

Does Spatial Verbal Information Interfere with Picture Processing in Working Memory? The Role of the Visuo-spatial Sketchpad in Multimedia Learning

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Abstract

The reported study examined whether the processing of spatial verbal information interferes in the visuo-spatial sketchpad with the execution of eye movements, associated with viewing pictures and reading. Seventy-four students were randomly assigned to six groups, resulting from a 2×2 mixed design, with spatial secondary task (with vs. without), text contents (visual vs. spatial), and text modality (spoken vs. written) as independent variables. Consistent with our assumptions, learners with text containing spatial contents showed worse recall performance than those with text containing visual contents. Furthermore, written presentation of text containing spatial contents loaded the visuo-spatial sketchpad to a higher extent than spoken presentation. Implications of these results for learning with multimedia are discussed.

Keywords: multimedia; working memory; modality effect; spatial verbal information; secondary task

Introduction

In the last two decades, a lot of research has been conducted on how people learn from multimedia, that is, from the presentation of texts together with pictures (Mayer, 2009).

The Cognitive Theory of Multimedia Learning (CTML; Mayer, 2009) is one of the most important theories concerning multimedia learning. One of its theoretical foundations is an older version of Baddeley's working memory model (1992). According to this model, working memory consists of three systems: The phonological loop (PL), where all verbal information is processed, the visuo-spatial sketchpad (VSSP), where visual and spatial information is processed, and the central executive, which governs the functioning of the phonological loop and the VSSP. Accordingly, the CTML assumes that texts are processed in the phonological loop, whereas pictures are processed in the VSSP. The working memory systems are limited in the amount of information that can be processed in parallel. Accordingly, processes accomplished within the same system can interfere with each other and hinder learning. Therefore, text-picture presentations should be designed in a way that a learner can make optimal use of the

cognitive resources so that an overload in one or both systems can be avoided.

However, since Baddeley's first comprehensive descriptions of his model there have been numerous new findings concerning the functioning of working memory that have been considered in newer versions of the Baddeley model, but have not yet been incorporated into the CTML. In particular, the structure of the VSSP has been further specified. According to our view, these specifications may play an important role in multimedia learning. Thus, the aim of this paper is to have a closer look at the VSSP and its implications for learning with multimedia.

A Closer Look at the Visuo-spatial Sketchpad

According to Logie (1995), the VSSP can be divided into a visual and a spatial part. Whereas the visual part deals with information like an object's color or form, the spatial part handles information like spatial sequences or spatial configurations (e.g., Darling, Della Sala, & Logie, 2007; Della Sala et al., 1999). Whereas Logie and colleagues focused on pictorial stimuli, other researchers have addressed the question whether the VSSP may also be involved in the processing of text. This research suggests that if text contains information about spatial and/or visual configurations, it will not be processed only in the PL but also in the respective part of the VSSP, whereas if it contains more abstract information, it will be processed in the PL alone (De Beni et al., 2005; Deyzac, Logie, & Denis, 2006). Another line of research on the spatial VSSP has also shown that this structure is not responsible only for the processing of spatial information but also for the control of movements, for example arm or eye movements (e.g., Postle et al., 2006).

Although from a theoretical perspective the VSSP should play a crucial role in multimedia learning, its involvement has not often been considered empirically in multimedia learning. One method to measure the involvement of the spatial VSSP in task performance is the secondary task paradigm. In this paradigm, two tasks are combined, a primary and a secondary task. The primary task is the main

task, for example a multimedia learning task, whereas the secondary task is a task that loads one of the working memory systems. If both tasks rely on the same working memory systems, they will compete for its limited resources. As a consequence, primary task and/or secondary task performance will decrease compared to a control condition in which participants perform the two tasks separately. A secondary task that is assumed to load the spatial VSSP is the spatial tapping task. In this task, participants have to press buttons in a predefined order on a keyboard, which is hidden from view (e.g., Della Sala et al., 1999). Because the spatial VSSP controls the execution of movements, the continuous tapping interferes with the processing of spatial information (Farmer, Berman, & Fletcher, 1986).

Another way of assessing the involvement of the VSSP focuses on determining the learner's capacity of the spatial and visual VSSP and relating them to learning outcomes. Two tasks have been used to measure the capacities of the spatial and the visual VSSP, respectively, the Corsi block task (Milner, 1971) and the Visual Pattern Test (VPT; Della Sala et al., 1997), respectively. In the Corsi block task, the instructor taps fixed spatial sequences of cubes on a wooden board, which the participant has to recall afterwards. In the VPT, the participant has to recall abstract visual patterns. These patterns are presented in two-dimensional matrices in which a random selection of half of the cells is colored black.

Implications for Multimedia Learning

Figure 1 shows which parts of the VSSP are needed to represent different combinations of pictures and text contents, different amounts of eye movements, and a spatial secondary task. Whereas pictures are assumed to be processed in the visual and spatial VSSP because they contain visual as well as spatial information, texts load the visual or spatial VSSP as a function of their contents. Text containing no visuo-spatial information loads neither the visual nor the spatial VSSP, whereas text containing visual contents loads the visual VSSP (Figure 1, upper row), and text containing spatial contents loads the spatial VSSP (Figure 1, bottom row). Furthermore, as the spatial VSSP controls the execution of eye movements, viewing pictures and reading written text will result in an additional load of the spatial part (Figure 1, b, d, f, h). Moreover, the load of the spatial VSSP can be increased by implementing a spatial secondary task (Figure 1, right column).

In the current paper we focus on three implications that result from this analysis and that will be outlined in the following.

First implication: A Spatial Secondary Task Interferes with Picture Processing, Text Containing Spatial Contents, and Eye Movements. The first implication of the preceding analysis refers to the effects of a spatial secondary task on learning. It is presupposed that the spatial secondary task loads the spatial VSSP but not the visual VSSP (Figure

1, compare left vs. right column). Therefore, the spatial secondary task should interfere with the processing of the picture, the processing of text containing spatial contents, and the execution of eye movements associated with reading. On the other hand, it should not interfere with the processing of texts containing visual contents, and it should interfere less with spoken than with written text, because no eye movements are required to listen to text.

Second Implication: Text Containing Spatial Contents interferes with Picture Processing. When presenting pictures together with text containing spatial contents, one would expect interference in the spatial VSSP, because the processing of the spatial picture and spatial text contents as well as the control of eye movements both take place here (see Figure 1, bottom row). When presenting pictures together with text containing visual contents, one would expect less interference because the load is distributed more equally (see Figure 1, upper row). Accordingly, pictures presented together with text containing spatial contents should result in worse learning outcomes than pictures presented together with text containing non-spatial contents. A study conducted by Schmidt-Weigand and Scheiter (2008) confirms this assumption by showing that pictures are helpful for learning only, when they accompany text with a low degree of spatial information compared to text with a high degree of spatial information.

Third Implication: Written Text Containing Spatial Contents Interferes more with Picture Processing than Spoken Text Containing Spatial Contents. A third implication of the preceding analysis refers to the modality of the text: Because eye movements are not needed only for picture inspection, but also for reading, one might expect worse performance with written text than with spoken text when processing text containing spatial contents. Figure 1 (bottom row) shows that the spatial part is less loaded with spoken text containing spatial contents than with written text containing spatial contents, because more eye movements are required to read the text and to switch between text and picture. This load difference might result in worse learning outcomes for written text containing spatial contents than for spoken text containing spatial contents. For text containing non-spatial contents the difference between written text and spoken text is not expected to be equally harmful, because the text contents are not processed in the spatial VSSP and therefore no interference with the control of eye movements is expected. Note that a general superiority of spoken over written text presentations has been acknowledged for a long time already in multimedia research (i.e., modality effect, Moreno & Mayer, 1998); however, its explanation is different from the one presented here and in particular does not depend on the text content. Hence, we will not address this effect here any further.

		Without Secondary Task		With Secondary Task	
		Spoken Text	Written Text	Spoken Text	Written Text
Text Containing Visual Contents	a)	VSSP visual spatial Visual Text Content Spatial Text Content Visual Pictorial Information Spatial Pictorial Information Eye movements Spatial SecTask		VSSP visual spatial Visual Text Content Spatial Text Content Visual Pictorial Information Spatial Pictorial Information Eye movements Spatial SecTask	
	b)	VSSP visual spatial Visual Text Content Spatial Text Content Visual Pictorial Information Spatial Pictorial Information Eye movements Spatial SecTask		VSSP visual spatial Visual Text Content Spatial Text Content Visual Pictorial Information Spatial Pictorial Information Eye movements Spatial SecTask	
Text Containing Spatial Contents	e)	VSSP visual spatial Visual Text Content Spatial Text Content Visual Pictorial Information Spatial Pictorial Information Eye movements Spatial SecTask		VSSP visual spatial Visual Text Content Spatial Text Content Visual Pictorial Information Spatial Pictorial Information Eye movements Spatial SecTask	
	f)	VSSP visual spatial Visual Text Content Spatial Text Content Visual Pictorial Information Spatial Pictorial Information Eye movements Spatial SecTask		VSSP visual spatial Visual Text Content Spatial Text Content Visual Pictorial Information Spatial Pictorial Information Eye movements Spatial SecTask	
	g)	VSSP visual spatial Visual Text Content Spatial Text Content Visual Pictorial Information Spatial Pictorial Information Eye movements Spatial SecTask		VSSP visual spatial Visual Text Content Spatial Text Content Visual Pictorial Information Spatial Pictorial Information Eye movements Spatial SecTask	
	h)	VSSP visual spatial Visual Text Content Spatial Text Content Visual Pictorial Information Spatial Pictorial Information Eye movements Spatial SecTask		VSSP visual spatial Visual Text Content Spatial Text Content Visual Pictorial Information Spatial Pictorial Information Eye movements Spatial SecTask	

Figure 1. The load (grey color) of the VSSP as a function of the processing of pictures, the processing of different text contents, the processing of a spatial secondary task (Spatial SecTask), and the control of eye movements.

There is some evidence for the prediction that the text contents may moderate the modality effect. Kürschner, Schnotz, and Eid (2007) showed modality effects only with spatial information but not with non-spatial information. One purely text-based study (Glass et al., 1985) explicitly examined the influence of text modality on the processing of text containing visual versus spatial contents. Whereas with regard to sentences about spatial relations a modality effect occurred, this was not the case with regard to sentences about visual characteristics like color.

Experiment

The aim of the current study was to investigate whether processing texts containing spatial contents would interfere with picture processing and whether reading written text containing spatial contents would interfere more with picture processing than listening to the same text. Furthermore, it was investigated whether a spatial secondary task would interfere with the processing of pictures, text containing spatial contents, and eye movements.

Method

Participants and Design. Seventy-four students of the University of Tuebingen (62 female, average age: $M = 21.89$ years, $SD = 3.08$ years, 6 left-handed) participated in the study. They were randomly assigned to one of four conditions, which resulted from a $2 \times 2 \times 2$ mixed design, with spatial secondary task (with vs. without) and text contents (visual vs. spatial contents) as between-subject factors and text modality (spoken vs. written text) as within-

subject factor. Due to the mixed design, between 18 and 19 students were assigned to one cell (see Table 1).

Materials. The materials were presented in a computerized learning environment. The system-paced learning phase consisted of six static pictures of fictitious fish accompanied by six corresponding texts. Each fish was presented on a single slide. The pictures were identical in all groups, whereas the texts differed with regard to contents and modality as a function of the experimental condition. The lengths and the Flesch reading ease scores (Flesch, 1948) of the two text versions were equivalent indicating that there were no differences in text difficulty across the two versions. The pace of presentation was determined by the duration of the spoken text conditions.

The independent variables were varied between groups in the learning phase as follows: Learners with secondary task had to press different buttons in a predefined order on a keyboard hidden from view during learning. Learners without secondary task learned without performing a secondary task. Learners with text containing visual contents received information about visual features of the depicted fish species, that is, the color or form of specific body parts (e.g., “The pectoral fin has the same light brown color as the dorsal fins”). Learners with text containing spatial contents received information about spatial features of the fish species, that is, the location of a body part or its spatial relation to other parts (e.g., “The pectoral fin lies between the two dorsal fins”). Text modality was varied within the learning environment. Three of the six fish were accompanied by spoken text, the other three fish by written

text (partially balanced design). In the conditions with spoken text, learners listened to the text while the picture was presented on the screen. In the conditions with written text, the text was presented below the picture (see Figure 2).

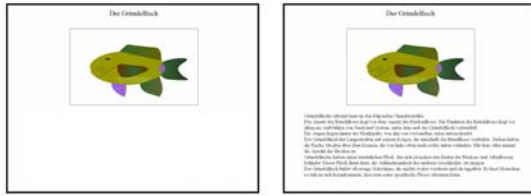


Figure 2: Presentation of the learning materials with spoken (left) and written (right) texts.

Measures. The test phase consisted of four open recall questions, which measured text or picture recall. To measure text recall, learners had to write down everything they remembered from the texts regarding two of the presented fish. To measure picture recall, learners had to draw two of the fish (only information not mentioned in the text was analyzed). Two independent raters blind for experimental condition scored the open recall questions afterwards with an interrater reliability of Cohen's kappa = .79 for text recall and Cohen's kappa = .73 for picture recall. With regard to picture recall, we distinguished between the recall of visual versus spatial picture information. Additionally, the VPT (Della Sala, et al., 1997) to measure the capacity of the visual VSSP and the Corsi Block test (Milner, 1971) to measure the capacity of the spatial VSSP were administered.

Procedure. Participants were tested individually. First, participants were given a short written instruction about the experiment (i.e., about the learning domain as well as the procedure of the experiment). Second, participants in the secondary task conditions were introduced to the task and practiced it for two minutes. Third, all participants entered the system paced learning phase that was subject to experimental manipulation. Fourth, they responded to the open recall questions. Finally, they performed the VPT and Corsi block test. A single experimental session lasted about 60 minutes.

Results

Because it could not be excluded that gender or handedness

interacted with the processing of spatial information, we conducted prior analyses in a first step. For gender, no significant interactions were observed, indicating that gender did not influence learning outcomes. Regarding handedness, the corresponding analyses were not possible because of an insufficient number of left-handed participants. However, due to the small number of left-handed participants we did not expect an influence on learning outcomes.

Because of the results of the prior analyses, we collapsed across gender and handedness for the following analyses. For text recall, an ANOVA was conducted. For spatial and visual picture recall, the corresponding variables were analyzed by means of a MANOVA. In all analyses, secondary task and text contents were incorporated as between-subject factors and text modality was incorporated as within-subject factor. To control for individual differences in the capacity of the visual and spatial VSSP, the Corsi block scores and VPT scores were incorporated as covariates. Note that there were no interactions between the two capacity measures and any of the experimental factors. In the following, the statistical details are only reported for significant results, because of space limitations. Adjusted marginal means and standard errors corrected for the influence of the visual and spatial VSSP capacity are reported in Table 1.

With regard to *text recall*, the results showed an effect of the VPT, $F(1, 68) = 4.11, p = .047, \eta^2_p = .06$: The higher the capacity of the visual VSSP was, the better learners recalled the text information ($r = .21, p = .08$). Furthermore, in line with the second implication, learners with text containing visual contents ($M = 32.82\%$, $SE = 3.37$) outperformed learners with text containing spatial contents ($M = 18.95\%$, $SE = 3.36$), $F(1, 68) = 8.29, p = .01, \eta^2_p = .11$. This indicates that text containing spatial contents and picture processing interfere in the spatial VSSP, resulting in worse learning outcome for the recall of spatial text information compared to visual text information.

With regard to *picture recall*, the MANCOVA showed a significant difference between learners with texts containing visual and spatial contents, $V = .46, F(3, 67) = 28.20, p < .001$, and an influence of the secondary task on learning outcomes, $V = .09, F(3, 67) = 3.21, p = .046$. Also the three-way interaction text modality $\times$ text content $\times$ secondary task was significant, $V = .09, F(3, 67) = 3.26, p = .045$.

Table 1: Adjusted marginal means and standard errors as a function of the experimental condition.

	text containing visual contents				text containing spatial content			
	without secondary task		with secondary task		without secondary task		with secondary task	
	spoken $n = 18$	written $n = 18$	spoken $n = 19$	written $n = 19$	spoken $n = 18$	written $n = 18$	spoken $n = 19$	written $n = 19$
Recall of text information (%)	35.91 (7.08)	35.30 (6.50)	30.32 (6.69)	29.79 (6.14)	20.48 (6.85)	20.12 (6.30)	15.82 (6.87)	19.37 (6.31)
Recall of visual picture information (%)	57.52 (4.79)	49.97 (4.37)	52.09 (4.52)	46.83 (4.13)	32.90 (4.63)	33.24 (4.23)	36.61 (4.64)	27.90 (4.24)
Recall of spatial picture information (%)	53.32 (5.43)	44.59 (5.87)	38.80 (5.13)	42.63 (5.54)	42.45 (5.26)	58.04 (5.68)	44.81 (5.27)	34.58 (5.69)

Follow-up three-way ANCOVAs confirmed the expected main effect of text content with regard to the recall of visual picture information: Learners with text containing visual contents ($M = 51.60\%$, $SE = 2.06$) recalled the visual aspects of the pictures (like color or form) better than learners with text containing spatial contents ($M = 32.67\%$, $SE = 2.06$), $F(1, 68) = 41.16$, $p < .01$, $\eta_p^2 = .38$). This confirms the second implication that text containing spatial contents interferes with picture processing, whereas text containing visual contents does not. With regard to the recall of spatial picture information the effect of the secondary task, $F(1, 68) = 6.24$, $p = .02$, $\eta_p^2 = .08$, as well as the three-way interaction, $F(1, 68) = 5.76$, $p = .02$, $\eta_p^2 = .08$, were confirmed: In line with the first implication, learners, who performed a spatial secondary task during learning, recalled the spatial picture information ($M = 40.21\%$, $SE = 2.58$) worse than learners who did not perform a secondary task ($M = 49.60\%$, $SE = 2.65$). This indicates that the spatial picture contents are processed in the spatial VSSP. However, the Bonferroni tests of the three-way interaction text modality $\times$ text content $\times$ secondary task, showed that this main effect of the spatial secondary task on spatial picture recall was due to interference between the spatial secondary task and the processing of written text containing spatial contents ($p = .01$, see Figure 3). This result supports the third assumption, because it indicates a higher load of the spatial VSSP with written than with spoken text presentation, when spatial text contents are presented.

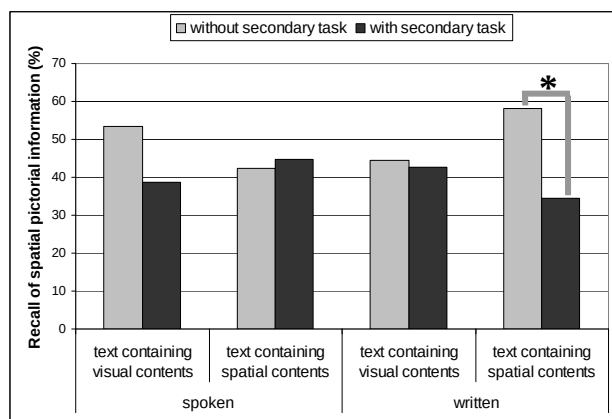


Figure 3: The pattern of results for spatial picture recall (adjusted means). $*p < .05$

Summary and Discussion

One purpose of the reported study was to examine whether pictures, text containing spatial contents as well as eye movements load the spatial VSSP. Furthermore, the hypotheses were tested that text containing spatial contents would interfere with picture processing and that this interference would be affected by the modality of the presented text.

The first assumption concerning interference between the spatial secondary task and the processing of pictures, text containing spatial contents as well as the execution of eye movements was only partially confirmed. Performance decrements while conducting a spatial secondary task were observed with regard to the recall of spatial picture information, especially for learners with written text containing spatial contents (see Figure 3). As mentioned before, the load of the VSSP is assumed to be extremely high in this specific case (see Figure 1, h). This may explain why the secondary task interfered particularly with the recall of spatial picture information accompanied by written text containing spatial contents. Contrary to our assumptions, the secondary task did not hinder the recall of spatial verbal information or the recall of written text in general. These findings imply that the processing of text containing spatial contents and the control of eye movements in general did not load the spatial VSSP to such a high degree that interference with a secondary task was observed.

The second assumption concerning worse learning outcomes with pictures accompanied by text containing spatial contents as compared to text containing visual contents was confirmed: Learners, who received pictures together with text containing spatial contents, showed overall worse performance in recalling text-based and visual picture-based information. Furthermore, learners with text containing visual contents recalled spatial picture-based information to the same extent as did learners with text containing spatial contents. Thus, text containing spatial contents did not support the recall of spatial picture information: These results indicate that learners with text containing visual contents processed the picture more thoroughly than learners with text containing spatial contents. How can these results be explained? In the theoretical part of the paper we assumed that text containing spatial contents leads to an additional load of the spatial VSSP, resulting in worse learning outcomes for text and picture recall. However, in total, the secondary task did not reduce the performance of learners with text containing spatial contents, which may indicate that spatial text contents do not increase the load of the spatial VSSP. Instead, as mentioned above, the secondary task interfered with the processing of spatial picture information only when the load of the spatial VSSP was assumed to be extremely high (see Figure 3). Thus, it cannot be definitely concluded that the observed performance decrement with text containing spatial contents is due to a higher load of the spatial VSSP. Rather, it is also possible that a spatial secondary task does not reduce performance when the spatial VSSP gets simply loaded but only if it gets overloaded.

An alternative explanation for the found performance decrement with text containing spatial contents might be the text difficulty. With regard to recall of text contents, one might argue that text containing visual information, that is, information about color and form, is easier to

recall than text containing spatial information, that is, information about spatial relationships or the position of a certain characteristic. Thus, the fact that learners with text containing visual contents performed better, when they had to recall text-based information might potentially be simply explained by differences in text difficulty and not by interference in the spatial VSSP. On the other hand, the Flesch scores indicated the same reading ease for both texts. Furthermore, one may ask why text difficulty should influence the processing of the pictures, which were the same in all groups. One might argue that because text containing spatial contents is more difficult to process, learners might concentrate more on the text and neglect the picture. This in turn might result in worse recall performance for pictures. However, a further study where we used eye tracking methodology to assess the amount of attention devoted to text and pictures showed no differences between learners with different text contents with regard to their viewing behavior. Thus, it seems as if text difficulty is not responsible for the results.

The third assumption concerning a modality effect that would occur only with text containing spatial contents was confirmed for the recall of spatial picture information, when learners additionally performed a secondary task. Thus, under extreme load conditions the eye movements necessary to read the text interfered with picture processing. This implies that written text can decrease performance when the load of the spatial VSSP is already high.

To conclude, these results show that the presentation of text containing spatial contents together with pictures might be detrimental to learning under certain circumstances such as restricted learning time or system-paced presentations. Under these conditions it might be better to convey spatial information only through visualizations, because visualizations are more efficient than texts for accomplishing tasks that require the processing of visuo-spatial properties (Larkin & Simon, 1987). If it is not possible to convey the spatial information only via picture, we recommend presenting spoken texts, because otherwise the eye movements associated with reading may decrease performance when the load of the spatial VSSP is high.

To get deeper insights into the interplay of working memory and multimedia learning, further research is needed that addresses more fine-grained processing aspects (e.g., measuring the amount of eye movements and relate it to spatial text processing). This is in line with our conviction that more cognitive basic research is needed to develop more precise theoretical frameworks for explaining how multimedia learning works.

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