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RESEARCH ARTICLE

Role of dual task design when measuring cognitive load during multimedia learning

Cornelia Schoor · Maria Bannert · Roland Brünken

Abstract This study assessed the role different kinds of secondary tasks play for researching the modality effect of cognitive load theory. Ninety-six university students worked with a computer-based training program for approximately 13 min and had to fulfill an additional secondary task. In a 2 × 2 factorial design, modality of information presentation (within factor) and design of secondary task (between factor) were varied. Students of both experimental groups learned with visual-only and audiovisual information presentation. The secondary task consisted of monitoring an object either displayed spatially contiguous (monitoring the screen background color, $N = 46$) or spatially non-contiguous (monitoring a letter color in the upper part of the screen, $N = 50$). Reaction times on this secondary task were used to measure cognitive load. Results show that the modality effect only appears with the spatially non-contiguous task but not with the spatially contiguous task. We interpret this effect as due to only partial utilization of working memory capacity by the combination of primary task and spatially contiguous secondary task. The results highlight the importance of an appropriate secondary task design when investigating the modality effect but also not to overgeneralize multimedia design guidelines.

Keywords Multimedia learning · Cognitive load · Dual task methodology · Modality effect

Much research (e.g. Ayres and Paas 2009; Ayres and Van Gog 2009; Verhoeven et al. 2009) has investigated cognitive load during multimedia learning under the perspective of

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C. Schoor
Psychology of Learning and Instruction, TU Dresden, 01062 Dresden, Germany

M. Bannert (✉)
Educational Media, University of Wuerzburg, Campus Hubland Nord,
Oswald-Kuelpe-Weg 82 97074 Wuerzburg, Germany
e-mail: maria.bannert@uni-wuerzburg.de

R. Brünken
Department of Education, Saarland University, Campus A4.2, 66123 Saarbrücken, Germany

cognitive load theory (Chandler and Sweller 1991; Sweller 1988) or multimedia learning theory (Mayer 2001). Both theories postulate that due to limited working memory capacity, it is important to design learning material carefully in order to avoid a too high cognitive load. They both assume an unlimited long-term memory but capacity and duration limited working memory. Everything to be learned has to pass this bottleneck in working memory. If the cognitive load evoked by the learning material exceeds working memory capacity, learning will be reduced. Therefore, a goal of instructional design should be to reduce cognitive load in order to free resources for learning processes (c.f. Bannert 2002). A bunch of multimedia design guidelines (c.f. Mayer 2005) has been developed to support multimedia designers in meeting this goal, like the multimedia principle (c.f. Fletcher and Tobias 2005), the redundancy principle (Sweller 2005) or the modality principle (c.f. Low and Sweller 2005).

According to cognitive load theory (Chandler and Sweller 1991; Sweller 1988) and multimedia learning theory (Mayer 2001), reducing cognitive load can be achieved by considering features of cognitive architecture: Assumptions underlying both cognitive load theory and multimedia learning theory distinguish between two subsystems of working memory: one for visuo-spatial information and one for phonological information (c.f. Baddeley and Hitch 1974) which are mainly independent. Consequently, the modality of learning material may influence the cognitive load experienced during learning, for example by requiring only one or several modalities. The modality effect (e.g. Low and Sweller 2005) refers to the empirical finding that for material with interrelated text and pictures, presenting text orally leads to less cognitive load and therefore to better learning outcomes than presenting text visually. For this finding, there are two (not mutually exclusive) explanations (Rummer et al. 2010): According to the *modality assumption*, by presenting text visually the visuo-spatial working memory was used only, while in the audiovisual case both visuo-spatial and phonological working memory capacities were used (c.f. Ginns 2005; Moreno and Mayer 1999; Tabbers et al. 2004). However, this widely used interpretation is not in line with Baddeley's working memory model, which states that verbal information is processed in the phonological working memory subsystem independent from its presentation modality (c.f. Baddeley 2001).

The *split attention assumption* views the modality effect as an example of the split attention effect (c.f. Chandler and Sweller 1992). It assumes that having to search for and integrate spatially or temporally distributed material leads to worse performance than when the material is presented in a non-distributed way (e.g. Mayer 2001). Concerning the modality effect, the auditory presentation of text makes it possible to simultaneously process the picture, while for visual text presentation, text and picture constitute distributed material leading to split attention (c.f. Rummer et al. 2008). Concerning the modality effect in sequentially presented material (Moreno and Mayer 1999), Rummer et al. (2010) showed that this is also in line with the split attention assumption so that there seems to be no need for assuming further mechanisms as, for example, proposed by the modality assumption.

Since measuring cognitive load in a valid way is a prerequisite for deriving valid multimedia design guidelines, we used the modality effect to further research different alternatives of measuring cognitive load by means of a dual task methodology. Therefore, we describe in the next section the dual task approach for measuring cognitive load.

Measuring cognitive load by means of the dual task methodology

Essential for research on cognitive load is its measurement in order to test assumptions about the influence of cognitive load on learning outcomes (c.f. Paas et al. 2003). The dual task methodology can be viewed as a direct, objective measurement of cognitive load (Brünken et al. 2003) which means that it is independent from the learner's self-report (so-called objective) and directly linked to cognitive load without further mediating variables (so-called direct). Direct objective measurements seem most promising in order to validly assess cognitive load without further confounding factors. Additionally, it might be possible to assess cognitive load during the learning *process*. Therefore, direct objective measurements are of high interest. Knowing more about the process of cognitive load during learning might help designing more effective multimedia learning environments. A direct objective measurement of cognitive load is possible by means of a dual task methodology (c.f. Brünken et al. 2002).

In dual task methodology, an additional secondary task has to be fulfilled in parallel to the primary task. The dual task methodology used for measuring cognitive load follows the logic of the secondary probe technique (Fisk et al. 1986): While carrying out a primary task, participants have to respond as fast as possible on a probe stimulus occurring at various times during performance. As cognitive resources are constrained, resources for the secondary task depend inversely on the resources already allocated to the primary task. Consequently, the more resources are allocated to the primary task, the fewer resources are available for the secondary task leading to a reduced speed of responding to the probe. Therefore, responding speed is assumed to reflect inversely the cognitive load imposed by the primary task (c.f. Brünken et al. 2002).

Several researchers used dual task methodology to measure cognitive load (e.g. Ayres 2001; Brünken et al. 2002; Chandler and Sweller 1996; De Leeuw and Mayer 2008; Madrid et al. 2009; Marcus et al. 1996; Renkl et al. 2003; Schoor et al. 2011; Sweller 1988). For example, Chandler and Sweller's (1996) participants had to remember an additional letter during learning. Marcus et al. (1996) let their participants respond to a tone with a foot pedal. Madrid et al.'s (2009) participants also had to respond to a tone, in their case by pressing the "z" key on a computer keyboard. Brünken et al. (2002) introduced a dual task approach referring to reaction times in multimedia learning research. They used the following monitoring task as secondary task: Participants had to monitor a letter in the upper part of the computer screen and indicate a color change (from black to red) by pressing the space bar on the computer keyboard. Their reaction time was meant to reflect cognitive load imposed by the primary learning task. Brünken et al. (2002) showed by means of a within-subjects design that learning with material presented audiovisually led to shorter reaction times than learning with visual-only material. They interpreted this finding in terms of the modality effect (Low and Sweller 2005).

Dual task methodology and modality of information presentation

However, in order to monitor a letter in the upper part of the computer screen (which comprises a spatially non-contiguous secondary task) additional cognitive resources have to be allocated to focus on the required screen area (Wickens 2002). This will be especially harmful in the case of visual-only learning, as the learner has to split her attention between three information positions (text, picture, letter), while in the audiovisual condition, the attention has to be split between picture and letter only. Therefore, using a spatially non-contiguous secondary task like monitoring a letter in the upper part of the computer screen might overestimate the differences in cognitive load induced by visual-only versus audiovisual presentation.

A secondary task where the monitoring object was within focus all the time (spatially contiguous) and therefore not requiring differential additional resources in audiovisual and visual-only conditions was used by De Leeuw and Mayer (2008). Their participants' secondary task comprised reactions to a change of background color (gradually from pink to black) on the computer screen where the learning material was also presented. De Leeuw and Mayer (2008) were able to detect a redundancy effect by means of this secondary task.

However, the gradual change of color raises a new methodological problem: Not all participants will be capable to detect the color change at the same point in time due to psychophysical ability. Like for detection of visual or auditory stimuli, there are inter-individual differences in the ability or willingness to classify gradual color changes as a color step (c.f. Boynton and Kambe 1980; Wright 1941). Therefore, time lapse between starting of the gradual change and reaction on it might not be a valid indicator for cognitive load, as every participant has an individual point in time when he or she is able to detect the change or is willing to classify this as a change (c.f. Swets et al. 1961; Wright 1941). A more valid measure could be the time lapse between this detectability point and the reaction.

Therefore, we used, in addition to a spatially non-contiguous secondary task (monitoring the color of a letter presented on the top of the screen, Brünken et al. 2002), a spatially contiguous secondary task of monitoring a background color change that occurred all of a sudden in order to avoid this methodological problem. In this case, every participant has the same chance to detect the change, assuming the color change is above all individual thresholds of which we can assure ourselves during baseline measurements, thereby holding the detectability point constant and thus eliminating an avoidable source of inter-individual variance in reaction times.

Rationale of the study and hypotheses

In current cognitive load research, the dual task methodology is a useful approach for measuring cognitive load directly and objectively, especially when investigating the modality effect. Several secondary tasks have been used so far, among them the visual ones by Brünken et al. (2002) and De Leeuw and Mayer (2008) who employed a spatially non-contiguous respectively spatially contiguous secondary task. Using a spatially non-contiguous secondary task leads theoretically to an additional cognitive load especially for visually presented material. As the difference between visually and audiovisually presented material is essential to the modality effect, the use of a spatially contiguous secondary task similar to that of De Leeuw and Mayer (2008) that is not demanding additional resources might be more adequate.

Therefore, we wanted to test the influence of different designs of a secondary task in order to measure cognitive load during learning with different modalities of information presentation. We used a spatially contiguous secondary task as well as a spatially non-contiguous secondary task that should consume additional cognitive resources. We expected the following results:

1. There should be a main effect of secondary task. Performing a spatially non-contiguous secondary task should be more difficult than performing a spatially contiguous secondary task.

2. Additionally, the modality effect of information presentation should occur with both secondary tasks although in the case of a spatially non-contiguous secondary task, the effect will be more pronounced.

Method

Participants and design

One hundred four university students participated in exchange for a certificate of attendance (they had to take part in two studies during their academic studies). However, due to severe language problems (foreign students) or technical failure, we had to exclude eight of them from the analysis. The remaining 96 university students (90.6 % first-year, 7.3 % second-year, 2.0 % third-year students; 13.5 % male, 86.5 % female) were enrolled in educational science (54.2 %) or media communication (45.8 %). The students' mean age was 20.7 years ($SD = 2.23$). The high percentage of females is representative for these courses of study.

We used a 2 × 2 factorial design with the between-subjects factor *secondary task* and the within-subjects factor *modality of information presentation* of the learning material. Participants were randomly assigned to one of the two experimental groups resulting in $N = 46$ for the spatially contiguous secondary task (background color change) and $N = 50$ for the spatially non-contiguous secondary task (color letter change).

Procedure

Participants were tested individually in groups of up to eight at one time in our multimedia laboratory. A trained experimenter welcomed them and randomly placed them in front of a computer (Pentium 4 with 17 inch monitor, 1,024 × 768 pixels, and Windows XP operating system). Participants first had to fill in a paper-based questionnaire covering control variables like demographics, learning preferences and learning strategies, and then took a prior knowledge test. After that, participants learned how to fulfill the secondary task at the computer and baseline measurements were taken. Then participants started working with the learning material (primary task) at the computer. During this, they had to fulfill their secondary task. Their instruction was to work through the learning material and to acquire as much knowledge as possible. During their learning, the secondary task would appear and they were asked to press the space bar as soon as they perceived the change, while continuing with their learning. After learning, they filled in a paper-based knowledge test on their learning outcome and were dismissed.

Materials

Primary task and learning material

Learning material was the same computer-based training (CBT) program used by Brünken et al. (2002). However, we rebuilt it in Eprime version 1.1 in order to integrate the secondary task into one and the same program. The CBT program comprised 22 different screen pages that each contained text and a related graphic covering the human cardiovascular system. The text was delivered either in a written (visual-only modality) or oral (audiovisual modality) form. Each participant received the pages alternately in visual-only and audiovisual modality (within-subjects factor modality of information presentation), e.g. first screen page audiovisually, second screen page visually-only, and so on. Starting modality was counterbalanced. Presentation time was system-paced and the same in both modalities of information presentation. The duration of presentation of each screen page was as long as it took the speaker in the audiovisual modality of information presentation to read out the text. The CBT program overall took 13 min 14 s. Table 1 displays for each screen page the duration and the modality it was presented in for the two groups.

Secondary task and baseline measurements

The kind of the secondary task constituted the between-subjects factor. Fifty participants received a *spatially non-contiguous secondary task* as already used by Brünken et al. (2002): In the middle of the upper part of the screen a black letter in a box was presented (2.81 cm × 3 cm, c.f. Fig. 1). After a random period of 5–10 s, the letter color changed

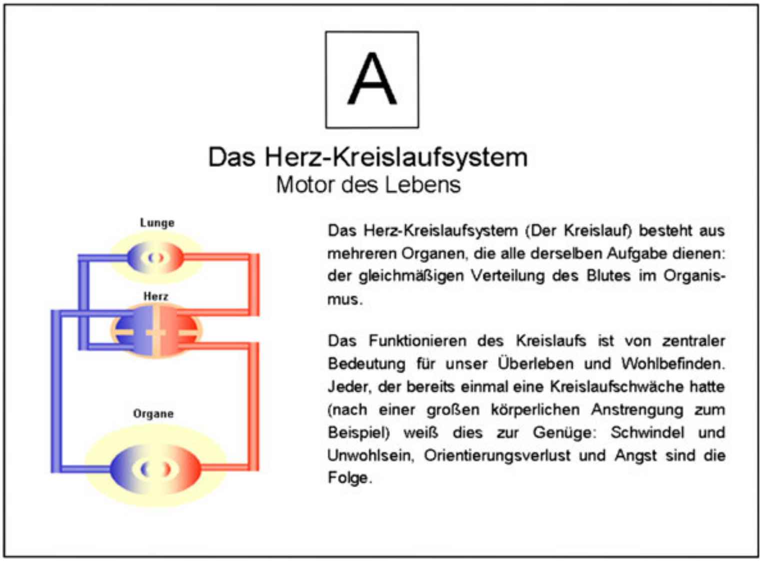
Table 1 Modality of information presentation, duration of screen presentation and number of secondary probes per screen

Screen page	Modality group 1[a]	Modality group 2[a]	Duration (s)	Number of secondary probes[b]
1	AV	VV	39	3–5
2	VV	AV	18	1–2
3	AV	VV	30	2–3
4	VV	AV	40	3–5
5	AV	VV	36	2–4
6	VV	AV	33	2–4
7	AV	VV	30	2–3
8	VV	AV	35	2–4
9	AV	VV	35	2–4
10	VV	AV	42	3–5
11	AV	VV	22	1–2
12	VV	AV	44	3–5
13	AV	VV	36	3–4
14	VV	AV	24	2
15	AV	VV	31	2–3
16	VV	AV	39	3–5
17	AV	VV	34	2–4
18	VV	AV	53	5–6
19	AV	VV	38	3–4
20	VV	AV	40	3–5
21	AV	VV	51	4–6
22	VV	AV	45	3–5

AV audiovisual modality, *VV* visual-only modality

[a] Group 1 and 2 differed only in starting modality

[b] Number of secondary task probes varied as there was a random time interval of 5–10 s after the reaction on the last probe before the occurrence of the next probe



Das Herz-Kreislaufsystem
Motor des Lebens

Das Herz-Kreislaufsystem (Der Kreislauf) besteht aus mehreren Organen, die alle derselben Aufgabe dienen: der gleichmäßigen Verteilung des Blutes im Organismus.

Das Funktionieren des Kreislaufs ist von zentraler Bedeutung für unser Überleben und Wohlbefinden. Jeder, der bereits einmal eine Kreislaufschwäche hatte (nach einer großen körperlichen Anstrengung zum Beispiel) weiß dies zur Genüge: Schwindel und Unwohlsein, Orientierungsverlust und Angst sind die Folge.

Fig. 1 Example screen of CBT with spatially non-contiguous secondary task (letter color change)

from black to red. In this case, participants had to press the space bar on the keyboard as soon as possible. Eprime recorded the time lapse between the color change and the pressing of the space bar. After pressing, the letter color changed back to black. If the participants did not react within 5 s, the time lapse for this probe was recorded as 5 s and the letter color was automatically set back to black.

For 46 participants, the secondary task consisted of monitoring the background of the whole screen. For this group, the upper part of the screen was empty (c.f. Fig. 2). This was a *spatially contiguous secondary task*. After a random period of 5–10 s, the background color changed from white to yellow. In this case, participants had to press the space bar on the keyboard as soon as possible. Eprime recorded the time lapse between the color change and the pressing of the space bar. After pressing, the background color changed back to white (c.f. Fig. 2). If the participants did not react within 5 s, time lapse of this secondary probe was recorded as 5 s and the background color was automatically set back to white. Over both groups, a non-reaction of a participant to a secondary probe was registered only for 112 out of 7,328 probes (1.5 %).

For both groups, *baseline measures* of the secondary task were taken: The participants had to fulfill the secondary task on an otherwise empty screen for 60 s. These baseline measures were first an exercise for the participants to react only on this task, which later on was used as secondary task. Additionally, it provided us with information about the individual reaction speed so that a priori differences between the groups could be controlled.

As the participants had to get used to the task, we did not use the reaction time on the first probe. Due to the random period of color change, the number of probes varied for each participant. As training effects are possible, we used the same (minimum) number of probes for building a mean baseline value for all participants (probes # 2–7).

In order to determine the *performance in the secondary task during learning*, we calculated mean reaction times per screen page as the number of secondary probes varied

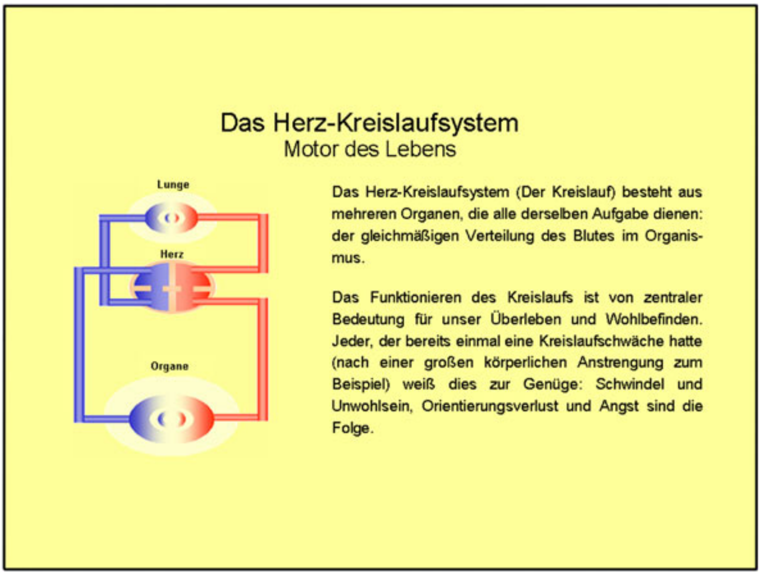


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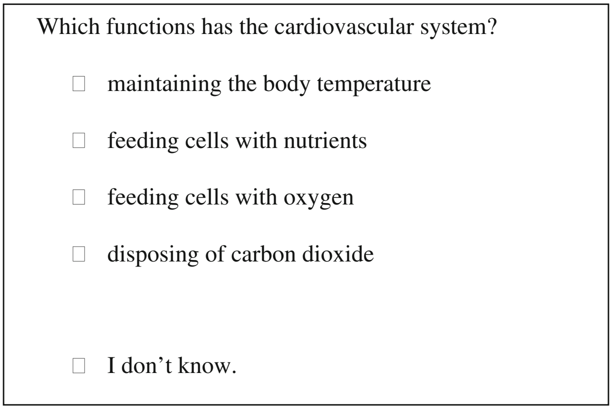
Fig. 2 Example screen of CBT with spatially contiguous secondary task (background color change)

between the participants due to the random time lapse between two probes (5–10 s). The possible number of secondary probes during each screen page is shown in Table 1. For example, if a participant had to react on three probes during screen page #1, we calculated a mean reaction time for this screen page for this participant from these three values. For a second participant who had to react on five probes during this screen page (due to the random appearance of secondary probes, the number of probes per screen could vary from 3–5 for screen page #1, see Table 1) we calculated the mean out of these five values. In order to get values for audiovisually (visually-only) presented material, we took the mean reaction time per screen page for those screen pages that were presented audiovisually (visually-only) and calculated a mean value of these. For example, for participants starting with an audiovisual presentation on screen page # 1, an audiovisual mean was calculated from the mean reaction times on screen pages #1, 3, 5 etc., and an visual-only mean was calculated from the mean reaction times on screen pages # 2, 4, 6 etc.

Prior knowledge test

The prior knowledge test comprised of 15 multiple-choice questions with four answer alternatives, each of which could be right or wrong, and with an *I don't know* option. The test covered knowledge presented in the learning material (for a sample item see Fig. 3). The knowledge test was developed and has previously been used by Brünken et al. (2002) and Brünken and Leutner (2001). In their work, the *I don't know* option was included why we applied it as well. The test was delivered in a paper–pencil format. There was no time limit. The scoring of the test was +1 point for each correctly chosen alternative, −1 point for each wrongly chosen alternative (thus correcting for guessing) and 0 points if the participants chose the *I don't know* option. Therefore, the maximum score was 60 points. The internal consistency (Kuder-Richardson 20) was 0.85.



Which functions has the cardiovascular system?

☐ maintaining the body temperature

☐ feeding cells with nutrients

☐ feeding cells with oxygen

☐ disposing of carbon dioxide

☐ I don't know.

Fig. 3 Sample item of the prior knowledge test (translated into English)

Knowledge test (learning outcome)

The knowledge test concerning the learning outcome was the same as the prior knowledge test (without an *I don't know* option) and was again delivered in paper–pencil-based form and without time limit. As there was no *I don't know* option, we scored +1 point for each correctly chosen alternative and −1 point for each wrongly chosen alternative (thus correcting for guessing). Therefore, the maximum score was again 60 points. The internal consistency (Kuder-Richardson 20) was 0.14. As internal consistency is a measure of homogeneity, this low value is not surprising for a knowledge test covering different knowledge aspects. In comparison with the prior knowledge test's internal consistency, it seems that differential learning of certain aspects had taken place leading to a lower internal consistency than in the prior knowledge test.

Results

Knowledge acquisition

As in Brünken et al.'s (2002) study, knowledge acquisition served only as a control variable as every participant received both visual and audiovisual material and therefore the modality effect cannot emerge between participants. It is also not possible to distinguish between knowledge that was presented visually and knowledge that was presented audiovisually. Therefore, there is one overall knowledge score per participant. The mean prior knowledge scores were 8.08 ($SD = 5.92$) out of 60 for participants in the spatially non-contiguous condition and 8.91 ($SD = 7.34$) for those in the spatially contiguous condition. Post test means for the two groups, respectively, were 14.76 ($SD = 6.39$) and 16.13 ($SD = 5.98$).

Although being rather low, the results of the prior knowledge test are comparable to those of Brünken et al. (2002), while the increase in test scores approximately matches those of the visual-only group in Brünken and Leutner's (2001) study. A repeated measurement ANOVA revealed that the testing factor (i.e. knowledge acquisition) was significant ($F(1, 94) = 67.70$, $p < 0.001$, $\eta_p^2 = 0.42$) while there were no group differences

($F(1,\ 94) = 1.20$, $p = 0.28$, $\eta_p^2 = 0.01$) or interaction ($F(1,\ 94) = 0.10$, $p = 0.75$, $\eta_p^2 = 0.00$). This finding indicates that the participants fulfilled the primary task of acquiring knowledge.

Baseline differences

Concerning the baseline measurement of reaction times, the participants in the spatially non-contiguous condition ($M = 336.88$, $SD = 69.84$) reacted significantly faster than the participants in the spatially contiguous condition ($M = 427.43$, $SD = 292.59$, $F(1, 94) = 4.51$, $p = 0.036$, $\eta_p^2 = 0.04$). This group difference might be due to three extreme outliers in the spatially contiguous secondary task group (c.f. the comparably high standard deviation in this group). Since all other analyses showed similar results whether outliers were excluded or not, they were included.

Baseline reaction times and reaction times during learning

As fulfillling the secondary task in parallel to the primary task should be more difficult than the baseline measurement, reaction times should be higher during learning. A repeated measurement ANOVA showed that baseline reaction times and secondary probe reaction times during learning differed significantly ($F(2,\ 190) = 43.23$, $p < 0.001$, $\eta_p^2 = 0.31$). Planned contrasts showed that the baseline reaction times ($M = 380.27, SD = 212.45$) were significantly shorter than both reaction times on audiovisual screen pages ($M = 658.15$, $SD = 325.46$, $F(1, 95) = 51.68$, $p < 0.001$, $\eta_p^2 = 0.35$) and reaction times on visual-only screen pages ($M = 729.64$, $SD = 462.70$), $F(1, 95) = 45.91, p < 0.001, \eta_p^2 = 0.33$).

Differences in secondary task reaction times during learning

For all participants, two secondary task reaction times values were computed: one for visual-only information presentation format and one for audiovisual information presentation format. A 2 (modality of information presentation, within-subjects) × 2 (kind of secondary task, between-subjects) factorial analysis of variance showed a significant interaction ($F(1,\ 94) = 10.43$, $p < 0.001$, $\eta_p^2 = 0.10$) as well as two significant main effects for the kind of the secondary task ($F(1, 94) = 19.47, p < 0.001, \eta_p^2 = 0.17$) and for modality of information presentation ($F(1,\ 94) = 8.93$, $p < 0.001$, $\eta_p^2 = 0.09$).

Planned simple effects analyses showed that for the group with a spatially non-contiguous secondary task (letter color change), reaction times on screens with visual-only information presentation format ($M_V = 916.19$, $SD_V = 564.57$) were longer than reaction times on screens with audiovisual information presentation format ($M_{AV} = 773.87$, $SD_{AV} = 393.14$; $F(1, 94) = 20.17, p < 0.001, \eta_p^2 = 0.17$). In the spatially contiguous secondary task group (background color change) there were no such differences between modality of information presentation ($\mathrm{M_V} = 526.87$, $SD_V = 155.56$; $M_{AV} = 523.37$, $SD_{AV} = 155.78$; $F(1,\ 94) = 0.03, p = 0.87, \eta_p^2 = 0.00$). Thus, the main effect for modality of information presentation is due to the effect in only one condition of secondary task and therefore must not be interpreted independently from the interaction. Figure 4 illustrates these results.

Additional analyses

As cognitive load might have been lower for participants with higher prior knowledge, we correlated the knowledge scores with the secondary task reaction times during learning.

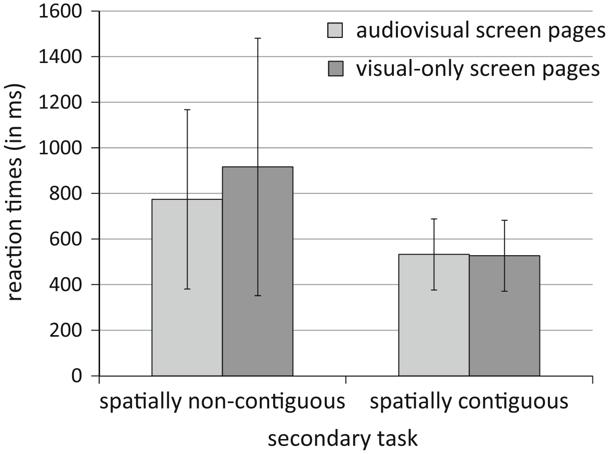


Fig. 4 Differences in secondary reaction times during learning with audiovisual versus visual-only screen pages and different secondary tasks

Table 2 Correlations of secondary task reaction times with knowledge scores and baseline reaction times

	Prior knowledge	Post knowledge	Knowledge acquisition	Baseline reaction times
Audiovisual screen pages	−0.13	−0.03	0.18	0.06
Visual-only screen pages	−0.07	−0.04	0.06	0.02
Overall reaction times during learning	−0.10	−0.01	0.12	0.04

Knowledge acquisition = post knowledge score minus prior knowledge score. All correlations are non-significant

Table 2 shows these correlations. All were non-significant. Including the post test knowledge score or knowledge acquisition (post test knowledge score minus prior knowledge score) as a covariate into the analyses of secondary task reaction times (visual-only vs. audiovisual) by group (kind of secondary task) revealed no major differences to the analyses reported above. Including prior knowledge as a covariate resulted in a non-significant main effect of modality of information presentation ($F(1, 93) = 2.01, p = 0.16$, $\eta_p^2 = 0.02$) but a still significant interaction of modality of information presentation by kind of secondary task ($F(1, 93) = 10.51$, $p < 0.01$, $\eta_p^2 = 0.10$) and main effect for the kind of secondary task ($F(1, 93) = 18.88$, $p < 0.001$, $\eta_p^2 = 0.17$). However, the main effect for modality of information presentation we found in the original analysis was not interpretable as shown above. Thus, this additional analysis revealed no new result.

Additionally, we tested whether the inclusion of baseline reaction times as a covariate changed the results. Table 2 displays the correlations of baseline reaction times and secondary task reaction times during learning. They were all non-significant. A 2 (modality of information presentation, within-subjects) × 2 (kind of secondary task, between-subjects) factorial analysis of covariance with the covariate baseline reaction times showed also a significant interaction ($F(1, 93) = 10.30$, $p < 0.01$, $\eta_p^2 = 0.10$) as well as a significant main effect for the kind of the secondary task ($F(1, 93) = 21.36$, $p < 0.001$, $\eta_p^2 = 0.19$) but no main effect for modality of information presentation ($F(1, 93) = 1.27$, $p = 0.26$, $\eta_p^2 = 0.01$).

Discussion

To sum up our results: We found a modality effect with respect to reaction times in the spatially non-contiguous secondary task group (letter color change group) favouring audiovisual presentation compared to visual-only presentation but no modality-related differences in reaction times in the spatially contiguous secondary task group (background color change group). So we were able to replicate the results of Brünken et al. (2002) with their spatially non-contiguous secondary task but not with an alternative spatially contiguous secondary task. Additionally, we found a main effect for the kind of secondary task in reaction times.

First of all, these findings support our assumption that monitoring a letter change in the upper part of the computer screen consumes more cognitive resources than monitoring a background color change. However, by means of the spatially contiguous secondary task we found no modality effect of information presentation. This might be due to different reasons: First, there might be no modality effect between different kinds of information presentation of this material at all. In this case, the modality effect we found with the spatially non-contiguous secondary task would be completely caused by the kind of secondary task itself. In this case, the spatially non-contiguous secondary task would be more difficult to perform on visual-only screen pages than on audiovisual screen pages. However, in contrast to this interpretation that there was no modality effect due to different kinds of information presentation, Brünken and Leutner (2001) were able to show a modality effect of knowledge acquisition in a between-subjects design with this same material.

We interpret this finding in favor of a second explanation referring to working memory utilization: In the spatially contiguous secondary task condition, participants might have had enough working memory capacity for perfectly performing both the primary and the secondary task—independently of the modality of information presentation—because the spatially contiguous secondary task demanded only a few additional cognitive resources. Therefore, possibly existing differences in cognitive load between the two modalities were not detectable in reaction times. In contrast, in the spatially non-contiguous secondary task condition (the visual-only presentation of primary and secondary task) participants might not have had enough working memory capacity to fulfill both tasks perfectly since the spatially non-contiguous secondary task demanded additional cognitive resources to focus on the required screen area (Wickens 2002). Therefore, differences in cognitive load of the primary task could be observed in the performance of the secondary task while these differences were not observable in the spatially contiguous secondary task condition albeit possibly existing (c.f. Wickens 1991). This interpretation is in line with findings by Bleckley et al. (2003) who showed that individuals with lower working memory capacity had greater difficulties in allocating their attention to spatially non-contiguous stimulus locations than individuals with higher working memory capacity. In our study, individuals should have had lower working memory capacity *available* with the visual-only presentation format screens than with the audiovisual presentation format screens (assumed modality effect). This should have hampered their ability to allocate their attention to a spatially non-contiguous stimulus (the letter) but not to a spatially contiguous stimulus (the background color) therefore resulting in differences in performance of the spatially non-contiguous secondary task but not in performance of the spatially contiguous secondary task.

Another possible interpretation of our results is that the color change of the background color task (spatially contiguous secondary task) was so obtrusive that it temporarily became the primary task (c.f. Paas et al. 2003). However, since the reaction times during learning were significantly higher than during all baseline measurements, we consider this interpretation as unlikely. Moreover, we cannot exclude that the choice of the background color (here: yellow) has also an important influence on the results obtained in dual task cognitive load research. For example, the color change to a strong shade of red would probably be very obtrusive.

A further explanation for no modality effect in reaction times could be that participants try to keep their performance in the secondary task constant (Schnotz and Kürschner 2007). However, this should be the case for both kinds of secondary task and does not explain the different results depending on the kind of secondary task.

An interpretation following Wickens' (e.g. 2002) model concerns the visual channels of the secondary tasks: The spatially non-contiguous secondary task has to be processed in focal vision, while the spatially contiguous secondary task can be performed by means of ambient vision. As both picture and written text also require focal vision, the spatially non-contiguous secondary task might be more appropriate to assess resource consumption by learning with text and picture than the spatially contiguous task. Therefore, the missing modality effect in the spatially contiguous secondary task condition might be due to a suboptimal choice of secondary task design according to Wickens (2002). A better choice would have been a spatially contiguous but focal secondary task.

As for knowledge acquisition, it is mentionable that there was overall little knowledge gain. The participants seem far from mastering the material. In the case of difficult material, we would have expected an even bigger modality effect. However, this was not the case. Moreover, neither prior knowledge nor post test knowledge nor knowledge acquisition correlated with secondary task reaction times. Yet, this is not that surprising as knowledge was tested overall and could not be related to material presented either visually or audiovisually.

Last but not least we have to mention that the observed differences in secondary task performance and the modality effect might not be due to differences in cognitive load, and therefore parameters of working memory, but might trace back to perceptual influences: In our spatially non-contiguous secondary task, participants might physically not be able to monitor the object (e.g. a letter) on the one hand and learn with the material on the other hand (c.f. Marcus et al. 1996). This might be especially pronounced with visual-only material leading to the observed modality effect. In the case of a spatially contiguous secondary task (e.g. background color change), participants might be able to monitor the object and learn at the same time, which might lead to the disappearance of the modality effect in this condition. This hypothesis should be tested by means of eye movement analyses.

From the present study we can conclude that the choice of an appropriate secondary task for research on cognitive load with dual task methodology is no trivial task. Concretely, researchers have to consider the additional load imposed by their secondary task very carefully in order to create a full utilization of working memory capacity. The present study shows that a spatially contiguous secondary task might in some cases be too easy to do so. On the other hand, a spatially non-contiguous secondary task might overestimate differences in cognitive load of different instructional conditions. And additionally, the secondary task has to be conformant to the underlying theory. For example, when we assume two mainly independent subsystems of working memory for visual and auditory information, an auditory secondary task might not be able to reflect cognitive load in the visual subsystem correctly (c.f. Brünken et al. 2004; Marcus et al. 1996). In the present research, we assumed a reduction of cognitive load in the visual subsystem by presenting information audiovisually compared to visually-only. Thus, the modality of the present secondary tasks was well chosen. However, according to Wickens' (2002) model, our secondary tasks tapped into different visual channels. Therefore, in further research, we have to take the modality of secondary task presentation (visual vs. auditory) as well as, if applicable, the visual channel (focal vs. ambient) into careful consideration. A secondary task using a third modality like the manual tapping tasks used by Kane and Engle (2000) and Park and Brünken (2010) might avoid this problem.

One implication of this study for cognitive load researchers using the dual task methodology is that we must carefully consider how the secondary task we use is expected to interact with the primary task. For that we have to ascertain where in the cognitive framework we assume the secondary task to target at. The framework of cognitive load theory (Chandler and Sweller, 1991; Sweller, 1988) or multimedia learning theory (Mayer, 2001) assumes two working memory subsystems: one for visuo-spatial information and a second for phonological information. Each is believed to have its own capacity. However, if a motor task like the one by Kane and Eagle (2000) is used as secondary task, this raises the question which subsystem it refers to or how the cognitive load measured by this task is related to the two subsystems. It also raises questions concerning the current state of cognitive load theory: What is the theoretical explanation for why a motor secondary task can show cognitive load? How are visuo-spatial and phonological load related to overall cognitive load?

These implications are not only true for further research using dual task methodology, but also for prior research. For example, Marcus et al. (1996) used an auditory stimulus as their secondary task for researching differences in textual versus diagram-based information. If text is processed immediately in the phonological subsystem as suggested by Baddeley (e.g., Baddeley, 2001), this might have led—like in our research—to higher utilization of auditory resources. A visual secondary task might have produced different results.

Therefore, a fruitful approach for further research might be to systematically investigate the influence of different kinds of secondary tasks on various effects known from cognitive load research like the modality effect, the redundancy effect or the multimedia effect. An implication for instructional research in general is to keep in mind that the instruments we use might as well influence the object of measurement.

Moreover, there are also consequences for instructional design. One of them concerns the design of computer-based learning material when several tasks have to be performed at the same time. In such cases, for example when the time has to be monitored during learning, we would conclude from the present study that a spatially contiguous display of the monitoring task has advantages compared to a spatially non-contiguous display. Additionally, this study indicates that guidelines for multimedia design, like the modality principle (Low and Sweller, 2005), are useful in general. However, there are also cases when a non-appliance of these guidelines may not harm learning, at least regarding the modality principle. In our study, displaying written text to a graphic did not influence cognitive load negatively when cognitive load was measured by means of a spatially contiguous secondary task. In multimedia design, there might be more conditions when providing written text referring to a graphic does not hurt. Therefore, we should be careful to not overgeneralize multimedia design guidelines. Moreover, we should be aware how cognitive load is measured during multimedia learning in order to derive valid implications for multimedia design.

Taken together, research on cognitive load during multimedia learning is essential for instructional designers of modern multimedia learning environments. They need consolidated knowledge on how to present multimedia learning material adequately, that is without overloading the students and thus supporting effective learning with modern computer technologies.

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Cornelia Schoor is a member of academic staff at the Institute of Educational and Developmental Psychology at TU Dresden. Her research interests are motivation, computer-supported collaborative learning, and cognitive load.

Maria Bannert holds a chair in Educational Media at Institute of Human–Computer–Media at the University of Würzburg. Her research interests are self-regulated learning, metacognition and learning with hypermedia.

Roland Brünken holds a chair in Educational Psychology at the Department of Education at the University of Saarbrücken. His research interests are multimedia learning and cognitive load.