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Exploring the interrupting potential of spatial separation, temporal delay and unrelated content in educational hypertexts

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Abstract

Hyperlinks became indispensable in our digital age and are an inherent feature of many computer-based learning environments. On the positive side, they can foster deeper understanding, but on the negative side they might also impair the construction of coherent mental models. To explore this duality further, we investigated selected hyperlink features that might cause the interrupting potential. Using a 2 x 2 x 2 between-subjects design, we manipulated link loading times, spatial link format and fit between link and learning page contents in a learning task on metabolism and energy generation. We assessed learners' previous knowledge, working memory capacity, learning performance, and cognitive load. Our results indicate negative effects of unrelated content on intrinsic and extraneous cognitive load and a negative effect of spatial separation on intrinsic cognitive load. Explanations for the resulting effect pattern relate to resource investment and compensating influences. In sum, the investigated hyperlink features did not show the potential to crucially impair schema acquisition.

Keywords: Hyperlinks; Schema acquisition; Interruption; Cognitive load; Multimedia learning

1 Introduction

Hyperlinks are a centerpiece of the world wide web and act as electronic cross-reference to other documents or passages of text within the same document but also pictures, graphs, audio and video files. They became an inherent part of many online learning facilities to present connected information fast and easy. This allows learners to build broad knowledge networks that extend across different topics and disciplines. At the same time, learners might be distracted from their actual learning topic by following a hyperlink and, consequently, suffer in performance. In the beginning of hypertext research, evidence focused predominantly on positive effects of the non-linear presentation of learning material (e.g., Lawless & Brown, 1997). The emerging work emphasized benefits for learners' attitude, motivation, and learning performance. More recent findings do not back up these claims (DeStefano & LeFevre, 2007) but show that the complex structure of hyperlinks results in increased cognitive load and impairs the processing of learning contents (e.g., Eveland, Cortese, Park, & Dunwoody, 2004).

A first potential explanation why hyperlinks impair learning performance relates to irrelevant additional decisions that arise from each hyperlink (e.g., Scharinger, Kammer, & Gerjets, 2015). According to the Cognitive Load Theory (CLT; Sweller, Ayres, & Kalyuga, 2011), the need to decide for or against following a hyperlink induces extraneous cognitive load (ECL). This source of cognitive load arises from the instructional situation, i.e., how learning content is presented or constraints in the learning situation. It reduces the available cognitive capacity for processing relevant learning content. A second component of cognitive load is referred to as intrinsic cognitive load (ICL). It describes the complexity of the used learning material in relation to learners' previous knowledge. In addition, germane cognitive load (GCL), is associated with schema acquisition and automation processes. Their initially described additive connection is increasingly questioned by existing evidence (e.g., Wirzberger, Herms, Esmaeili Bijarsari, Eibl, & Rey, 2018; Kalyuga & Singh, 2016). Together with the assumption of limited working memory resources, an unlimited long-term memory, and the organization of knowledge representations via schemata, the trinity of cognitive load facets forms a central building block of the CLT framework (Sweller et al., 2011).

The facet of GCL raises a second potential explanation for negative hyperlink effects related to impaired schema acquisition (DeStefano & LeFevre, 2007). In general, a schema is an abstract mental structure that internally organizes knowledge. It can contain an unlimited amount of information and – once successfully acquired – reduces cognitive load (Sweller et al., 2011; Wirzberger et al., 2018). These structures are not static but constantly change by incorporating and integrating new information (Lawless & Brown, 1997). This involves both the processes of elaboration, assigning meaning to new information, and induction, transforming concrete experience to abstract structures. Generalization enables learners to transfer acquired knowledge to other tasks and situations (Wouters, Tabbers & Paas, 2007). As multimedia learning material often involves several sources of information, these need to be integrated to form coherent schemata. Without considering relevant design principles, the activation of hyperlinks is prone to interrupt this process and impair both local and global coherence (Thüring, Hannemann, & Haake, 1995). Related to research on desirable difficulties (Bjork & Bjork, 2011), hyperlinks might also serve as a potential source of GCL, facilitate the construction of more complex schemata and promote their adaptive automation (e.g., Spiro, Coulson, Feltovich & Anderson, 1988). In general, this line of research advocates the insertion of obstacles in learning material to foster more robust and transferable performance.

Building on these contrasting perspectives, we aim for experimentally investigating factors that accompany hyperlink activation and might cause an interruption in the schema acquisition process. In contrast to previous studies (e.g., Betrancourt & Bisseret, 1998; Maes et al., 2006; Salmerón et al., 2010), which were concerned with creative solutions, we investigated spatial, temporal, and content-related features that potentially cause a disruption of schema acquisition. To provide a valid assessment, we chose a concise experimental methodology, including the control for relevant individual differences between learners.

Subsequently, the paper first discusses core findings on the inspected interrupting features and control variables that informed our hypotheses. Afterward, we introduce the experimental methodology and characteristics of the learning task. Approaching the results, even if we observe negative effects on perceived cognitive load, our findings cannot confirm that the manipulated features crucially impair schema acquisition. We discuss potential explanations for the emerging pattern related to resource investment and task characteristics.

1.1 Spatial separation

Usually, the activating of a hyperlink will result in a transfer to a spatially separate website or a different location within the current document. Hence, hyperlinks initiate a spatial interruption and learners have to split their attention between two sources of information.

Comparable mechanisms are described by the split attention effect (Chandler, & Sweller, 1992), also known as spatial contiguity principle (Beege, Wirzberger, Nebel, Schneider, Schmidt, & Rey, 2019; Ginns, 2006; Mayer & Moreno 2003; Schroeder & Cenkci, 2018), which postulates a deeper understanding by presenting corresponding content next to each other. A spatially separate presentation of information increases the necessity to perform visual search during the learning process, as learners have to jump back and forth between presented contents to be able to draw conclusions. This results in increased ECL (Parush, Shwartz, Shtub, & Chandra, 2005), which in consequence decreases learning performance (Antonenko & Niederhauser, 2010; Maes, van Geel, & Cozijn, 2006). By contrast, studies that presented hyperlink content with a pop-up window instead of separate web pages indicated a higher learning performance with the same or even lower learning times (e.g., Bertrancourt & Bisseret, 1998). Thus, instead of eliminating the hyperlink structure, tools such as mouseover effects or pop-up windows can be used to facilitate the mental integration of the information into coherent schematic structures. Based on the outlined evidence, we assume that spatial interruption by hyperlink activation results in decreased learning performance (**H1a**) and increased cognitive load (**H1b**).

1.2 Temporal delay

When learning with hyperlinks, schema acquisition might also be interrupted in time. Clicking on a hyperlink usually causes a redirection to a new tab or a jump within the document that takes a few seconds. Depending on the duration of the resulting interruption, learners have to maintain the already recorded information in working memory, to be able to integrate it with the linked content. Limitations arise due to the restricted temporal capacity, which are addressed by the temporal contiguity effect (Ginns, 2006). As a result, the temporal separation of corresponding information in learning material restricts mental integration, which results in lower learning performance. A lack of temporal contiguity forces learners to increase resource investment to compensate for inappropriate information presentation. So far, broad evidence on effects of temporal interruptions in hypertext research are lacking. Based on research in the context of task interruptions (Altmann, Trafton, & Hambrick, 2014; Monk, Trafton, & Boehm-Davis, 2008) we assume that longer interruptions impair schema acquisition more, i.e., result in decreased learning performance (**H2a**) and increased cognitive load (**H2b**).

1.3 Unrelated content

In line with the coherence principle (Mayer & Fiorella, 2014), the information context is important to form coherent representations of the learning content. When reading hypertexts, learners can usually decide about the order and time of hyperlink attendance. With an increased level of navigation control, the risk of disorientation also increases (Charney, 1994). This potentially results in losing track of the relevance and context of the presented information (Salmerón, Gil, Bråten, & Strømsø, 2010). Since not all content included in hyperlinks is relevant to the actual learning topic, mechanisms inspected in terms of the seductive detail effect might apply here as well. Considering this background, learning impairments could be explainable by the activation of inadequate existing schemata and the interruption of text coherence (Harp & Mayer, 1998). Based on that, we assume that content-related interruption by hyperlink activation results in decreased learning performance (**H3a**) and increased cognitive load (**H3b**). A negative influence of spatial or temporal disruption might be reduced if a hyperlink activates unrelated content that does not have to be integrated and thus lacks the need to be remembered. Thus, we further postulate that the interaction of all interrupting hyperlink features alters effects on learning performance (**H4a**) and cognitive load (**H4b**).

2 Methods

2.1 Participants

We tested 114 students from different study courses at a mid-sized German university (M_{age} = 23.32 years, SD_{age} = 4.54, 69.4% female). They either were native German speakers or had been actively using the language for about 10 years. Participants received course credits according to their curricula (n = 40) or an alternative monetary reward of 6€ (n = 74) for compensation of participation. They were assigned randomly to one of the eight study conditions. Due to technical problems, several participants from one group had to be excluded and were replaced to ensure an equal cell population, which explains the greater number of participants in this condition.

2.2 Design

Our 2 x 2 x 2-factorial, multivariate between-subjects design included interrupting spatial, temporal and content-related factors as independent variables. We used retention and transfer performance and participants' cognitive load as dependent variables. Due to the well-established influence of individual cognitive abilities on learning performance (e.g., Wirzberger & Rey, 2018), we used prior knowledge and working memory capacity as control variables. By recording participants' navigation behavior, we could obtain information about learning times and the activation of hyperlinks. We also recorded frustration, perception of link loading time, length and difficulty of the task to control their possible influences.

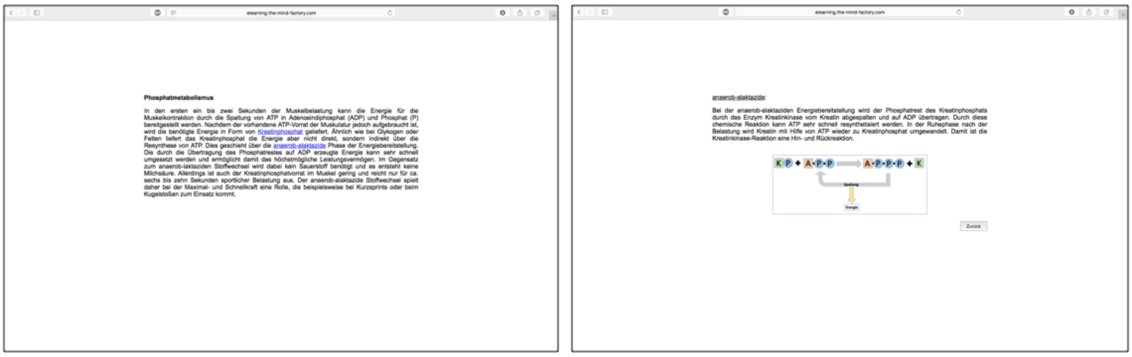

Figure 1. Link content displayed on separate page in condition with spatial separation.

Our learning environment manipulated spatial interruption (IV1) by either forwarding participants to a separate website, as indicated in *Figure 1*, or displaying a pop-up window after activating the hyperlink, as shown in *Figure 2*. To focus participants' attention on the hyperlink content, the main website content went dark in the latter condition.

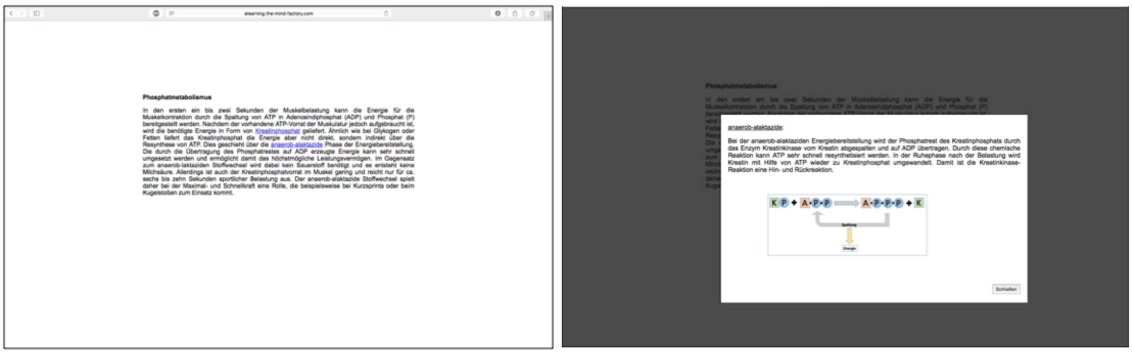

Figure 2. Link content displayed in pop-up window in condition without spatial separation.

A delay of either 1 s or 5 s after activating the hyperlink induced temporal interruption (IV2), which was visually accompanied by a loading animation (see *Figure 3*). We chose these durations in line with a short pretest to ensure a comparable and plausible appearance.

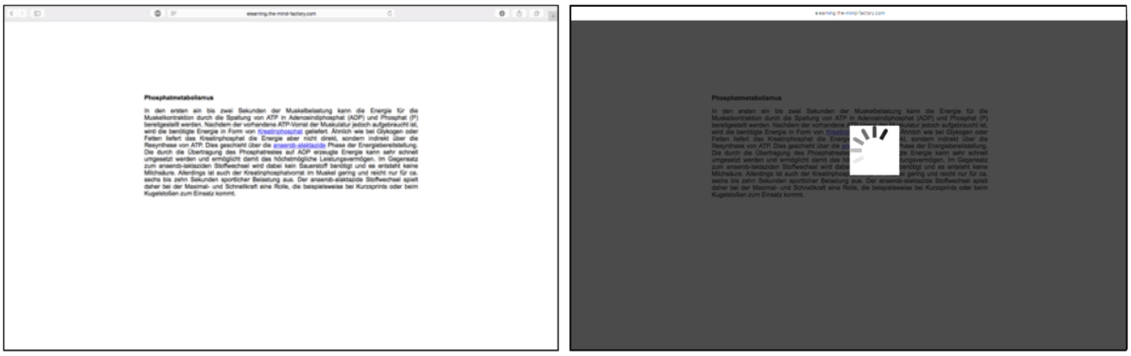

Figure 3. Loading animation after activation of hyperlink.

To induce content-related interruption (IV3), we used hyperlink content that was either related or unrelated to the learning content on the website before. To ensure comparability, all participants received the same additional information in hyperlinks, but at different positions in the learning material.

2.3 Materials and scoring

We presented our computer-based learning material on a standard desktop computer with a 24’’ monitor. The learning content dealt with metabolic processes and energy production in the human organism. Each introduced process formed an independent process chain but was linked to the overall process at the same time. The visual material comprised 1591 words and five figures in some of the hyperlinks to clarify the included content. A learning page consisted of about 160.5 words (*SD* = 42.1) with a font size of 16 px. Our learning material contained a total of ten hyperlinks, one to two hyperlinks on each page that were underlined and highlighted in blue. On average, the information presented in the hyperlinks contained 62.8 words (*SD* = 10.9). To enable close monitoring of participants’ navigation behavior, we separated the entire learning text on six individual pages. An underlying timer recorded the time spent on both learning and hyperlink content.

We measured retention performance by ten multiple-choice questions with four response options each, which referred to the correct representation of information presented in the learning content. For each correctly evaluated option participants received one point, thus in sum a maximum value of 40 points could be achieved. The scale attained a reliability score of α = .59. Transfer performance was addressed by ten questions that went beyond pure reproduction of the presented factual knowledge and partially included graphical elements.

They were either presented in multiple-choice format or as rank order tasks with drag-and-drop elements. The scoring of the multiple-choice questions aligned to the procedure applied for retention performance. In the rank order tasks, one point was awarded for each correctly placed element according to the partial credit scoring principle (Masters, 1988). One question had to be excluded due to technical problems, thus a total of 64 points could be achieved for transfer performance, with a scale reliability of $\alpha = .71$. Four multiple-choice questions with three answer options and the category "I do not know" were used to obtain participants' level of prior knowledge. In addition, participants had to rate their subjectively perceived level of prior knowledge on human metabolism and energy production on a 5-point Likert-scale. One point was awarded for each correctly evaluated answer option, resulting in a maximum score of 12 points. The entire scale achieved a Cronbach's alpha of .62.

Cognitive load was determined by a translated version of the questionnaire from Leppink, Paas, Van der Vleuten, Van Gog and Van Merriënboer (2013), which differs between ICL, ECL and GCL on 11-point Likert-scales. The corresponding items are summed up to achieve total scores with a maximum of 30 points for ICL and ECL and a maximum of 40 points for GCL. All scales have proven sufficient reliability with $\alpha = .81$ for ICL, $\alpha = .75$ for ECL and $\alpha = .82$ for GCL.

We derived participants' working memory span from a translated version of the Reading Span Task (RSPAN; Unsworth, Redick, Heitz, Broadway, & Engle, 2009). According to Rummel, Steinsdorf, Marevic and Danner (2017), the internal consistency was satisfactory and achieved a Cronbach's alpha of .85. The working memory span was calculated based on the partial credit scoring principle by awarding one point for each correctly noted letter at the correct position in each run (Redick et al., 2012) and summarizing all runs afterward.

To capture participants' frustration, we split the translated frustration item from the NASA Task Load Index (NASA-TLX; Hart & Staveland, 1988) into separate questions. The resulting individual questions had to be evaluated on an 11-point Likert-scale and achieved a Cronbach's alpha of above .80 (Xiao, Wang, Wang & Lan, 2005). By summing up the points achieved on all scales, a maximum of 55 points resulted, with higher values indicating a higher level of frustration.

2.4 Procedure

The study was conducted in a computer pool with up to nine participants per testing session. On average, a testing session lasted about 50 min. In the beginning, participants were welcomed, signed the consent form and performed the RSPAN task. After filling the questionnaires on demographic data and prior knowledge, the learning task was presented in a web-based learning environment. Participants went through the material in their own pace and were instructed to pay attention to the hyperlink content as well. Before measuring retention and transfer performance with a set of test questions, a questionnaire on perceived cognitive load and frustration was presented. Finally, participants were debriefed and received their compensation for participating in the study.

3 Results

Table 1

Descriptive statistics of retention performance, transfer performance, ICL, ECL and GCL across experimental conditions

Experimental condition				**Retention performance**		**Transfer performance**		**ICL**		**ECL**		**GCL**	
IV1	IV2	IV3	*N*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
+	-	-	13	24.62	5.44	25.31	9.07	22.85	6.31	10.54	8.08	22.31	9.53
+	-	+	12	22.83	2.44	23.58	6.57	28.33	1.97	17.50	8.84	16.08	11.76
+	+	-	11	26.18	4.19	31.18	8.06	22.64	2.84	12.18	5.51	21.73	8.91
+	+	+	12	26.00	4.79	27.42	8.36	25.17	4.97	13.75	6.30	15.67	7.95
-	-	-	15	25.00	4.96	28.87	8.61	20.07	8.41	7.87	7.47	19.73	10.06
-	-	+	10	27.60	6.00	29.90	10.80	22.80	7.07	14.70	7.85	18.20	11.26
-	+	-	12	28.00	3.80	30.00	5.22	20.42	7.96	11.42	6.33	21.00	9.71
-	+	+	13	24.85	4.70	28.31	6.12	23.15	5.77	13.92	7.98	19.62	11.41
Total			**98**	25.55	4.73	28.00	8.03	23.09	6.43	12.54	7.62	19.34	10.04

Notes. IV1: spatial separation ("+" separate page vs. "-" pop-up window), IV2: temporal delay ("+" 5 s vs. "-" 1 s), IV3: Fit of link content ("+" unrelated vs. "-" related); *N*: group size.

We performed analyses of covariance (ANCOVAs) with prior knowledge and working memory capacity as covariates to assess the individual and combined influence of the outlined interrupting spatial, temporal, and content-related hyperlink features on retention and transfer performance and facets of cognitive load. *Table 1* shows descriptive characteristics of all dependent variables across study conditions. As already mentioned, we had to exclude some participants due to technical problems in carrying out the experiment, an accuracy rate of less than 85% when working on the RSPAN (Unsworth et al., 2009) or severe violations of task instructions. Participants' level of prior knowledge about the used topic on metabolic processes and energy production was predominantly low, with an average of $M = 4.54$ ($SD = 3.22$) points over all experimental conditions. We computed Bayes factors to obtain additional support for the observed effects by contrasting a reduced model without the indicated effect, representing the null hypothesis, with a full model including all tested effects, representing the alternative hypothesis. The resulting values specify the likeliness of one hypothesis compared to the other (Dienes 2014) and indicate support for the null hypothesis for values below 1/3 and support for the alternative hypothesis for values above 3 (Jeffreys, 1961; Lee & Wagenmakers, 2014). Anecdotal support is provided by Bayes factors holding values in between.

3.1 Effects of spatial separation

No significant differences resulted in terms of retention performance between students with pop-up windows ($M = 26.20$, $SD = 4.94$ points) and students with separate websites ($M = 24.88$, $SD = 4.46$ points), $F(1, 88) = 1.01$, $p = .32$, $\eta_p^2 = .01$, $BF_{10} = 0.37$ (error ± 2.61%). For transfer performance, no significant main effect could be found either, $F(1, 88) = .90$, $p = .35$, $\eta_p^2 = .01$, $BF_{10} = 0.32$ (error ± 4.07%). Learners achieved an average of $M = 29.20$ ($SD = 7.64$) points in the conditions with pop-up windows and $M = 26.75$ ($SD = 8.31$) points in the conditions with spatially separated pages. Approaching the facets of cognitive load, a significant effect of spatial separation resulted for ICL, $F(1, 88) = 4.00$, $p = .05$, $\eta_p^2 = .04$, $BF_{10} = 1.55$ (error ± 2.73%). Learners perceived the ICL in conditions with separate pages ($M = 24.75$, $SD = 4.90$ points) as significantly higher compared to conditions with pop-up windows ($M = 21.50$, $SD = 7.33$ points). For ECL, participants receiving pop-up windows provided a mean score of $M = 11.66$ ($SD = 7.72$) points, whereas under the condition of spatially separated pages they scored an average at $M = 13.46$ ($SD = 7.50$) points. No significant differences between both groups emerged, $F(1, 88) = 0.27$, $p = .60$, $\eta_p^2 < .01$, $BF_{10} = 0.27$ (error ± 6.14%). On average, the perceived GCL in conditions with pop-up windows was rated with $M = 19.70$ ($SD = 10.30$) points, while in conditions with separate sides it scored at $M = 18.96$ ($SD = 9.85$), without a significant difference, $F(1, 88) = 0.02$, $p = .89$, $\eta_p^2 = .00$, $BF_{10} = 0.21$ (error ± 3.68%). According to these results, the spatial interruption caused by the activation of a hyperlink does not negatively affect either retention or transfer performance, which does not confirm hypothesis **H1a**. The same applies to ECL and GCL, as no significant differences caused by the spatial separation were found. However, spatial separation increased participants' ICL, thus hypothesis **H1b** receives at least partial support.

3.2 Effects of temporal delay

No significant differences in retention performance showed up between students with a temporal delay of 1 s ($M = 24.90$, $SD = 4.98$ points) and 5 s ($M = 26.23$, $SD = 4.41$ points), $F(1, 88) = 1.88$, $p = .17$, $\eta_p^2 = .02$, $BF_{10} = 0.55$ (error ± 2.63%). Learners in conditions with a temporal delay of 1 s achieved an average transfer performance of $M = 26.88$ ($SD = 8.88$) points, which was similar to conditions with a temporal delay of 5 s ($M = 29.17$ points, $SD = 6.95$). Again, we did not find a significant main effect, $F(1, 88) = 2.26$, $p = .14$, $\eta_p^2 = .03$, $BF_{10} = 0.62$ (error ± 3.35%). The mean value for ICL under conditions including a temporal delay of 1 s added up to $M = 23.32$ ($SD = 7.04$) points, and $M = 22.85$ ($SD = 5.01$) points for a temporal delay of 5 s. There were no significant differences between both conditions, $F(1, 88) = .33$, $p = .57$, $\eta_p^2 < .00$, $BF_{10} = 0.23$ (error ± 3.51%). In addition, temporal delay had no significant influence on ECL, $F(1, 88) = .01$, $p = .93$, $\eta_p^2 = .00$, $BF_{10} = 0.24$ (error ± 4.94%). Participants with a temporal delay of 1 s indicated a mean ECL of $M = 12.24$ ($SD = 8.60$) points, whereas participants with a temporal delay of 5 s averaged $M = 12.85$ ($SD = 6.52$) points. A similar pattern arose for GCL, as participants with a temporal delay of 1 s achieved $M = 19.22$ points ($SD = 10.52$), while with a temporal delay of 5 s a mean value of $M = 19.46$ points resulted ($SD = 9.62$). No significant effect was found, $F(1, 88) = .07$, $p = .80$, $\eta_p^2 = .00$, $BF_{10} = 0.22$ (error ± 3.07%). According to these results, participants learning performance does not decrease with increasing interruption duration, as postulated in hypothesis **H2a**. In addition, the negative influence on learners' cognitive load expected according to hypothesis **H2b** could not be confirmed either.

3.3 Effects of unrelated content

On average, participants achieved a retention performance of $M = 25.86$ points ($SD = 4.73$) in the conditions with related content, and a mean retention performance of $M = 25.21$ points

(*SD* = 4.76) in the conditions with unrelated content. The ANCOVA showed no significant difference between the conditions, $F(1, 88) = .10$, $p = .75$, $\eta_p^2 < .01$, $BF_{10} = 0.25$ (error ± 2.58%). A similar pattern of results showed up for transfer performance. In conditions with related content participants average score reached *M* = 28.73 points (*SD* = 8.02), while in conditions with unrelated content an average score of *M* = 27.21 points (*SD* = 8.06) resulted. Group mean differences did not reach significance $F(1, 88) = .41$, $p = .53$, $\eta_p^2 = .01$, $BF_{10} = 0.26$ (error ± 3.05%). However, the analysis revealed a significant effect of content fit on ICL, $F(1, 88) = 5.91$, $p = .02$, $\eta_p^2 = .06$, $BF_{10} = 3.65$ (error ± 3.98%). Participants with unrelated content reported higher ICL (*M* = 24.91, *SD* = 5.50 points) compared to participants with related content (*M* = 21.41, *SD* = 6.82 points). We found similar results related to ECL, as the ANCOVA pointed out a significant influence of the content-related interruption, $F(1, 88) = 7.55$, $p < .01$, $\eta_p^2 = .08$, $BF_{10} = 8.43$ (error ± 6.86%). Participants with unrelated content (*M* = 14.96, *SD* = 7.60 points) on average perceived higher ECL, compared to participants with related content (*M* = 10.31, *SD* = 7.00 points). In contrast, the difference in GCL between conditions with related (*M* = 21.12, *SD* = 9.37 points) and unrelated contents (*M* = 17.40, *SD* = 10.48 points) did not achieve significance, $F(1, 88) = 2.60$, $p = .11$, $\eta_p^2 = .03$, $BF_{10} = 0.68$ (error ± 4.07%). In terms of content-related interruption, the influence on learning performance postulated in hypothesis **H3a** could not be confirmed. By contrast, although content-related interruption does not have a significant influence for GCL, the significant increase of ICL and ECL indicates the partial confirmation of hypothesis **H3b**.

3.4 Interactions between interrupting features

Analyzing the interaction between spatial, temporal, and content-related interrupting features, a nonsignificant trend on retention performance resulted, $F(1, 88) = 3.91$, $p = .051$, $\eta_p^2 = .04$, $BF_{10} = 1.61$ (error ± 2.78%). As indicated by *Table 3*, particularly the combination of pop-up window, related content and extended temporal delay increases retention performance (*M* = 28.00, *SD* = 3.80 points). By contrast, lower retention rates occurred with spatially separated pages, shorter temporal delay and unrelated content (*M* = 22.83, *SD* = 2.44 points). *Figure 4* shows that retention performance increases with separate pages and increased temporal delay for both related and unrelated content. Moreover, while learners with unrelated link content in pop-up windows performed better under shorter temporal delay, the pattern reversed for related content. In this case, learners achieved increased retention performance with a temporal delay of 5 s. No significant interaction of the three factors was found with respect to transfer performance, $F(1, 88) = 0.03$, $p = .87$, $\eta_p^2 = .00$, $BF_{10} = 0.39$ (error ± 3.12%). Similarly, in terms of cognitive load, no significant effect resulted, neither for ICL, $F(1, 88) = 0.43$, $p =. 51$, $\eta_p^2 = .01$, $BF_{10} = 0.40$ (error ± 2.74%), ECL, $F(1, 88) = 0.06$, $p = .81$, $\eta_p^2 = .00$, $BF_{10} = 0.39$ (error ± 5.55%), nor GCL, $F(1, 88) = 0.02$, $p = .90$, $\eta_p^2 <.01$, $BF_{10} = 0.33$ (error ± 9.10%). Hence, hypothesis **H4a** did not receive support, as no significant effect was shown for retention and transfer performance. Similarly, no support for the interaction of spatial, temporal, and content-related factors in terms of cognitive load emerged, which contradicts hypothesis **H4b**.

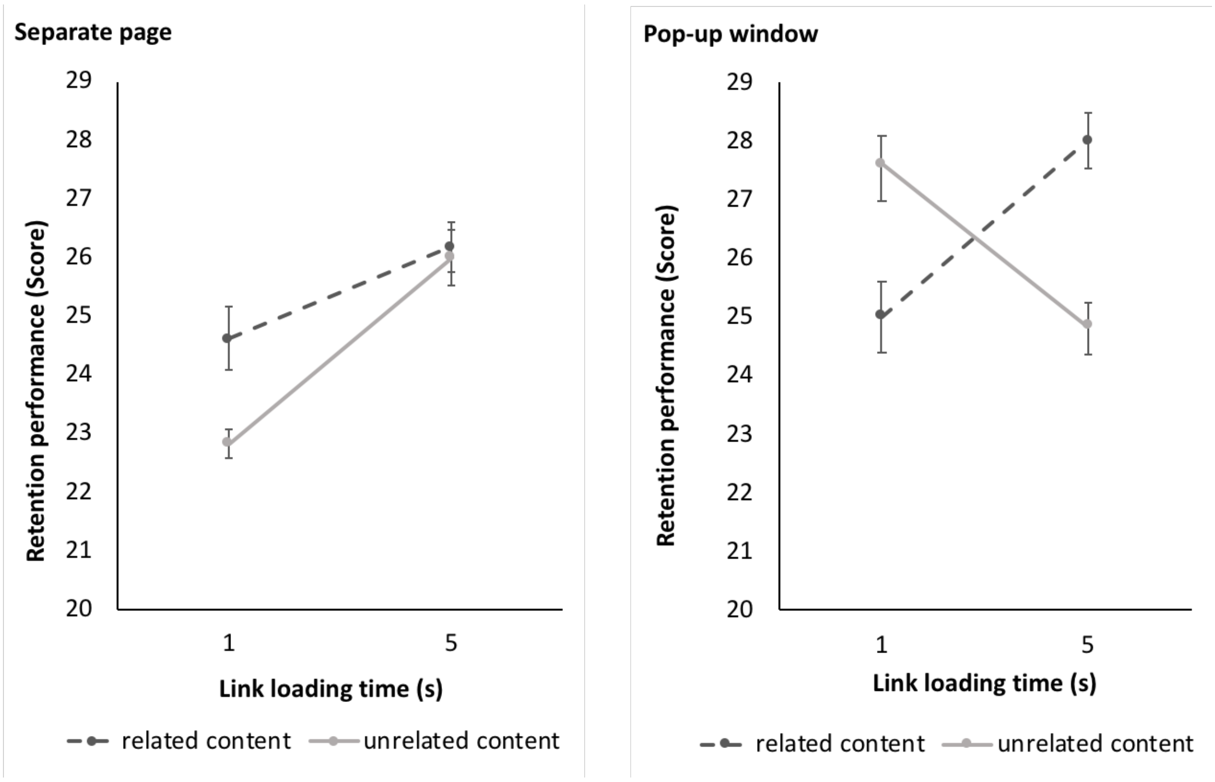

Figure 4. Interaction between spatial, temporal, and content-related interrupting factors of hyperlinks on retention performance. Error bars indicate standard errors. Lines were inserted to clarify interactions.

3.5 Additional analyses

On average, participants spent 63.84 s (SD = 21.85) on learning pages and 27.08 s (SD = 22.60) on link pages. Analyses showed a significant correlation between the time spent on learning pages ($r = .40$, $p <.001$) respectively the time spent on link pages ($r = .37$, $p <.001$) and participants' retention performance. Obviously, the more time participants spent in the learning environment, the more information they were able to memorize. Furthermore, participants' average frustration scores were rather high (M = 29.95 points, SD = 11.60). Analyses also revealed a significant correlation between prior knowledge and perceived frustration ($r = -.33$, $p < .001$), indicating that participants with increased prior knowledge were less frustrated. Perceived frustration also correlated significantly with retention performance ($r = -.36$, $p < .001$) and transfer performance ($r = -.45$, $p < .001$), indicating that decreased performance was associated with greater frustration. Participants further reported higher ICL ($r = .58$, $p < .001$) and ECL ($r = .55$, $p < .001$) with increased frustration, whereas a higher GCL was accompanied by lower frustration ($r = -.57$, $p < .001$).

4 Discussion

In the presented study, we investigated impairing influences of hyperlinks on learning performance and cognitive load. For this purpose, we experimentally manipulated spatial, temporal, and content-related factors that were supposed to interrupt schema acquisition, while controlling participants' prior knowledge and working memory capacity. The postulated impairment of schema acquisition by using hypertexts (e.g., DeStefano & LeFevre, 2007) could not be demonstrated with the investigated interrupting hyperlink features, at least in terms of participants' retention and transfer performance. These findings may be explained by the fact that learners were able to compensate for arising negative effects by investing a higher amount of cognitive resources. On this account, they were able to develop an overall understanding of the learning topic, despite an interrupted schema acquisition process. In addition, the generally high level of frustration could have masked existing effects. On a descriptive level, mean values of retention and transfer performance indicate that both the spatially and temporally interrupting features resulted in lower scores. Although this tendency does not reach significance, we can take it as a hint on the postulated underlying effect patterns.

In more detail, we expected that a spatially separated presentation of hyperlink-related information would have a negative effect on learning performance (**H1a**) and cognitive load (**H1b**) compared to a more integrated presentation in pop-up windows. However, this could not be confirmed in the experiment, as no significant deterioration of retention and transfer performance due to spatial interruption was observed. In addition, no significant differences in ECL and GCL resulted from spatial interruption but we found a significant influence of ICL.

According to our results, the presentation of hyperlink content on a separate page compared to an integrated version with pop-up windows seemed to increase the perceived complexity of the learning task. This supports both previous findings on the split attention effect and existing design recommendations from hypertext research (e.g., Antonenko & Niederhauser, 2010; Maes et al., 2006; Betrancourt & Bisseret, 1998). It can be traced back to higher cognitive demands resulting from the need to visually search and mentally integrate physically separated contents.

Furthermore, we postulated a significant effect of temporal interruption, which was operationalized by the duration of link loading times (1 vs. 5 sec). Increased interruption durations required to maintain previously presented information in working memory for a longer period, before it could be integrated with already existing cognitive schemata. Longer link loading times should therefore result in lower learning performance (**H2a**) and higher cognitive load (**H2b**). However, these assumptions could not be confirmed based on the observed statistical evidence, as we could not find significant differences between the experimental conditions in terms of learning performance and cognitive load. This may be attributed to the insufficient difference of four seconds between the experimental conditions. In the literature there are different assumptions about the time span after which the information stored in working memory is lost. Following Peterson and Peterson (1959), the effect of temporal interruption had only become apparent after 20 to 30 seconds, so we might have been able to observe an effect with longer link loading times. However, we avoided overly extended loading times to map realistic hypertext environment and ensure the transferability of the emerging results.

Our third hypothesis related to interruption of schema acquisition due to the presentation of unrelated content in hyperlinks. Topically unrelated compared to topically related link content was expected to negatively impact participants' learning performance (**H3a**) and cognitive load (**H3b**). In this case, we did not find significant effects on learning performance. However, a lack of fit between learning and hyperlink contents resulted in both higher perceptions of ICL and ECL, whereas no significant differences between experimental conditions emerged for GCL. We can explain these findings by learners losing overview of the relevance and context of the individual information due to reading the link content. If the linked information contains unrelated content, it might activate inadequate schemata and disrupt text coherence. This results in increased cognitive load when trying to reconstruct a coherent mental model and supports previous findings on the seductive detail effect and the coherence principle of CTML.

Approaching the interaction between spatial separation, temporal delay, and unrelated content, postulated in our fourth hypothesis (**H4a** and **H4b**), no significant interaction on retention and transfer performance and cognitive load could be observed, even though we observed a nonsignificant trend for retention performance. On this account, the fourth hypothesis could not be confirmed in this study. Inspecting the nonsignificant trend for retention performance in more detail, the pattern for the *spatially integrated version* with pop-up windows might suggest that learners had linked the hyperlink content (related or unrelated) with the information presented on the learning pages. Here, link loading times of five seconds required to keep the most recently presented information active in working memory for a longer duration. We assume that related content could be integrated into a common mental model more easily under these circumstances, while learners in conditions with unrelated link content may be cognitively overloaded and show lower retention performance. With a link loading time of only one second, the previously presented information needs to be maintained in working memory for a shorter duration. This would have allowed even learners with unrelated link content to integrate the presented information into a coherent mental model. Lower retention performance in groups with related link content and a loading time of one second may be attributed to less cognitive resource investment. Learners might have underestimated the difficulty of the task, which could be reflected in a more superficial processing of the content. For the *spatially separated version*, the longer link loading time of five seconds might have acted as an interruption lag and provided time for preparatory cognitive processes. Following the time-course model of interruptions and the resumption by Trafton, Altmann, Brock and Mintz (2003), learners could have rehearsed information related to the learning page during this time span. With only one second of link loading time, no such compensatory processes could be executed. According to the results, this led to lower retention rates of learners with both related and unrelated link content.

4.1 Implications

On the one hand, the immense flexibility to access and explore different navigation paths constitutes a main advantage of web-based learning environments. On the other hand, the additional requirement to make navigation decisions that potentially interrupt task-related cognition seems to impair the construction of coherent mental schemata. Many studies report design approaches to overcome this dilemma (e.g. Betrancourt & Bisseret, 1998; Maes et al., 2006; Salmerón et al., 2010). We extend this perspective with inspecting effects on underlying cognitive processes. According to our results, the design of hypertext learning environments should avoid spatial separation of information by presenting link contents on a new website. Instead, they could be displayed using a pop-up window or a mouseover effect at the corresponding position in the document (cf. Maes et al., 2006; Betrancourt & Bisseret, 1998). This enables learners to recognize connections and consequently leads to a reduction of cognitive load.

Furthermore, selecting hyperlink content increases the complexity of the task and results in unnecessary cognitive load if there are only minor content-related connections. Learning texts should therefore only contain hyperlinks that can be easily integrated into the overall schema of the website. A further possibility that has already proven to be conducive is to increase the salience of content-related connections (e.g., Cress & Knabel, 2003; Salmerón et al., 2010). This could be done by means of overview graphics or signaling.

In the context of the present study, the aspect that shorter interruptions did not necessarily lead to better performance seems particularly interesting. If the contents were presented on spatially separated websites, comparable to common hypertext environments such as Wikipedia, we even observed the opposite effect. This raises the question, if longer delays might have been used for engaging in monitoring strategies and improved mental organization of the presented content under less favorable presentation conditions. We need further empirical research to explore and verify this assumption.

In addition, prior knowledge had a significant effect on learners' retention and transfer performance and cognitive load. To foster optimal learning outcomes, the adaptation of the learning content to the respective level of knowledge is therefore advisable. In the context of web-based learning environments, this could be achieved by weakening the support measures, i.e., implementing guidance-fading procedures depending on the learner's expertise (e.g., Blayney, Kalyuga & Sweller, 2015, Exp. 2) or the element interactivity of the learning content.

Further analyses also found a connection between learning performance and cognitive load and learners' frustration, which should also be taken into account when designing digital learning environments. Since the overall frustration of learners due to the interaction with the learning content was relatively high in this study, the emotional impact of design measures should be given greater attention in future studies. Based on the relationship between learning time and retention performance, we also recommend providing learners with sufficient time to process the given content.

4.2 Limitations

A shortcoming of the current study is the lack of control of participants' navigation path. Although they were instructed to open the links in the order given in the learning text, recordings of their navigation behavior show that they did not always follow these instructions. As already mentioned, from a technical perspective participants could only reach the next learning text page after activating all links on a respective page. However, we could not control the frequency and sequence of activation within a website in advance, resulting in a number of people repeatedly clicking on hyperlinks.

In addition, some participants first read the entire learning page before opening the links, which resulted in a shift of the interruption to the end of the learning text. However, we inspected different navigation strategies in more detail but found no significant differences with regard to the dependent variables. Given that background, we could also argue that flexible navigation in hypertext environments corresponds to natural learning situations. Furthermore, these free exploration possibilities might act as source of GCL and thus promote the construction and automation of schemata (e.g., Lawless & Brown, 1997; Jacobson & Spiro, 1995; Barab et al., 1999).

4.3 Future Directions

Based on the above-mentioned limitations, future studies should examine the interruption of schema acquisition in digital learning settings with hyperlinks with different contents and target groups as well as significantly larger sample sizes in order to arrive at reliable and meaningful results.

An interesting possibility for future research in this area arises from the observed interaction effect of spatial separation, temporal delay and unrelated content. Research on task interruption and resumption already dealt with the manipulation of the length of interruption lags (e.g., Monk et al., 2008; Altmann et al., 2014; Morgan, Patrick & Tiley, 2013). Related to hyperlink environments, future research could inspect whether a longer temporal delay due to activating a hyperlink will be used for mental preparation for resuming the task later, as described in the time-course model of interruption and resumption by Trafton, Altmann, Brock and Mintz (2003). Altmann and Trafton (2004) also investigated if environmental cues can facilitate resumption processes. Future studies could examine to what extent their findings can be applied to hypertext environments.

According to the results, learners experienced quite high levels of frustration when interacting with our hypertext environment. On this account, the investigation of emotional and motivational effects of hypertext environments as well as their connection to learning performance seems important. Following Schneider, Nebel and Rey (2016), both positive emotions and activation of the learners could be increased by positively connotated, decorative images in a bimodal learning environment. Future studies should investigate to what extent the integration of such images in hypertext environments results in more positive emotions and, consequently, better learning outcomes.

5 Conclusion

Hyperlinks became an indispensable part of communication and information acquisition in modern societies. Thus, the study of adequate and fostering design principles as well as underlying cognitive processes should play a central role in digital teaching and learning. In hypertext research, comparisons of traditional learning material with web-based learning environments are widely distributed. However, these comparisons are not suited to answer in-depth questions on the facilitative use of educational hypertexts. This is also illustrated by the findings of numerous studies that have shown that under certain conditions hypertext have the potential to promote a profound and flexible understanding. With the current study, we took a step further in the direction of exploring potentially facilitative or harmful features of hyperlinks in digital learning environments. Our results do not support generally negative effects on performance but suggest increased cognitive resource demands. They might pave the way for future research on the inspected features in different learning domains.

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