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Effects of finger and mouse pointing on learning from online split-attention examples

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Abstract

Background: Self-management of cognitive load is a recent development in cognitive load theory. Finger pointing has been shown to be a potential self-management strategy to support learning from spatially separated, but mutually referring text and pictures (i.e., split-attention examples).

Aims: The present study aimed to extend the prior research on the pointing strategy and investigated the effects of finger pointing on learning from online split-attention examples. Moreover, we examined an alternative pointing strategy using the computer mouse, and a combination of finger pointing and computer-mouse pointing.

Sample: One-hundred and forty-five university students participated in the present study.

Method: All participants studied an online split-attention example about the human nervous system and were randomly allocated to one of four conditions: (1) pointing with the index finger, (2) pointing with the computer mouse, (3) pointing with the index finger and the computer mouse and (4) no pointing.

Results: Results confirmed our main hypothesis, indicating that finger pointing led to higher retention performance than no pointing. However, the mouse pointing strategy and the combined finger and mouse pointing strategy did not show supportive effects.

Conclusions: Finger pointing can be used as a simple and convenient self-management strategy in online learning environments. Mouse pointing may not be as effective as finger pointing.

KEYWORDS
Cognitive load theory, learning, pointing, self-management, split-attention effect

INTRODUCTION

Learning from multiple sources of information, such as a picture with explanatory text (i.e., multimedia learning) is generally more effective than learning from a single source of information (e.g., Mayer, 2021). Research in the context of cognitive load theory (Sweller et al., 1998, 2019) has shown that learning from spatially separated, multiple sources of mutually referring information sources presented within the visual modality, such as written text and graphics, is impaired because learners have to split their attention between, and mentally integrate the sources for understanding to commence. This phenomenon has been referred to as the split-attention effect (Ayres & Sweller, 2014). To reduce the negative effects of split-attention, researchers have proposed a variety of strategies that can be used by instructional designers, such as physically integrating the sources (Tarmizi & Sweller, 1988) and presenting spoken text instead of written text (i.e., modality effect; Mousavi et al., 1995).

A more recently introduced strategy, which can be used by learners themselves to learn more effectively from split-attention materials, is the use of finger pointing to connect related information in the text and graphics (Zhang et al., 2022). Prior research has shown the potential effectiveness of pointing that learners can use to support mental integration with split-attention examples. Building on cognitive load theory, this study extends prior work and focuses on effects of the pointing strategy on learning from online split-attention examples. Moreover, we investigated two alternative pointing strategies, namely computer-mouse pointing, and a combination of finger pointing and computer-mouse pointing.

Cognitive load theory and the self-management approach

Cognitive load theory (CLT; Sweller et al., 1998, 2019) is an instructional theory that provides principles to support the efficient use of working memory in learning and instruction. The theory is built on the premise that human cognitive architecture consists of a working memory (WM) with a very limited capacity and duration, which interacts with an effectively unlimited long-term memory (LTM). In WM no more than a few information elements (i.e., 3–5, Cowan, 2010) can be processed consciously at a time for no longer than a few seconds (i.e., 18 s; Peterson & Peterson, 1959). If the information is high in element interactivity (i.e., the number of elements that must be processed simultaneously in working memory), it could possibly impose a high or too high cognitive load, which can be detrimental to learning. Knowledge that an individual has acquired is stored and organized in LTM in schemas, which are cognitive constructs that incorporate multiple elements of information into a single element with a specific function. By bringing acquired schemas from LTM to WM the level of element interactivity can be reduced. Two types of cognitive load are distinguished: intrinsic cognitive load and extraneous cognitive load (Sweller et al., 2019). Intrinsic cognitive load is determined by intrinsic factors, such as the intrinsic complexity of a task, and a learner's prior knowledge while the extraneous cognitive load is determined by extraneous factors, such as the way the task is presented, and how learners are instructed to learn the task. These two types of load can be added up to the total load a task can impose. Due to the capacity limitations of working memory, the more working memory resources invested in processes related to extraneous cognitive load, the less working memory capacity is available for intrinsic cognitive load. CLT is used to generate instructional guidelines to manage the cognitive load, to be specific, to decrease the extraneous cognitive load and increase the working memory resources that can be used for engaging in activities that contribute to learning (i.e., germane processing) (Sweller et al., 2019).

Two directions have been explored to manage learner's cognitive load: instructor management of cognitive load and self-management of cognitive load. Instructor-managed cognitive load focuses on optimizing the design of instructional materials based on CLT guidelines by teachers or instructional designers (Sweller et al., 2019). For example, to deal with the split-attention effect, spatially integrated information sources can be provided to replace the spatially separated information sources. According to CLT, the main cause of the split-attention effect is the high extraneous cognitive load that is imposed by the requirement to engage in search and match processes to connect mutually referring but spatially separated sources of information and integrate this into a coherent mental representation in working memory (Ayres & Sweller, 2014). When the different sources of information are presented close together, such as in an integrated format, the demand for search and match processes, and its associated extraneous cognitive load, is reduced. The working memory resources that have become available can be used for germane processing, and thus create the opportunity to obtain better learning performance.

The self-management of cognitive load is a more recent development in CLT research, which focuses on how learners can be guided to self-manage their cognitive load (Castro-Alonso et al., 2021; Roodenrys et al., 2012; Zhang et al., 2021). This approach assumes that many instructional materials that students may encounter have not been designed with the consideration of CLT guidelines. According to this approach it is possible to teach learners to identify the problematic design (e.g., split-attention format), and use strategies to decrease the negative influence of such design. The self-management approach is particularly interesting because it is not only an alternative option for the instructor-managed approach, it also connects CLT and self-regulated learning (SRL) (for recent discussions see e.g., Seufert, 2020; Wirth et al., 2020). The self-management strategy can be seen as a form of self-regulation in learning strategies, providing empirical evidence of how cognitive load interacts with self-regulated learning. So far, the self-management strategies are mainly dealing with the split-attention effect (e.g., Roodenrys et al., 2012; Sithole et al., 2017) and incidentally with the redundancy effect (Mirza et al., 2020: when students have to process two sources of information that are self-contained and can be understood without reference to each other, Chandler & Sweller, 1991). Because the current study focused on the split-attention effect, in the next section, we will discuss the self-management strategies that have been investigated to support learning from split-attention examples and explain what pointing strategies could contribute to this.

Self-management strategies

Self-management strategies aim to help learners mentally integrate the spatially separated information in order to reduce the extraneous cognitive load (Sweller et al., 2019; Zhang et al., 2021). Four self-management strategies have been studied: signalling with external tools (build a link between the multiple information sources by circling, highlighting and drawing arrows, e.g., Sithole et al., 2017), physical integration by dragging and dropping (move the elements from one information source into the other, related information source using a dragging-and-dropping technique with a mouse, e.g., Tindall-Ford et al., 2015), mental integration using imagination (imagine to drag and drop text segments to the corresponding position in diagram, e.g., De Koning et al., 2020a, 2020b) and finger pointing (e.g., Zhang et al., 2022). These studies showed mixed results regarding the effectiveness of self-management strategies for learning and cognitive load. Signalling with external tools provided the strongest (d = .63–2.17) and most consistent results, indicating that university students who used this strategy obtained higher recall and transfer scores than students who did not use this strategy when learning from psychology and accounting knowledge in a split-attention format (Roodenrys et al., 2012; Sithole et al., 2017). Mental integration using imagination also showed strong effects (d = .77–.94) with university students who imagined dragging-and-dropping text elements performing better on recall and comprehension tests than those who did not use the strategy when learning from split-attention examples about electrical circuit (De Koning et al., 2020a). Physical integration by dragging and dropping was found to be effective in one study (d = .89) in which secondary school students who used this strategy obtained better transfer performance than those who did not use the strategy when learning from geometry (Tindall-Ford et al., 2015). In two other studies investigating physical integration in adult samples in the domains of psychology (d = .13–.16) and engineering (d = .05–.35), no effects of the physical integration strategy on learning were found (Agostinho et al., 2013; De Koning et al., 2020a). When combined with another physical strategy (i.e., highlighting) the physical integration strategy showed a medium-sized (d = .49) beneficial effect on learning in primary school students who learned about the water cycle (Gordon et al., 2016). The finger pointing strategy also led to inconsistent results. In a study by Zhang et al. (2022), university students who were instructed to use either one hand or two hands to point at text elements and/or corresponding parts of a diagram in paper-based materials in the domain of Biology did not perform better on retention and comprehension tests than students not instructed to point. In a subsequent phase a novel split-attention example of a nuclear water reactor was presented and students in all condition received no instructions to point. Results showed that students who spontaneously used pointing in studying the novel split-attention example performed significantly better on comprehension test than those who did not point (d = .41). A pilot study of these authors using the same Biology materials in A3-size paper also showed that when students could choose their preferable way of pointing (instead of being instructed to point in a specific way as was the case in Zhang et al., 2022) in the pointing condition performed better on a recall test (d = .67) than those who did not point. Among all the above studies, only one study (Sithole et al., 2017) indicated that students who used a self-management strategy perceived lower cognitive load than those who did not (d = 1.99–3.90) during learning and in the tests. The other studies reported no differences in cognitive load.

Although for each strategy, at least one study showed positive effects, replications and further investigations are needed in different learning domains and different populations. In the present study, we aimed to extend the research on the finger pointing strategy as until now it has received relatively little attention from self-management researchers, effects on learning are inconclusive, and the strategy has high practical interest. The pointing strategy is easy for educators to guide and easy for learners to use. Moreover, it can be used in various situations independent of whether physical interaction with the learning materials is possible, for example, with learning materials that cannot be manipulated or drawn on. Given that previous studies investigating other self-management strategies (e.g., highlighting, mental integration, drag and drop) showed learning benefits in both offline (paper-based) and online learning environments, it is interesting to further investigate whether the pointing strategy, which was solely investigated in an offline environment, can also be applied to online learning materials. Online environments comprise a large part of contemporary learning environments and afford pointing movements by the index finger (e.g., iPad-like computers) or the computer mouse (e.g., personal computers). In the online context it would also be interesting to investigate whether mouse pointing can be as effective as finger pointing.

Finger pointing and mouse pointing

Various theoretical accounts can provide an explanation for the beneficial effects of finger pointing on learning. Evolutionary educational psychology and CLT have been most frequently used to explain why finger pointing can enhance learning (Paas & Sweller, 2012; Sweller, 2021). Pointing can be regarded as a form of biologically primary knowledge, which is knowledge that humans have evolved to use effortlessly. Comparably, there is biologically secondary knowledge, such as reading and mathematics, which humans can only learn deliberately and with explicit instructions (Geary, 2008). According to this view, the use of biologically primary knowledge can facilitate the acquisition of biologically secondary knowledge because it can contribute to learning and be used without a discernible working memory load. Studies informed by this evolutionary account found that students who performed pointing and tracing gestures when learning physiology knowledge had better retention and comprehension than those who did not (e.g., Ginns & Kydd, 2019; Macken & Ginns, 2014).

Another relevant theoretical account is embodied cognition. From this view, body movements could be used to support cognitive processing because cognition is closely linked to the body and the environment (Barsalou, 1999, 2008). Cognitive off-loading can explain this process (Tang et al., 2019). Searching and matching related textual and pictorial information in split-attention examples requires learners to remember the location of the information, and by pointing the index finger to this information, working memory resources can be decreased because the finger pointing provides a stable marker in the environment that does not need to be kept active in working memory. Task engagement can also explain the process (Marks, 2000). Finger pointing may enhance the cognitive engagement in the process of learner-task interaction, which is helpful for constructing high-quality schemas and thus can enhance learning (Paas & Sweller, 2012).

The last theoretical account comes from the perspective of visual guidance. Human beings gain the ability to use their fingers to point at 1 year of age (Liszkowski et al., 2007), and throughout their lives use it effortlessly to guide attention in various situations (e.g., conversations, reading). The attention guiding function of finger pointing (Cosman & Vecera, 2010) can help learners to automatically allocate more attention resources to the pointed area, which can benefit the information selection and organization in the learning process. Many studies have supported the attention guiding function of finger pointing, indicating that pointing leads to faster and more accurate attention to the pointed place and the area around the hand (e.g., Agauas et al., 2020; Reed et al., 2010).

An interesting question is whether mouse pointing can be similarly effective as finger pointing on learning. The embodied cognitive view may provide some supportive evidence. Tool use to some extent can be regarded as a kind of extension of one's body (Schettler et al., 2019). Research has shown that for habitual mouse users, the computer mouse extended the representation of peripersonal space (i.e., the space immediately surrounding the body) from the hand area to far space (Bassolino et al., 2010). In this sense, use of the computer mouse can be regarded as the extended format of the human hand and could have similar benefits as finger pointing. However, without the direct interaction between the finger and learning materials, mouse pointing may lead to less engagement and less multisensory experience (i.e., visual and haptical experience) compared to the finger pointing. Mouse pointing and finger pointing can also function in the same way that cues (or anchors) are both provided for guiding attention and helping off-load working memory resources. In the study of Du and Zhang (2019), finger tracing and mouse tracing led to superior learning performance among primary school students in geometry than no tracing, and no difference was found between finger tracing and mouse tracing.

The present study

The present study aimed to investigate pointing as a self-management strategy in online split-attention examples and compare the relative effectiveness of finger pointing and mouse pointing strategies. In previous self-management studies, some strategies required direct interaction with the hand (e.g., drag and drop paper cut out figures) while other strategies involved an extended form of interaction for which a tool was used (e.g., pen to highlight, mouse to move text boxes). No self-management studies have yet directly compared such direct interaction with extended forms of interaction, so our study provides a first comparison. We also included a combination strategy to look at whether the effectiveness of pointing still exists when both hands are involved. Therefore, we investigated three pointing strategies in a between-subjects design: finger pointing directly on the computer screen, mouse pointing (to control an arrow icon on the computer screen) and a combination of finger pointing and mouse pointing. A fourth condition without pointing served as the control condition. In all conditions, participants studied a spatially separated text and picture (i.e., split-attention example), and subsequently answered retention and comprehension questions and indicated their cognitive load. The split-attention example was taken from Florax and Ploetzner (2010) as their results showed that compared to a spatially integrated format learning outcomes were lower and thus offered room for additional instructional strategies to support learning. We also collected learners' prior knowledge rating and visual–spatial working memory capacity as control variables as they are highly correlated to the learning performance (Ayres & Sweller, 2014; Fenesi et al., 2016).

According to the theoretical assumptions and empirical evidence on the benefits of finger pointing (Paas & Sweller, 2012; Zhang et al., 2022), we expected that students in the finger pointing condition would obtain higher retention and comprehension test scores and report lower cognitive load than students in the non-pointing condition (Hypothesis 1). Because people nowadays are used to pointing with the mouse in online environments, and theoretical and empirical evidence supported a similar effectiveness of virtual manipulation and physical manipulation (Du & Zhang, 2019; Schettler et al., 2019), we expected that students in the mouse pointing condition would also obtain higher retention and comprehension test scores and report lower cognitive load than students in the non-pointing condition (Hypothesis 2).

Corresponding to Hypothesis 2, we expected no difference between the finger pointing condition and the mouse pointing condition (Hypothesis 3). In addition, based on the previous studies on the finger pointing strategy (Zhang et al., 2022), using two hands (one hand to point on the text and one hand to point on the diagram) is the most common way learners chose when they learnt from split-attention examples. From the perspective of ecological validity, the finger pointing strategy and mouse pointing strategy are more similar with only one hand involved in the present study. The combined strategy could be a simulation of a two-hand-pointing strategy, which can facilitate learning because two attentional cues can be provided at the same time. Thus, we expected that students in the combined pointing condition would have higher retention and comprehension test scores but report lower cognitive load than students in the non-pointing condition (Hypothesis 4).

METHOD

Participants and design

One-hundred and fifty-seven university students participated in this online study. Twelve participants were excluded because of technical problems. The resulting sample consisted of 145 participants (127 females, 17 males and 1 person preferred not to say, M_{age} = 20.59 years, SD_{age} = 2.64) from Erasmus University Rotterdam. Most students were right-handed (87.60%) and Non-English native speakers (91.03%). Ethical approval for this study was obtained from the Ethics Review Committee at Erasmus University Rotterdam. Participants participated in the experiment voluntarily via online registration. Participants signed an informed consent form before the start of the study and received course credits as reward.

Participants were randomly assigned to one of four between-subject conditions: (1) finger pointing condition: participants point at the material on the computer screen using the index finger of their dominant hand ($N = 34$), mouse pointing condition: participants point at the material using the mouse to control an arrow icon on the computer screen by their dominant hand ($N = 37$), (3) combined pointing: participants point at the material using the index finger of one hand and using their other hand to control the mouse ($N = 40$), and (4) control condition: participants do not point with their finger or the mouse ($N = 34$).

Materials

The whole study was presented online in a Qualtrics environment (Qualtrics, Provo, UT, https://www.qualtrics.com).

Demographic information

A questionnaire collected demographic information on age, gender, handedness and English proficiency. English proficiency was reported by participants on a 9-point rating scale ('1 Beginner', '5 Intermediate', '9 Advanced').

Background information

An expository text on the human nervous system was provided to ensure participants started with a comparable basic level of understanding regarding synaptic transmission. Participants were given a maximum of 10 min to read this information.

Prior knowledge test

A 12-item multiple-choice test was adopted from the study of Florax and Ploetzner (2010) to assess participant's prior knowledge and understanding of the background information about the human nervous system (e.g., what is a synapse?). Each multiple-choice question had four alternatives, which could possibly be correct and a fifth alternative: I do not know. Participants were encouraged select the fifth answer alternative instead of guessing when they were not sure which answer alternative was correct. One point was awarded to each correctly answered question. Thus, participants could score a maximum of 12 points on the prior knowledge test. A maximum of 9 min was given to complete this prior knowledge test.

Learning materials

The learning materials were adapted from the study of Florax and Ploetzner (2010). The materials consisted of one page with graphical and written explanation concerning information transmission in the human nervous system (see Figure 1). The information transmission process showed how different neurotransmitters are released into the synaptic cleft, which either activate or inhibit information transfer. Both the text and the graphics are needed to understand the process. The learning material was presented in the size of 1199 × 757 pixels. This size was chosen because this enabled a full one-page presentation (without scrolling) on a 13-inch screen and larger screens. It was indicated in the study introduction for participants that only screens 13-inch and larger were allowed. All participants had 18 min to study the materials.

Instructions for pointing

The instructions for pointing (see Figure 2) were adapted from the study of Macken and Ginns (2014). The instructions differed in each condition and were presented in one page before the learning materials. An example containing a text and diagram of the human eye was presented along with each instruction.

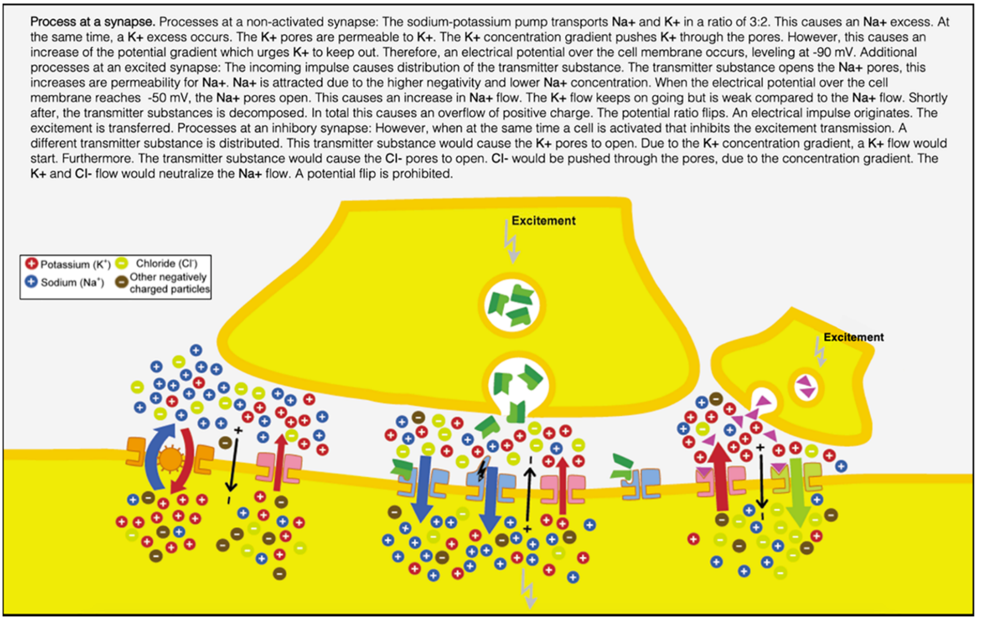

FIGURE 1 Learning material page

Retention and comprehension tests

The post-test was also adapted from the study of Florax and Ploetzner (2010), consisting of 30 multiple-choice questions. Twenty-two retention questions required recall of the textual and pictorial information presented in the learning phase (e.g., 'what is the potential of a cell membrane when a cell is not activated?'). Eight comprehension questions required participants to make inferences based on this information (e.g., 'how would the potential ratio over the membrane be if a non-activated cell would be permeable to potassium instead of sodium?'). Both retention and comprehension questions had four possible answer alternatives and a fifth alternative 'I do not know' as prior knowledge test. A total of 30 points could be obtained for post-test. Separate counts were made for retention and comprehension, resulting in a maximum score of 22 points on the retention questions and eight points on the comprehension questions. The retention and comprehension questions were presented in mixed order as one post-test. Participants had max. 25 min to complete the post-test. Cronbach's alpha for the post-test, retention questions and comprehension question were .85, .82 and .54, respectively.

Cognitive load ratings

Participants were asked to indicate how much mental effort they invested in learning, how difficult they perceived the learning task, and how engaged they were in learning on three 9-point rating scales (Paas, 1992), ranging from 1 (very, very low effort / very, very low difficulty / very, very low engagement) to 9 (very, very high effort / very, very high difficulty / very, very high engagement). Participants were also asked to rate these three questions related to the post-test.

(a) combined pointing condition

Please use both hands to make a link between the text and the corresponding part of the graphics; one hand controls the mouse/trackpad (cursor), and the other hand is used for pointing at graphical information on the screen.

Some ways you might like to do this are:

- Move the cursor with the mouse/trackpad to a specific text segment, then use the index finger of your other hand to point at the corresponding part of the graphics, or the other way around.

(b) finger pointing condition

Please use the index finger of your dominant hand to make a link between the text and the corresponding part of the graphics. Please do not use the mouse (you can leave the cursor outside the material).

Some ways you might like to do this are:

- Point with the index finger of your dominant hand at the text segment, then point at the corresponding part of the graphics
- Leave your index finger on the graphics as you read about the corresponding element in the text.

(c) mouse pointing condition

Please move the cursor with the mouse/trackpad to make a link between the text and the corresponding part of the graphics.

Some ways you might like to do this are:

- Move the cursor with the mouse/trackpad to a specific text segment, then to the corresponding part of the graphics.
- Leave the mouse cursor on the graphics as you read about the corresponding element in the text.

(d) no pointing condition

Please only use your eyes to read and attempt to understand the materials. Please keep your hands still.

FIGURE 2 Instructions for each condition

Working memory capacity

Participants' working memory capacity was measured by the online symmetry pattern task of VAR developed by Castro-Alonso et al. (2019). Dual tasks were employed: a memory task was interrupted by a processing task. The stimuli to memorize in the memory task were matrices of squares highlighted in different positions. Each matrix of squares was presented for 700 ms. The inter-stimuli lapse with a blank display was 500 ms. The task was started with 2 patterns and ended with 5 patterns. Three trials were set per pattern length. In the processing task, judgements had to be made on whether the display was symmetrical or asymmetrical around the Y-axis. Performance on the memory and processing tasks were scored separately. For the memory task, each correctly memorized element (i.e., correct element and correct order) was awarded one point (max. 42 points). For the processing task, each correctly judged symmetrical item was also awarded one point (max. 42 points). In line with Unsworth et al. (2005), participants who scored below 85% on the processing task were not included in the analysis. Only scores on the memory task were used to represent visual–spatial working memory performance (max. 42 points). The complete task took approximately 7 min.

Post-survey

The post-survey collected information about participants' learning environment and equipment used, such as the (estimated) screen size of the computer screen (participants could choose from the following options: <13(inch), 13, 15, 17, 19, 21, >21(inch)), whether the environment was quiet during the study, whether they had been interrupted, and what they used to control the cursor (mouse, trackpad, touchscreen).

Procedure

Four Qualtrics links were created corresponding to each of the four conditions. The information presented was exactly same except for the instruction page, which differed per condition. Participants could register for the study in a digital recruitment system in Erasmus University Rotterdam. After registration, they received an experiment invitation email sent by the first author, which contained one of four Qualtrics links, determined by a predetermined pseudorandom order. Once participants clicked on the link, they were directed to the Qualtrics environment that first presented the introduction of the study followed by the informed consent form. The formal study contained five parts. In part 1, participants' demographic information was collected. In part 2, they completed the symmetry pattern task (working memory capacity). After that, a two-minute break was provided. In part 3, participants engaged in the learning task, which subsequently included the pre-test, background information page, instruction page and the learning phase. During the learning task, in all conditions mouse movements were automatically recorded during the learning phase by a JAVA script in Qualtrics. In part 4, participants completed the post-test. Cognitive load ratings were asked after the learning phase and the testing phase. In part 5, participants filled in the post-survey. Participants were asked to complete the study in one try without pause, except for the break provided. Except for the learning phase, participants could manually proceed to the next page when they finished the task before the time limit. The whole study took around 75 min.

Compliance check

Due to the online nature of the study, participants' learning behaviour (i.e., pointing movements with the hand and/or mouse) could only be inferred indirectly based on the mouse movements recorded during the learning phase. The basic rationale is that in the two-handed pointing condition and mouse pointing condition, the cursor should be moved very often (at least more than 10 movements: clicking the ‘3 minutes left’ prompts takes a few movements), and in the one-handed pointing condition and no pointing condition, the cursor should not be moved except for necessary movements. The recordings showed that 90% of the participants in the two-handed pointing condition and 100% of the participants in the mouse pointing condition moved the mouse at least 10 times. In the one-handed pointing condition and the no pointing condition 94% and 85% of the participants, respectively, moved the mouse <10 times. According to these results, we can infer that the experimental control was successful.

Data analysis

Data were analysed using SPSS 27 and R. One-way analyses of variance (ANOVAs) were conducted to compare the four conditions on English proficiency, prior knowledge test score and WMC score. Due to the norminal data, cross-tabulation and Chi-Square tests were used to check if conditions were comparable regarding the distribution of estimated computer screen size and control of the cursor (mouse, trackpad, touchscreen). Separate ANOVAs were conducted to test the difference of four conditions on outcome measures (i.e., total score, retention test score, comprehension test score), and the three self-rating (i.e., cognitive load ratings on difficulty, mental effort and engagement level for the learning task and the post-test). Planned contrasts of ANOVA were conducted in R to test the specific effect of each condition. Planned contrasts were more appropriate than Post Hoc analyses (multiple comparisons) when specific hypotheses, which is in our case, are formulated (Schad et al., 2020). To conduct the planned contrasts, different weight coefficients were assigned to the two-handed pointing condition, one-handed pointing condition, mouse pointing condition and the no pointing condition, respectively, which can be seen in Table 1. The coefficients '0', '1' and '−1' were chosen to represent the expected pattern in each contrast. More specifically, contrasts 1, 2 and 4 were testing Hypothesis 1, 2 and 4 on the effect of each pointing strategy. Contrast 3 was testing Hypothesis 3 predicting no difference between the one-handed pointing condition and the mouse pointing condition. One-tailed p-value and Bonferroni's adjustment were used in all planned contrasts. Before conducting ANOVAs and planned contrasts, normal distribution and homogeneity of variances of the dependent variables were tested to determine whether the assumptions for ANOVAs were met. For each condition, all the dependent variables were approximately normally distributed based on Normal Q-Q plots and showed equal variances using Levene's test except for the comprehension test score ($F = 3.06$, $p = .030$) and the mental effort rating for completing the test ($F = 3.46$, $p = .018$). Therefore, independent-samples Kruskal-Wallis tests and contrasts were conducted to compare the differences on comprehension score and mental effort for completing the test between conditions using the Real Statistics Resources Pack software (Release 7.6). Copyright (2013–2021) Charles Zaiontz. www.real-statistics.com.

RESULTS

Preliminary analyses

The means and standard deviations on the English proficiency, WMC score and prior knowledge score for each of the four conditions are presented in Table 2. There were no significant differences between

TABLE 1 Coefficients assigned for each contrast

	Combined pointing	Finger pointing	Mouse pointing	No pointing
Contrast 1	0	1	0	−1
Contrast 2	0	0	1	−1
Contrast 3	0	1	−1	0
Contrast 4	1	0	0	−1

TABLE 2 Means and SDs for English proficiency, WMC scores, prior knowledge score, learning outcomes and cognitive load ratings

	Combined pointing	Finger pointing	Mouse pointing	No pointing
	N **= 40**	***N*** **= 34**	***N*** **= 37**	***N*** **= 34**
	M **(*SD*)**	***M*** **(*SD*)**	***M*** **(*SD*)**	***M*** **(*SD*)**
English proficiency	8.00 (1.20)	7.74 (1.16)	7.70 (1.31)	7.29 (1.22)
WMC memory score	23.54 (7.92)	24.47 (6.81)	22.29 (6.63)	23.68 (7.53)
WMC processing percentage (%)	46.97 (1.09)	47.86 (1.10)	46.22 (1.06)	45.48 (1.17)
Prior knowledge score	3.68 (1.86)	4.12 (2.20)	3.57 (1.97)	3.26 (1.60)
Learning outcomes				
Total score	9.95 (5.96)	13.06 (6.49)	11.62 (5.82)	8.79 (4.28)
Retention test	7.92 (4.73)	10.70 (5.10)	9.32 (4.76)	7.24 (3.58)
Comprehension test	2.02 (1.70)	2.41 (2.08)	2.30 (1.58)	1.56 (1.31)
Task difficulty				
Learning task	6.55 (1.52)	6.26 (1.73)	6.05 (1.25)	6.45 (1.37)
Post-test	7.55 (1.36)	7.41 (1.31)	7.57 (1.24)	7.79 (1.04)
Mental effort				
Learning task	6.05 (2.17)	6.53 (2.14)	6.41 (1.66)	6.29 (1.57)
Post-test	5.80 (2.11)	6.76 (1.30)	6.70 (1.51)	6.15 (1.58)
Task engagement				
Learning task	4.88 (2.17)	5.76 (1.92)	5.19 (2.21)	5.15 (1.81)
Post-test	5.35 (2.35)	6.18 (2.17)	5.43 (2.08)	5.56 (2.46)

conditions in participants' English proficiency, $F(3, 141) = 2.06$, $p = .109$, $\eta_p^2 = .04$, WMC score, $F(3, 133) = .54$, $p = .657$, $\eta_p^2 = .01$ and prior knowledge, $F(3, 141) = 1.23$, $p = .302$, $\eta_p^2 = .03$. It is worth to mention that regarding the WMC score, participants who scored below 85% on the processing task would not be included in the analysis; however, in the present sample, participants scored between 31% to 62% ($M = 46.65\%$) on the processing task, which means that they may not have invested enough effort on the processing task, leading to an inaccurate memory task score.

Across conditions there was a comparable distribution of the estimated computer screen size, $\chi^2(18, N = 144) = 14.80$, $p = .710$, and way of controlling the cursor, $\chi^2(9, N = 145) = 9.24$, $p = .360$, as reported by participants.

Means and standard deviations for scores on the retention test, comprehension test and self-ratings are displayed in Table 2.

Learning outcomes

Total score

There was a significant difference between the conditions on the total score of the post-test, $F(3, 141) = 3.72$, $p = .013$, $\eta_p^2 = .07$. Contrast 1 revealed a significant difference between the finger pointing condition and the no pointing condition, $t(141) = 3.08$, $p = .005$, $d = .75$, showing that participants in the finger pointing condition obtained a significantly higher total score than participants in the no pointing condition. Contrast 2 revealed no significant differences between the mouse pointing condition and the no pointing condition on the total score, $t(141) = 2.09$, $p = .078$, $d = .50$. Contrast 3 revealed no significant differences between the finger pointing condition and the mouse pointing condition on the total score,

$t(141) = 1.06$, $p = .500$, $d = .25$.[1] Contrast 4 revealed no significant difference between the combined pointing condition and the no pointing condition on the total score, $t(141) = .87$, $p = .500$, $d = .20$.

Retention test

A significant difference was found between the conditions on the retention test score, $F(3, 132) = 3.92$, $p = .010$, $\eta_p^2 = .08$. Contrast 1 revealed a significant difference, $t(141) = 3.12$, $p = .004$, $d = .76$, showing that participants in the finger pointing condition obtained a significantly higher retention test score than participants in the no pointing condition. Contrast 2 revealed no significant difference between the mouse pointing condition and the no pointing condition on the retention test, $t(141) = 1.92$, $p = .114$, $d = .46$.[1] Contrast 3 revealed no significant difference between the finger pointing condition and the mouse pointing condition on the retention test, $t(141) = 1.27$, $p = .414$, $d = .30$. Contrast 4 revealed no significant difference between the combined pointing condition and the no pointing condition on the retention test, $t(141) = .65$, $p = .500$, $d = .15$.

Comprehension test

No significant differences were found between the conditions on the comprehension test scores, $H(3) = 4.17$, $p = .244$, η_p^2 [H] = .01. None of the contrasts showed significant differences, contrast 1, $\chi^2(3, N = 145) = 2.74$, $p = .216$; contrast 2, $\chi^2(3, N = 145) = 3.439$, $p = .163$; contrast 3, $\chi^2(3, N = 145) = .03$, $p = .499$; contrast 4, $\chi^2(3, N = 145) = 1.10$, $p = .388$.

Cognitive load ratings

Task difficulty

No significant differences were found between the conditions on the difficulty rating for the learning task, $F(3, 141) = .79$, $p = .504$, $\eta_p^2 = .02$; contrast 1, $t(141) = -.41$, $p = .500$, $d = -.10$; contrast 2, $t(141) = -1.02$, $p = .500$, $d = -.24$; contrast 3, $t(141) = .60$, $p = .500$, $d = .14$; contrast 4, $t(141) = .40$, $p = .500$, $d = .09$. No significant differences were found on the difficulty rating for the post-test, $F(3, 141) = .55$, $p = .649$, $\eta_p^2 = .01$; contrast 1, $t(141) = -1.27$, $p = .416$, $d = -.31$; contrast 2, $t(141) = -.76$, $p = .500$, $d = -.18$; contrast 3, $t(141) = -.53$, $p = .500$, $d = -.13$; contrast 4, $t(141) = -.84$, $p = .500$, $d = -.20$.

Mental effort

Similarly, no significant differences were found between the conditions on the mental effort rating for the learning task, $F(3, 141) = .43$, $p = .733$, $\eta_p^2 = .01$; contrast 1, $t(141) = .51$, $p = .500$, $d = .12$; contrast 2, $t(141) = .25$, $p = .500$, $d = .06$; contrast 3, $t(141) = .27$, $p = .500$, $d = .06$; contrast 4, $t(141) = -.55$, $p = .500$, $d = -.13$. No significant differences were found on the mental effort rating for the post-test, $H(3) = 4.67$, $p = .197$, η_p^2[H] = .01; contrast 1, $\chi^2(3, N = 145) = 2.17$, $p = .269$; contrast 2, $\chi^2(3, N = 145) = 1.86$, $p = .301$; contrast 3, $\chi^2(3, N = 145) = .02$, $p = .500$; contrast 4, $\chi^2(3, N = 145) = .02$, $p = .500$.

[1]Equivalence tests were conducted for all non-significant contrasts to check whether the differences of the contrasts were actually absent and not just undetected (Lakens, 2017). *TOSTER* R package was used to conduct two one-sided tests to examine the equivalence of the results to zero (TOST). The lower and upper bound were set to $d = -0.30$ and $d = 0.30$ (small to median), respectively, to indicate the smallest effect of interest for contrasts 1, 2 and 4. Given that contrast 3 was based on Hypothesis 3 predicting no differences between conditions, the lower and upper bound were set to $d = -0.10$ and $d = 0.10$ (see Lakens et al., 2020). None of the equivalence tests were significant ($p > .05$), suggesting we cannot reject the presence of the smallest effect of interest.

Task engagement

Identical to task difficulty and mental effort, no significant differences were found among the conditions on the engagement rating for the learning task, $F(3, 141) = 1.20$, $p = .313$, $\eta_p^2 = .03$; contrast 1, $t(141) = 1.24$, $p = .430$, $d = .30$; contrast 2, $t(141) = .09$, $p = .500$, $d = .02$; contrast 3, $t(141) = 1.18$, $p = .477$, $d = .28$; contrast 4, $t(141) = -.57$, $p = .500$, $d = -.13$. No significant differences were found on the engagement rating for the post-test, $F(3, 141) = .96$, $p = .412$, $\eta_p^2 = .02$; contrast 1, $t(141) = 1.12$, $p = .500$, $d = .27$; contrast 2, $t(141) = -.24$, $p = .500$, $d = -.06$; contrast 3, $t(141) = 1.38$, $p = .339$, $d = .33$; contrast 4, $t(141) = -.40$, $p = .500$, $d = .05$.

DISCUSSION

Building on CLT and prior self-management research on pointing (Zhang et al., 2022), the present study aimed to investigate the pointing effect with online split-attention examples and compare the effectiveness of different types of pointing strategies: finger pointing, mouse pointing and a combination of finger pointing and mouse pointing.

Results showed that students who used finger pointing obtained better post-test performance than students in the no pointing condition, which confirmed Hypothesis 1. This finding shows that finger pointing is an effective self-management strategy to support learning from split-attention examples in a digital online context. It also shows that in addition to being an effective self-management strategy in studying split-attention examples from an A3-size paper, finger pointing also supports learning from split-attention examples presented in a smaller size (approximately A4-size paper, which corresponds to a 13-inch screen size). More replications are needed in different mediums and with different types of split-attention examples. An interesting direction for future research would be to directly compare pointing in a digital learning environment (e.g., finger pointing on a computer screen) with offline pointing (e.g., finger pointing on paper). Recent studies have shown that participants gained higher reading comprehension scores when reading on paper than on a digital screen (Delgado & Salmerón, 2021; for a meta-analysis, see Kong et al., 2018). It would be useful to investigate whether the effectiveness of the pointing strategy is affected accordingly.

Taking a closer look at the performance measures indicates that post-test scores significantly differed between the finger pointing condition and the no pointing condition. This difference only showed up on the retention scores; no difference was found in comprehension scores. Two possible explanations can be given for this. First, compared to retention, pointing may have an indirect effect via attention and off-loading on comprehension. Attention guiding and off-loading seem to serve shallow processing strategies more than deep processing strategies (Chi et al., 2018). Comprehension requires deeper levels of information organization and integration and might, therefore, be less facilitated by the shallow processing encouraged by the pointing strategy. Second, students could have used a passive way of pointing. If students were implementing the strategy as a requirement without explicit awareness of why using the strategy, they could engage less actively in the cognitive process and meta-cognitive processes. Active engagement could be more crucial for comprehension than retention (De Koning et al., 2010). In previous studies using the highlighting strategy (Roodenrys et al., 2012; Sithole et al., 2017) and mental integration strategy (De Koning et al., 2020a, 2020b) both retention and comprehension scores improved, while in studies using a physical strategy (Agostinho et al., 2013; Gordon et al., 2016; Tindall-Ford et al., 2015) this was not the case. This observation may suggest that strategies providing a more salient connection between text and picture (e.g., a permanent external visual link is created by highlighting) and supporting active integration (e.g., more active mental integration encouraged by imagination) between spatially separated information sources can have a more robust effect. However, because different materials and tests have been used in self-management studies, it is difficult to draw a clear conclusion. More research that uses comparable materials and tests is need. Moreover, we should not neglect that the comprehension test in the present study had relatively low reliability (perhaps because it contained only 8 items), which could also have influenced the results and its interpretation. Future studies could consider using a comprehension test with higher reliability, for example the 20-item comprehension test used by Macken and Ginns (2014) and Ginns and Kydd (2019), which showed good reliability.

Students in the mouse pointing condition did not perform better than students in the no pointing condition, which does not support Hypothesis 2 (i.e., mouse pointing > no pointing). The performance of the mouse pointing condition did not differ from the finger pointing condition either, which confirms Hypothesis 3 (i.e., mouse pointing = finger pointing). These findings suggest that compared to not pointing, mouse pointing may not be as effective as the finger pointing strategy to support learning from split-attention examples. However, from the means we can see the mouse pointing performed only minimally lower than the finger pointing condition. One explanation for the lower effectiveness of mouse pointing could be the unfamiliarity with using the mouse for pointing as an instructional aid. We assumed that nowadays students use the mouse very frequently and effortlessly, which can make pointing with the mouse an intuitive act. In reality, learners may have been less familiar with or unwilling to use mouse pointing and apply it as a specific learning strategy. Future studies could consider the frequency of use and habitual preference of participants in using the mouse to investigate to what extent this relates to the effectiveness of mouse pointing. Another possibility is that mouse pointing would indeed lead to less engagement and multisensory experience than finger pointing. In the study of Du and Zhang (2019) results showed no differences between mouse tracing and finger tracing. This could be the functional differences between pointing and tracing since they have been implemented in different learning scenarios. Moreover, when involving human embodied elements, an extended form of interaction (mouse pointing) might be less effective due to lower embodied effects. In support of this, in a study of De Koning and Tabbers (2013), university students who viewed an animation followed by an arrow performed worse than those who viewed the animation followed by an on-screen human hand. Future studies can further compare whether there is a difference in mouse pointing effectiveness depending on whether a virtual finger icon is used as a cursor or whether an arrow cursor is used.

In contrast to our expectation (Hypothesis 4), the two-handed pointing condition (i.e., mouse and finger pointing combined) showed no superiority over the no pointing condition. We expected that by using two hands, two attentional cues are provided at the same time, and therefore, mental integration can be facilitated. The present result may stem from the instructions that are of low ecological validity. In practice, it is uncommon that learners simultaneously use one hand to point at the screen and the other hand to move the mouse. In terms of CLT, the requirement to coordinate the use of two hands can be too cognitively demanding because students have to coordinate actual finger movements directly on the screen with extended interaction via the mouse. Such instructions might be difficult to implement for students and eventually might hamper learning.

With regard to the cognitive load ratings, none of the results confirmed our hypotheses that using pointing strategies would lead to lower cognitive load (i.e., lower mental effort, lower task difficulty, and higher engagement). These findings were in line with earlier self-management studies showing no effects on cognitive load (Agostinho et al., 2013; De Koning et al., 2020a; Gordon et al., 2016; Roodenrys et al., 2012; Tindall-Ford et al., 2015; Zhang et al., 2022). It is not clear whether this might be related to the use of a single-item subjective rating scale in our study and these earlier studies. Studies investigating both pointing and tracing or purely tracing used a multi-item cognitive load scale (Leppink et al., 2013) and found significant differences of pointing and tracing on extraneous cognitive load self-reports compared to intrinsic load self-reports (Ginns & King, 2021; Tang et al., 2019; Wang et al., 2022). Future studies could consider the use of multi-item scales to investigate whether this would yield any differences in cognitive load for the pointing strategies. It is worth noting though that the means of cognitive load ratings in the present study showed some interesting trends, indicating that the finger pointing condition reported the highest mental effort and perceived engagement among all the conditions. Although this pattern of mental effort was opposite to what we hypothesized, the fact that self-reported engagement was highest in this condition may offer several alternative explanations. One possible explanation is that higher engagement was associated with higher germane cognitive load, which resulted in higher overall cognitive load. Using this explanation, it could be argued that the embodied effect of pointing could be stronger than its attention guiding effect, because the latter was supposed to decrease the extraneous cognitive load. Another possibility is that giving learners the freedom to point in any way they wanted, makes learners consciously think about how to point which imposes extraneous cognitive load on learners, which reduces the efficiency of the pointing strategy.

Several limitations of the present study should be noted. First, while an online study is considered to be more ecologically valid than a laboratory study, it may come at the cost of confounding factors. For example, there were three types of cursor control reported in the present study: mouse ($N = 42$), trackpad ($N = 99$), touchscreen ($N = 3$) and one missing. The mouse and trackpad allow for different levels of embodied interaction. Compared to using the mouse, when using a trackpad to control the cursor the index fingers more closely mimic the finger movements involved in actual finger pointing. For another example, screen size used by participants varied. Presenting the same materials at different screen sizes may lead to a different preference on strategy use, affords different movements or make the pointing strategy easier or more difficult to perform. For instance, on a larger screen pointing can be done with more precision and thus a more direct link can be created between the text and the corresponding part of the picture. Although the results showed that different types of mouse use and screen sizes were distributed over all condition evenly, these aspects need to be controlled in future studies. Furthermore, the experimental control was based on participants' (retrospective) self-report rather than on objective data (e.g., estimate of computer screen size). Similarly, while the compliance check was based on the mouse movements that were made, we can only infer that there was high compliance with the pointing instructions as real-time operation of the mouse was not recorded. Future research should include a laboratory setting or a more well-controlled online study to draw further conclusions. Another limitation is that the present study did not compare the split-attention format to a spatially integrated format. We used a split-attention example that was used in previous research demonstrating that an integrated format yielded better learning than studying the split-attention format (Florax & Ploetzner, 2010), and thus we considered it unnecessary to replicate this effect in the present study. By comparing the split-attention format (with and without pointing) to an integrated format it becomes possible to investigate the relative effectiveness of pointing performed by the learner and presenting an integrated format that has been adjusted by an instructor, which so far has not yet been done (Zhang et al., 2021). This comparison would also help to get more insight into whether the effects of pointing are primarily due to attentional effects or embodied effects. Future research could examine this, perhaps together with process-related measures such as eye movements to investigate the mechanisms underlying the effectiveness of pointing as a self-management strategy.

CONCLUSION

The present study extends previous research on finger pointing as a self-management strategy and suggests that this simple and convenient strategy can be effectively used in online learning environments to support learning from split-attention examples. The present study also compared the use of finger pointing to mouse pointing and provided suggestive evidence that mouse pointing may not be as effective as finger pointing. These findings help advance our understanding of the possibilities and impossibilities of pointing as a self-management strategy, which also gives promising directions to explore in the future study.

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; data curation; methodology; supervision; writing – review and editing.

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CONFLICT OF INTEREST

All authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The materials and the data sets generated and/or analysed for the current study are available from the corresponding author upon request.

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