education sciences

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Best of Both Worlds? Combining Physical and Mental Self-Management Strategies to Support Learning from Split-Attention Examples

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Abstract: The self-management principle holds that higher learning performance is obtained when learners actively use instructional strategies to manage the working memory load imposed by a learning task. Self-management studies with spatially separated but mutually referring text and pictures (split-attention examples) demonstrate the learning benefits of physical (e.g., annotation) and mental (imagined drag-and-drop) strategies. We investigated whether combining physical and mental strategies supports learning beyond a single strategy. Eighty-four participants studied a split-attention example with or without using a physical strategy and/or a mental strategy. Participants completed retention, comprehension, and transfer tests, and rated their cognitive load. Results showed that the combined use of physical and mental strategies resulted in lower cognitive load during learning than using the physical strategy and was more instructionally efficient compared to all other conditions. There were no significant differences regarding learning outcomes. Together, this suggests that combining physical and mental strategies is most supportive for studying split-attention examples.

Keywords: self-management of cognitive load; self-management strategies; split-attention examples; cognitive load theory; comprehension of text and graphics

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Citation: de Koning, B.B. Best of Both Worlds? Combining Physical and Mental Self-Management Strategies to Support Learning from Split-Attention Examples. *Educ. Sci.* **2024**, *14*, 284. https://doi.org/10.3390/educsci14030284

Academic Editor: Myint Swe Khine

Received: 13 February 2024
Revised: 4 March 2024
Accepted: 6 March 2024
Published: 7 March 2024

1. Introduction

The presentation of text and pictures for explaining concepts or procedures, such as the functioning of the heart or assembly of musical instruments, is by now quite common in formal (e.g., study books) and informal (e.g., websites) instructional resources. While multimedia learning research has yielded numerous guidelines for how to present text and pictures in a way that learner processing is optimized (for an overview, see [1]), many available instructional resources are still not presented in the most effective format. For example, mutually referring text and pictures are frequently presented in a spatially separated format (i.e., split-attention format), whereas research has shown that presenting text and pictures close to each other in space (i.e., integrated format) improves learning and reduces cognitive demands on the learner; this has become known as the split-attention effect or spatial contiguity effect [2,3]. Therefore, there is increasing attention on equipping learners with strategies to help them learn more effectively from such sub-optimally designed instructional materials [4]. The present study builds on this emerging line of research and extends it by investigating the relative effectiveness of such strategies and whether the combined use of two strategies is more effective for learning than using a single strategy.

2. The Self-Management Principle

The centrality of the learner to manage their cognitive load when studying text–picture materials is at the core of the self-management principle. The self-management principle holds that higher learning performance is obtained when learners actively use instructional strategies to manage the working memory load imposed by a learning task [5,6]. According to cognitive load theory (CLT; [1]), an instructional theory to optimize learning activities and materials while taking into account the limited capacity of working memory, the provision of specific guidance to learners enables learners to reduce the high and unnecessary cognitive load that instructional materials impose and help them more effectively learn from these materials [4,6]. The emphasis on the learner as a manager of their own cognitive load contrasts with the decades-long practiced "instructor-managed approach" wherein teachers/designers made decisions—based on CLT—on how to present learning materials to optimize learning [5]. The "self-management approach" is a relatively unexplored direction in CLT research, but an increasing number of studies have investigated what self-management strategies can be used to effectively support learning.

2.1. Self-Management with Physical and Mental Strategies

Prior studies investigating the self-management of cognitive load demonstrate that learning from mutually referring but spatially separated text and pictures (i.e., split-attention examples) is enhanced when learners use a physical or a mental self-management strategy compared to when they do not use these strategies (for an overview see [6]). Specifically, physical strategies that require learners to identify the key information in the text and connect this with the corresponding element in the picture using (1) annotation, such as drawing connecting arrows, numbering, and underlining [5,7]; (2) dragging and dropping text into the picture [8]; or (3) finger pointing (e.g., [9]) have been shown to support learning outcomes such as retention, recognition, and transfer performance and/or to reduce cognitive load. However, there is also research showing no benefits for learning and cognitive load when using a physical self-management strategy, and this appears to be especially the case when instructing learners to only physically move text boxes to the corresponding element in the accompanying picture [10–12].

Research on the mental self-management strategy shows clear and unequivocal learning benefits, consistent with the benefits of using an imagination strategy in, for example, reading comprehension tasks [13]. In studies by De Koning et al. [11,12], learners using the strategy of imagining dragging and dropping text boxes to the corresponding element in the picture had higher retention and comprehension scores than learners using a physical drag-and-drop strategy and learners not using any strategy. No differences were found in the cognitive load scores. The authors explained the differences in learning by arguing that the mental self-management strategy is possibly more generative in nature, encouraging learners to engage in active and meaningful cognitive processing (germane cognitive load), whereas the act of physically moving text to a specific location in the picture might be performed without any cognitive processing. This raises the question of whether the same findings would be obtained if the mental self-management strategy were compared to a physical self-management strategy that has proven effective and might elicit more generative processing in learners. One such physical self-management strategy that was successfully used in prior self-management studies to support learning from text and pictures in a split-attention format [5,7] is making annotations. Using an annotation strategy has been shown to be an effective strategy in other fields of study, as well such as learning from text (e.g., [14]). While there exist obvious differences between the mental drag-and-drop strategy and the annotation strategy (e.g., in terms of physical involvement), with both, the focus is on reducing the search-and-match processes for corresponding text–picture information (extraneous cognitive load) and encouraging learners to actively make sense of the presented information in order to construct an accurate mental representation of the content (germane cognitive load).

One aim of the present study was, therefore, to directly compare the learning effectiveness of the mental self-management strategy and that of the annotation self-management strategy. So far, prior self-management research has focused primarily on investigating whether self-management strategies are effective for learning, and much less attention has been devoted to investigating the relative effectiveness of different strategies. Having this focus in the present study contributes to further understanding of the effective use of self-management strategies in split-attention examples.

2.2. Combining Physical and Mental Strategies

Another aim of the present study was to investigate whether combining physical and mental self-management strategies would further enhance the effectiveness of self-managing the cognitive load during learning from split-attention examples. The study by Gordon and colleagues [15] represents the only reported attempt to investigate the effects of combining two self-management strategies when studying split-attention examples on learning and cognitive load. For the combined strategy condition, they instructed participants to use the physical drag-and-drop strategy together with the annotation strategy (highlighting, drawing arrows). They compared this to a control condition not using any strategy to study and a condition where the text and picture information was spatially integrated. The results showed that there were no significant differences between the self-management condition and control condition on recognition or transfer performance, nor on cognitive load. While, as argued by the Gordon et al. [15], the lack of an effect might be due to the low number of participants, there is another explanation that is more directly connected to the self-management strategies themselves. In the self-management condition, learners were encouraged to engage in two physical strategies, and it is possible that this was not supportive for learning. For example, using one physical strategy and then trying to engage in an additional strategy in the same modality (physical movement) might cause interference between strategies in such a way that engaging in one physical strategy prevents one from engaging in the other physical strategy. Additionally, coordination costs associated with alternating the two physical strategies might unnecessarily increase the cognitive load on the learner, which could hinder learning [16]. Moreover, the requirement to use two physical strategies has possibly led learners to believe that behavioral involvement was the main focus of their task, which might have occurred at the expense of any more substantial cognitive involvement.

In the present study, we therefore investigated whether the combination of a physical and a mental self-management strategy might be a more effective combination to support learning from split-attention examples. Engaging in mental and physical strategies eliminates the competition between two physical strategies, and, moreover, offers the opportunity to execute the two strategies in tandem or simultaneously. That is, while using the physical annotation strategy to highlight relevant information in the text and then the corresponding element in the picture, learners could use the mental drag-and-drop strategy to mentally integrate the text into the picture, as if creating a personal spatially integrated format in their mind that they can continuously revise and update with new incoming information.

Evidence outside the context of self-management strategies and split-attention examples suggests that the combination of a mental strategy and a physical strategy might indeed be an effective combination to improve performance. For example, combining mental and physical training is an effective means to increase motor skill learning (e.g., [17]), enhance executive functioning (e.g., [18]), and support comprehension of text [13]. Also, in learning from mutually referring graphical and textual information, there is preliminary evidence that combining physical and mental strategies supports learning [19]. In the study by Wang et al. [19], it was investigated whether performance on a mathematics test was impacted by having studied mathematics examples by tracing out the study examples with hand movements, tracing out the examples with hand movements followed by imagining tracing out the examples with the eyes closed, and without any physical or imagined tracing. The results showed that participants in the combined tracing and imagination condition solved more mathematics examples correctly, and accomplished this more quickly and with less cognitive load than those in the control condition and physical-tracing-only condition. Translating these findings to the present study, it can be assumed that the combination of mental and physical self-management strategies might be particularly effective in split-attention examples, at least more effective than a condition not engaging in any self-management strategies and a condition that only uses a physical strategy. By examining these comparisons, the current study extends earlier self-management research in the sense that now, insight is also given into the relative effectiveness of using a combination of two strategies versus using either of these strategies alone, instead of only comparing it to a no-strategy condition (as was the case in Gordon et al. [15]).

3. Hypotheses

To achieve the aims of the study outlined above, learners were presented with a learning task containing a mutually referring text and picture (i.e., split-attention example). They studied this split-attention example while engaging in a physical self-management strategy (annotation), a mental self-management strategy (imagined drag-and-drop), both physical and mental self-management strategies, or no physical or mental self-management strategies. After learning, the learners completed retention comprehension and transfer tests, and indicated their cognitive load after learning and after each test. Based on theoretical considerations from CLT and prior research, the following hypotheses were formulated. First, we made a prediction regarding the involvement in self-management strategies versus not engaging in such strategies. It was expected that, compared to not using any self-management strategy, using either the physical annotation self-management strategy or the mental self-management strategy in isolation, or the two strategies in combination, resulted in higher learning outcomes (Hypothesis 1a) and lower cognitive load (Hypothesis 1b). Second, we made a prediction regarding the relative effectiveness of combined vs. single self-management strategies. It was expected that the combination of the physical annotation strategy and the mental self-management strategy would result in higher learning outcomes (Hypothesis 2a) and lower cognitive load (Hypothesis 2b) than using either of these self-management strategies in isolation. Third, we were interested in the relative effectiveness of using a single self-management strategy. The annotation self-management strategy and the mental self-management strategy both outperformed a control condition without engagement in a self-management strategy, and there has been no direct comparison between self-management strategies in prior studies that can inform a directional hypothesis regarding the annotation strategy and the mental self-management strategy. The physical strategy used in the studies of De Koning et al. [11,12] did not support learning, yielding an unfair comparison to the mental strategy to which it was compared in that study. Therefore, we did not formulate a directional hypothesis, but were interested in exploring the relative effectiveness of the annotation self-management strategy and the mental self-management strategy.

4. Methods

4.1. Design

The study had a 2 $\times$ 2 between-subjects design, with the factors physical strategy (yes, no) and mental strategy (yes, no). Participants were randomly assigned to one of four conditions (n = 21 per condition): physical condition, mental condition, physical and mental condition, or control condition (without physical or mental strategies). The comparability of conditions regarding the participants' ages was tested using an univariate ANOVA, with condition as the independent variable and participant age as the dependent variable, which showed no significant differences between conditions: $F(3.83) = 0.49$, $p = 0.691$, $\eta_p^2 = 0.018$. The gender distribution across conditions was examined using the chi-square test, for which the chi-square goodness of fit indicated no significant differences: $\chi^2(6, N = 84) = 4.09$, $p = 0.665$. Together, the conditions were comparable regarding age and gender.

4.2. Participants

The participants comprised 84 students from various higher education institutes in the Netherlands. This number was justified by power calculations in G*Power (version 3.1.9.6; [20]), indicating that, using an alpha of 0.05 and 80% power, at least 80 participants were required in order to find a medium-sized effect (see [9]). Participants identified as female (n = 61), male (n = 22), or non-binary (n = 1) and had a mean age of 23.77 years (SD = 3.34). They participated voluntarily and gave active consent before the study.

4.3. Materials

This study used the materials from De Koning et al. [12]. For all conditions, the tests were administered via Qualtrics, a digital survey tool, but the learning task was presented on paper. The digital test administration had several advantages, including automatic recording of participants' answers. The learning task was paper-based to enable participants in the conditions involving the physical strategy to make physical annotations. This avoided any potential unwanted effects for participants of having to learn to use a digital annotation tool for this study.

4.3.1. Prior Knowledge Test

Participants' prior knowledge about electrical circuits was assessed with a one-item self-rating asking them to indicate their knowledge of electrical circuits on a five-point scale (1—very little; 5—very much) and six statements about electrical circuits that required a yes/no answer (e.g., I know what a starter is). Each "yes" answer yielded one point, and no points were given to 'no' answers. Per participant, the scores on the self-rating item (0–5) and the statements (0–6) were added to one overall prior knowledge score (0–11). There were no significant differences in prior knowledge across the four conditions: $F(3.83) = 2.52$, $p = 0.064$, $\eta_p{}^2 = 0.086$.

4.3.2. Tests

Retention Test

The retention test assessed participants' memory of the studied electrical circuit's components and their position in the system. Five retention questions asked participants to name the symbol from the circuit that was shown in a picture. A correct answer yielded one point, while an incorrect answer was not awarded points. One question asked participants to draw the studied system from memory. One point was awarded to each component that was drawn in the right location and for each component that was correctly linked to another component. For this question, a score between 0 and 28 could be obtained. Per participant, the overall retention score was calculated by summing the scores on all retention questions (0–33).

Comprehension Test

The comprehension test contained 11 open-ended questions asking about the functioning of the studied electrical circuit. An example question is: "Which switches are pressed when the light is operating?" For each question, there was one correct answer that was given one point (incorrect answers were not awarded points). Per participant, all points were summed to obtain an overall comprehension score (0–11). Consistent with prior research using these materials [11,12,21], participants were given the picture depicting the on/off light-switching circuit (without text) on paper while answering the comprehension questions (this also was the case for the transfer questions).

Transfer Test

The transfer test contained six open-ended questions asking participants to reason regarding the studied electrical circuit. An example of a transfer question is: "After the stop button is released, the bell and the light start working again. What is the cause of this problem?". For each question, one point was obtained if the correct answer was given (no points for incorrect answers). Per participants, all points were summed to obtain an overall transfer score (0–6).

Cognitive Load

Participants' cognitive load during the learning task and tests was assessed with a 9-point rating scale (1—very, very little; 9—very, very much) originally developed by Paas [22].

4.4. Procedure

Participants were tested individually in a quiet room, and sat at a desk with a 24-inch computer screen (Eizo FlexSccan, (Eizo, Hakusan, Japan)), keyboard, and mouse in front of them. The experimenter was present for the entire duration of the experiment and sat to the side of the participant. After a short welcome, participants completed the prior knowledge test. Then, they received instructions commensurate with their condition regarding studying the on/off-light switching circuit. They engaged in the practice task, and subsequently were given the paper for the learning task.

The learning task focused on the operation of an on/off light-switching circuit that was explained in a picture with accompanying text. In all conditions, the picture and text were presented in exactly the same way, in a split-attention format on A4-sized paper (portrait orientation). The picture and text were presented as far apart from each other as possible within the dimensions of the paper to increase the need for integration of the mutually referring picture and text. The paper was placed on a desk in front of the participant. In all conditions, participants were instructed to try to understand how the electrical system depicted in the picture and text worked. In the physical strategy condition, participants were required to support their learning by making annotations (i.e., circle and/or underline relevant pictorial and textual information; draw arrows and/or lines to connect textual and pictorial information) on the paper to help them connect the corresponding information in the text with that in the picture (cf. [5,7]). Participants were given a pen, pencil, and highlighter for annotating. In the mental strategy condition, participants had to support their learning by imagining that they moved a text segment (one at the time) to the corresponding part in the picture (cf. [12]). No annotation tools were available in this condition. In the physical and mental condition, participants engaged in both physical (annotation tool available) and mental strategies to support their learning. There was no specific guidance regarding whether or how to sequence the two strategies. In the control condition, participants studied the learning task without physical or mental strategies, and no annotation tools were provided. To familiarize participants with the strategies they had to use during the learning task, they engaged in a short practice task in which the to-be-used strategy/strategies was/were explained and practiced depending on the condition to which a participant belonged. To check for compliance with the instructions, we asked participants afterwards whether they had used the strategy/strategies they had to use to support their learning. All except three participants (one in the physical and mental condition, two in the mental strategy condition), indicated that they had used the physical and/or mental strategy/strategies. The response patterns of these three participants were comparable to those of the other participants, and including their data in the analyses yielded comparable results, so we retained all scores in the analyses so as not to give in in terms of the power of the study. All participants were given four minutes to study the learning task.

After having completed the learning task, the experimenter took away the paper from which participants had studied, and participants rated their cognitive load. Thereafter, participants completed the retention test, comprehension test, and transfer test, and after each test, they rated their cognitive load. The entire experiment lasted about 40 min.

5. Results

Consistent with our 2 × 2 between-subjects design, separate univariate analyses of variance (ANOVAs), with physical strategy (yes, no) and mental strategy (yes, no) as between-subjects factors, were conducted in SPSS on the learning outcome measures (retention, comprehension, transfer) and cognitive load measures. Given the small sample and mild skewness of the data, we also report (after the regular ANOVA statistics) bootstrapped ANOVAs, and we calculated the bias-corrected and accelerated confidence interval (BCa CI) estimates for the main effects and the interaction effects (including the simple effects analysis following a significant interaction). If a 95% confidence interval includes the null value, there was no statistically significant difference between conditions. For effect sizes, partial eta-squared (η_p^2) is reported where values of 0.01, 0.06, and 0.14 represent small, medium, and large effect sizes, respectively [23].

5.1. Learning Outcomes

Table 1 displays the means and standard deviations of the scores on the retention, comprehension, and transfer tests per condition.

Table 1. Means (standard deviations) per condition of the learning outcome measures.

	Physical	Mental	Physical and Mental	Control
Retention (0–33)	16.05 (5.38)	16.38 (5.96)	17.95 (5.84)	16.95 (5.52)
Comprehension (0–11)	5.38 (1.47)	5.24 (2.14)	5.71 (2.10)	5.95 (2.18)
Transfer (0–6)	2.81 (1.21)	2.38 (1.40)	2.95 (1.20)	2.57 (1.33)

On the retention test, there were no significant main effects of physical strategy ($F(1.80) = 0.07$, $p = 0.789$, $\eta_p^2 = 0.001$; B = 0.168, $p = 0.768$, BCa CI = [−0.989, 1.411]) or mental strategy ($F(1.80) = 0.29$, $p = 0.592$, $\eta_p^2 = 0.004$; B = 0.335, $p = 0.584$, BCa CI = [−0.956, 1.478]), and there was no significant physical × mental strategy interaction ($F(1.80) = 0.99$, $p = 0.321$, $\eta_p^2 = 0.012$; B = 0.627, $p = 0.315$, BCa CI = [−0.508, 1.747]).

On the comprehension test, there were no significant main effects of physical strategy ($F(1.80) = 0.01$, $p = 0.913$, $\eta_p^2 < 0.001$; B = −0.024, $p = 0.914$, BCa CI = [−0.417, 0.371]) or mental strategy ($F(1.80) = 0.19$, $p = 0.663$, $\eta_p^2 = 0.002$; B = −0.096, $p = 0.670$, BCa CI = [−0.504, 0.278]), and there was no significant physical × mental strategy interaction ($F(1.80) = 1.45$, $p = 0.232$, $\eta_p^2 = 0.018$; B = 0.265, $p = 0.231$, BCa CI = [−0.130, 0.674]).

On the transfer test, there were no significant main effects of physical strategy ($F(1.80) = 2.08$, $p = 0.153$, $\eta_p^2 = 0.025$; B = 0.204, $p = 0.153$, BCa CI = [−0.067, 0.467]) or mental strategy ($F(1.80) = 0.01$, $p = 0.933$, $\eta_p^2 < 0.001$; B = −0.012, $p = 0.943$, BCa CI = [−0.274, 0.276]), and there was no significant physical × mental strategy interaction ($F(1.80) = 0.35$, $p = 0.554$, $\eta_p^2 = 0.004$; B = 0.084, $p = 0.543$, BCa CI = [−0.165, 0.309]).

5.2. Cognitive Load

Table 2 displays the means and standard deviations for the cognitive load ratings reported after learning and after each of the learning outcome tests per condition.

Table 2. Means (standard deviations) per condition for the cognitive load ratings.

	Physical	Mental	Physical and Mental	Control
Cognitive load—learning	7.05 (1.50)	6.67 (1.43)	5.71 (1.93)	6.38 (1.72)
Cognitive load—retention	6.24 (2.17)	6.29 (1.95)	5.48 (2.23)	5.90 (1.97)
Cognitive load—comprehension	7.48 (1.25)	6.91 (1.48)	6.95 (1.47)	6.29 (1.62)
Cognitive load—transfer	7.42 (1.60)	6.95 (1.50)	6.95 (1.36)	6.48 (2.04)

For the cognitive load reported after learning, there was a significant physical × mental strategy interaction ($F(1.80) = 5.03$, $p = 0.028$, $\eta_p^2 = 0.059$; B = −0.410, $p = 0.019$, BCa CI = [−0.749, −0.099]). Simple effects analyses indicated that lower cognitive load ratings were given when physical and mental strategies were combined compared to when the physical strategy was not combined with the mental strategy ($p = 0.01$; BCa CI = [−2.364, −0.295]). There was no significant difference in cognitive load ratings between the conditions without the physical strategy, nor the mental strategy versus no strategy conditions

(p = 0.577; BCa CI = [−1.347, 0.779]). There were no significant main effects for physical strategy (F(1.80) = 0.16, p = 0.693, η_p^2 = 0.002; B = −0.072, p = 0.688, BCa CI = [−0.422, 0.270]) or mental strategy (F(1.80) = 2.11, p = 0.151, η_p^2 = 0.026; B = −0.263, p = 0.148, BCa CI = [−0.614, 0.084]).

For the cognitive load reported after the tests, there were no significant main effects of physical strategy (retention: F(1.80) = 0.27, p = 0.602, η_p^2 = 0.003; B = −0.120, p = 0.607, BCa CI = [−0.565, 0.314]; comprehension: F(1.80) = 3.78, p = 0.055, η_p^2 = 0.045; B = 0.311, p = 0.059, BCa CI = [−0.025, 0.611]; transfer: F(1.80) = 2.54, p = 0.115, η_p^2 = 0.031; B = 0.287, p = 0.106, BCa CI = [−0.038, 0.596]) or mental strategy (retention: F(1.80) = 0.18, p = 0.676, η_p^2 = 0.002; B = −0.096, p = 0.655, BCa CI = [−0.571, 0.336]; comprehension: F(1.80) = 0.02, p = 0.881, η_p^2 < 0.001; B = 0.024, p = 0.883, BCa CI = [−0.288, 0.344]; transfer: F(1.80) = 0.07, p = 0.791, η_p^2 = 0.001; B = −0.048, p = 0.785, BCa CI = [−0.373, 0.303]). There were also no significant physical × mental strategy interactions for cognitive load after any of the tests (retention: F(1.80) = 1.58, p = 0.212, η_p^2 = 0.019; B = −0.289, p = 0.240, BCa CI = [−0.752, 0.164]; comprehension: F(1.80) = 3.22, p = 0.076, η_p^2 = 0.039; B = −0.289, p = 0.090, Bca CI = [−0.609, 0.041]; transfer: F(1.80) = 2.54, p = 0.115, η_p^2 = 0.031; B = −0.289, p = 0.139, BCa CI = [−0.664, 0.062]).

5.3. *Efficiency*

The mean learning outcome scores and cognitive load ratings together suggest that there might have been differences between conditions in the efficiency of the instructional strategies. An instructional strategy is more efficient when the same test performance is achieved with fewer cognitive resources [24]. Therefore, we calculated instructional efficiency based on the test performance (separately for retention, comprehension, and transfer) and the cognitive load reported after learning [25], resulting in three efficiency scores. Table 3 displays the means and standard deviations for the efficiency scores per condition.

Table 3. Means (standard deviations) per condition for instructional efficiency.

	Physical	Mental	Physical and Mental	Control
Efficiency (retention)	−0.35 (1.05)	−0.15 (0.99)	0.45 (0.94)	0.05 (0.87)
Efficiency (comprehension)	−0.32 (0.79)	−0.21 (0.93)	0.36 (1.35)	0.17 (0.71)
Efficiency (transfer)	−0.18 (0.71)	−0.25 (0.88)	0.46 (1.18)	−0.03 (0.82)

The results showed a significant physical × mental strategy interaction for the efficiency scores based on retention performance (F(1.80) = 5.50, p = 0.022, η_p^2 = 0.064; B = 0.250, p = 0.021 BCa CI = [0.041, 0.449]), comprehension performance (F(1.80) = 6.06, p = 0.016, η_p^2 = 0.070; B = 0.266, p = 0.021, BCa CI = [0.075, 0.446]), and transfer performance (F(1.80) = 4.64, p = 0.035, η_p^2 = 0.055; B = 0.217, p = 0.035, BCa CI = [0.018, 0.417]). Simple effects analyses indicated that there was higher efficiency if physical and mental strategies were combined than if the physical strategy was not combined with the mental strategy for efficiency based on retention performance (p = 0.009; BCa CI = [0.203, 1.390]), comprehension performance (p = 0.028; BCa CI = [−0.032,1.353]), and transfer performance (p = 0.027; BCa CI = [0.040, 1.263]). There were no significant differences in efficiency scores between the conditions without the physical strategy, nor the mental strategy versus no strategy conditions; this was the case for efficiency based on retention performance (p = 0.523; BCa CI = −0.774, 0.399]), comprehension performance (p = 0.218; BCa CI = [−0.883, 0.140]), and transfer performance (p = 0.429; BCa CI = [−0.252, 0.681]). There were no significant main effects of physical strategy or mental strategy on any of the three efficiency scores (all ps > 0.10).

6. Discussion

This study investigated the individual and combined effects of physical (annotation) and mental (imagined drag-and-drop) self-management strategies in learning from a split-attention example. Overall, the results provide initial evidence that the combination of physically annotating the split-attention example and imagining dragging and dropping text segments to the corresponding element in the picture resulted in a lower cognitive load during learning compared to only using the annotation strategy. This was not accompanied by higher learning outcomes on retention, comprehension, or transfer tests, meaning that the same learning performance was obtained with less cognitive effort (Hypothesis 2a). The efficiency scores confirm this and further demonstrate that the combination of strategies appeared to be more instructionally efficient than using either strategy in isolation or not using any strategy. In support of Hypothesis 2b, this shows that the combined use of both physical and mental self-management strategies is a less cognitively demanding way to learn from split-attention examples. These findings add to prior self-management research by showing that combining self-management strategies can be beneficial for learners, particularly when physical and mental strategies are combined. This contrasts with the findings of Gordon et al. [15], who did not observe any learning benefits or changes in cognitive load when learners were required to use two physical strategies. Together, this suggests that a key element for the effectiveness of the combined use of two self-management strategies lies in combining strategies that not only require physical involvement, but include a component that explicitly encourages more active mental processing of the content. This interpretation needs to be tested in future research, for example, by directly comparing physical–physical strategies versus physical–mental strategies.

The results do not provide evidence for higher learning outcomes (Hypotheses 1a) or reduced cognitive load (Hypothesis 1b) when either using the annotation strategy or the mental drag-and-drop strategy over not using any of these strategies. This contrasts with earlier research reporting the learning benefits of using the annotation strategy (e.g., [5]) and the mental strategy [11,12] when learning from split-attention examples. Particularly the lack of an effect of the mental self-management strategy was unexpected, given that we used exactly the same materials and procedures as the studies by De Koning et al., which reported medium to large effects for the mental strategy compared to a no-strategy control condition and a physical self-management condition. One key difference, however, is that in their studies, the learning task was presented on a computer screen, while in the present study the learning task was presented on a sheet of paper lying on a desk in front of the learner. Both presentation types have different affordances, which might contribute to an explanation of these diverging findings. That is, paper-based learning materials more strongly invite physical interaction (e.g., placing the finger on a relevant element) than computer-based learning materials do. A non-touchscreen-based computer screen elicits much less physical interaction, because learners know that the screen cannot be controlled with direct physical interaction. Instead, learners presumably might have relied more on mental processing when confronted with the computer-based learning task that was used in the studies by De Koning et al. [11,12]. Using the paper-based materials in the present study might possibly have directed learners more to physical interactions than encouraged mental integration processes; therefore, the potential benefits of the mental strategy might not have been fully realized. This interpretation is in line with other research showing that there are differences in learning outcomes when using paper-based or computer-based materials in learning from split-attention examples (e.g., [3]), and more broadly, such as in reading comprehension (e.g., [26]). Future research could investigate to what extent the medium and associated affordances impact the effectiveness of physical and mental self-management strategies.

Regarding the physical annotation strategy, the differences between the current findings and those of prior research could be attributed to the available study duration. In the present study, there was a 4 min learning phase, which might have been too short of a time to use the annotation strategy to make the relevant connections between spatially separated text and picture elements and also use this as a basis to cognitively process this information into an accurate and coherent mental representation. In earlier studies using the physical annotation strategy, the learning phase was considerably longer. For example, the Roodenrys study [5] had a 12 min learning phase. It is conceivable that, in earlier studies, benefits of using the physical annotation strategy could have materialized because there was sufficient time to engage in both the physical and mental activities, thus supporting learning. Future research is warranted to investigate whether learning time is actually a determining factor in the effectiveness of the physical annotation strategy and other physical or mental self-management strategies.

7. Limitations

The results and interpretations are subject to some limitations. First, as is consistent with other studies investigating the self-management effect, and to enable direct comparisons of our results to those in earlier studies, we used an overall measure of the cognitive load. One-item measures of the cognitive load can give reliable and valid indications of the experienced cognitive load, but are insufficient to detect changes in different types of cognitive load. Future studies could consider using other measures, such as multi-item self-report scales, which can give more specific insight into how different types of cognitive load are impacted by using self-management strategies (e.g., [27,28]). Second, given that our aim was to investigate the relative effectiveness of self-management strategies on learning and cognitive load, the study does not provide insight into how the two self-management strategies were used. Especially for the combination of strategies, this would be valuable to investigate in future studies, as it might provide more information regarding the way in which self-management strategies are used. It would, for example, be insightful to investigate whether and when learners alternate between strategies by analyzing video recordings of participants employing self-management strategies during learning. Third, the physical strategy and mental strategies investigated in this study did not produce a learning benefit over the control condition (which might have been due to the quite high performance of this control condition). It was, therefore, not possible to examine the relative effectiveness of each of these strategies when used in isolation. Except for the study by De Koning et al. [11,12], no other self-management studies have attempted to directly compare the effectiveness of two different self-management strategies, and this would thus be a useful future direction to explore further. In pursuing this direction of research, comparison of a variety of self-management strategies and/or use of different learning tasks could provide further insights into the effectiveness of self-management strategies.

8. Conclusions

The present study attempted to gain more insight into the whether it is helpful for learners studying split-attention examples to engage in physical and/or mental self-management strategies to support their learning. The results indicate that, within the context of this study, using a physical annotation strategy together with a mental drag-and-drop strategy is less cognitively demanding (compared to the physical strategy) and more instructionally efficient than using either a single self-management strategy or no self-management strategy. The present study also offers new research directions for future studies that could provide more insight into the effective use of physical and mental self-management studies.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and was conducted in the context of a research project approved by the Ethics Committee of Erasmus University Rotterdam (18-026, 16 October 2018).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data is available on request by the author.

Conflicts of Interest: The author declares no conflict of interest.

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