findings regarding learning outcomes (Zhang et al., 2022, 2023) indicates that more research is needed about the conditions under which the split-attention effect can and cannot be obtained. Additionally, our findings regarding presentation size ask for more research as presentation sizes vary considerably in practice and may have more pronounced effects for more extreme presentation sizes. By addressing these aspects we can come to a better understanding of when and why learning from split-attention materials and integrated materials sometimes helps learning while in other situations it does not.

## AUTHOR CONTRIBUTIONS

**Shirong Zhang:** Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; writing – original draft; writing – review and editing. **Bjorn B. de Koning:** Conceptualization; data curation; methodology; supervision; writing – review and editing. **Fred Paas:** Conceptualization; methodology; writing – review and editing; data curation; supervision.

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## CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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## ENDNOTE

[1] Compared to the comprehension test used in Zhang et al. (2023) and Zhang et al. (2022), we added 12 parallel items in the present study to increase the reliability of the test. The results remained insignificant when we adopted the original 12-item comprehension test ($p > .05$).

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