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RESEARCH ARTICLE

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The moderating role of arousal on the seductive detail effect in a multimedia learning setting

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Summary

Arousal has been found to increase learners' attentional resources. In contrast, seductive details (interesting but learning-irrelevant information) are considered to distract attention away from relevant information and, thus, hinder learning. However, a possibly moderating role of arousal on the seductive detail effect has not been examined yet. In this study, arousal variations were induced via audio files of false heartbeats. In consequence, 100 participants were randomly assigned to a 2 (with or without seductive details) × 2 (lower vs. higher false heart rates) between-subjects design. Data on learning performance, cognitive load, motivation, heartbeat frequency, and electrodermal activity were collected. Results show learning-inhibiting effects for seductive details and learning-enhancing effects for higher false heart rates. Cognitive processes mediate both effects. However, the detrimental effect of seductive details was not present when heart rate was higher. Results indicate that the seductive detail effect is moderated by a learner's state of arousal.

KEYWORDS

arousal, cognitive load, false heartbeats, learning with media, physiological measurement, seductive detail effect

1 | INTRODUCTION

Learners have to cope with a huge amount of learning-relevant information sources in rather complex multimedia environments (e.g., texts, pictures, or videos). Consequently, learners might quickly suffer from a cognitive overload due to their limited working memory capacity (Sweller, Ayres, & Kalyuga, 2011). This overload is caused, inter alia, by the costs of directing attention to possible learning-relevant information. If multimedia designers additionally include interesting but learning-irrelevant details (referred to as *seductive details*; e.g., Garner, Gillingham, & White, 1989; for an overview of research, see Rey, 2012) in order to promote a situational interest, learners have to additionally assess the relevance of the given information and further divide their attention. In addition, all these cognitive processes are strongly intertwined with an emotional response (for an overview, see Okon-Singer, Pessoa, & Shackman, 2015). For example, learning processes in technology-based environments depend on a variety of emotional experiences (for a meta-analytic review, see D'Mello, 2013). In order to understand how emotions influence underlying cognitive processes, researchers focused on the examination of the two orthogonal dimensions of *valence* (ranging from negative to positive) and *arousal* (ranging from calm to exciting), which can be used to comprise sets of emotions rather than single manifestations (Anderson et al., 2003; Russell & Carroll, 1999). Each dimension is found to affect cognitive processes differently (for an overview, see Sakaki, Niki, & Mather, 2012). For example, higher states of arousal improve learners' attentional focuses (e.g., Gomes, Brainerd, & Stein, 2013; Mather & Sutherland, 2011). In this case, it seems plausible that learners might profit from extra attentional resources caused by higher levels of arousal. However, the possible moderating effect of differences in the amount of learners' arousal on cognitive overload situations caused by seductive details is still unexplored—a research gap that was addressed in this study.

2 | THEORETICAL BACKGROUND

2.1 | Cognitive load theory

Cognitive load theory (CLT; Sweller, 1988; Sweller et al., 2011) operates on the assumption that humans' working memory exhibits limitations in both the amount and the duration of the to-be-processed information. Besides this limited cognitive resource, the long-term memory as a further cognitive feature can maintain information without such boundaries. Successfully acquired knowledge is represented and organized in long-term memory via schemata—clusters of information, which are constructed in order to be applied in an automatized way at later stages. In detail, CLT deals with the existence of three operating facets of cognitive load that claim cognitive capacity. At first, intrinsic cognitive load (ICL) is determined by the complexity of certain learning material (referred to as element interactivity) in relation to learners' previous knowledge. Such aspect is traditionally assumed to be hardly influenceable by design efforts. In contrast, extraneous cognitive load (ECL) arises from the instructional presentation itself, for instance, the inclusion of seductive details, into relevant learning material. Although these can increase learners' interest for the learning topic, they are prone to distract attention from relevant learning content (Harp & Mayer, 1998; Rey, 2012, 2014; Sanchez & Wiley, 2006) and thus impair learning performance. Lastly, the processes of schema acquisition and automation form the germane cognitive load (GCL). Beyond that initial three-factorial framework, several researchers postulated a reformulation due to difficulties in validly separating the outlined facets (Kalyuga, 2011; Sweller, 2010). In particular, the GCL was stated to bear considerable conceptual interference with the facet of ICL. In consequence, a dual framework of germane resources dealing with relevant aspects of instructional material (ICL) and extraneous resources dedicated to handle irrelevant situational characteristics (ECL) would provide a sufficient approach in explaining demands on learners' resources without redundancy (Kalyuga, 2011).

Considering possible influences of the working memory capacity, a learner's functional state determines the availability of cognitive resources (e.g., Galy, Cariou, & Mélan, 2012). These results indicate that a learner's performance is fostered with an increased state of arousal and that variables related to the learners' autonomous nervous system can serve as valid indicators of cognitive resource availability throughout a task. The moderating role of affective processes on cognitive load is also investigated by Huk and Ludwigs (2009) within their augmented CLT framework. They postulate that supporting learners on affective accounts, compared with the traditional cognitively oriented view, can increase their overall interest in the learning situation and thus positively influence their motivation to achieve optimal learning outcomes.

2.2 | The seductive detail effect and its moderators

There is a long tradition of research on seductive details, which are defined as interesting but learning-irrelevant design elements such as texts or pictures (e.g., Garner et al., 1989; Wang & Adesope, 2016). In a meta-analysis (Rey, 2012), seductive details, compared with materials without seductive details, are found to mainly hinder learning. However, this *seductive detail effect* (Harp & Mayer, 1997) depends on a variety of boundary conditions.

For example, Park, Moreno, Seufert, and Brünken (2011) have shown that learners in a low cognitive load condition profited from seductive details in contrast to a group without seductive details. This result shows that additional resources are needed to process the information of seductive details adequately without risking learning-inhibiting overload situations. However, this constitutes a mainly cognitive explanation of the seductive detail effect, because the capacity of free resources depends on learner's prior knowledge, the ability of coherence formation, and the security in coping with unpredictable information—processes subsumed under the ICL (Sweller, 2010). In this context, low prior knowledge learners are found to be more sensitive to the seductive detail effect than are learners with high prior knowledge (Park, Korbach, & Brünken, 2015).

A second moderator can be found in the level of interestingness of seductive details. For example, Mayer, Griffith, Jurkowitz, and Rothman (2008) obtained evidence that low-interest seductive text passages (e.g., facts and numbers) outperformed high-interest seductive passages (e.g., results from scientific articles) when reading a learning text about how viruses attack the human body. They conclude that the interestingness of seductive detail is an attention consumer, which distracts learners from relevant information. This result was also confirmed by Wang and Adesope (2016), who showed that situational interest, in detail, was triggered by seductive details, which distracted learners' attention away from learning material. Learners with high individual interest, however, were found to profit from seductive details when asked to solve problems.

Seductive details are also found to foster transfer performance when the included details are able to arouse and maintain trainee's mindfulness (Towler et al., 2008). In particular, seductive details, which increase learners' emotional interest (i.e., the level of arousal; Harp & Mayer, 1998; Kintsch, 1980), reached higher scores of motivation (Park & Lim, 2007) than did details that are dedicated to increase cognitive interest (i.e., the satisfaction of understanding; Harp & Mayer, 1998). In this vein, an increase of learners' positive affect, or at least a decrease of negative affect, might be a result of seductive details, which are rather emotionally interesting (Sitzmann & Johnson, 2014). This emotional or motivational effect of seductive details is still underestimated (Schneider, Nebel, & Rey, 2016), especially as a study by Park, Flowerday, and Brünken (2015) suggests that the elicited interest is not part of the detrimental effect of seductive details.

As highly interesting details are found to distract attention (Chang & Choi, 2014; Rey, 2014), learners' attentional resources while learning can be identified as another moderator of the seductive detail effect. In this context, Park and colleagues (2015) revealed that learners with a low spatial ability or low prior knowledge are more affected by the seductive detail effect than are learners with a high spatial ability or a high prior knowledge. In multimedia settings, both factors might be reduced to attentional effects, as a spatial ability is assumed to affect learners' focus of attention (Park, Korbach, et al., 2015). In this context, prior knowledge is found to shift learners' attention towards knowledge-relevant features more often than to irrelevant ones (Park, Korbach, et al., 2015). More directly, other studies revealed that learners with a low ability of controlled attention are more prone to this effect (Rey, 2014; Sanchez & Wiley, 2006). In conclusion, any factors that increase learners' attentional resources might also decrease or eliminate the detrimental effect of seductive details.

2.3 | Arousal and learning performance

Much effort has been invested in the examination of effects of emotionally charged learning environments (e.g., Schneider et al., 2016) or different emotional states of learners induced prior to the learning material (e.g., D'Mello, 2013). Emotional or affective experiences can be described along the axes of two dimensions: valence and arousal (Kensinger, 2004). Both dimensions were proven to trigger distinct mechanisms, which influence learning. For example, arousal was confirmed to mainly affect learners' attentional resources (e.g., Anderson, 2005; Cahill, Gorski, & Le, 2003) as learners' focus and speed of attention are enlarged for arousing events (for an overview, see Kensinger, 2004). In addition, arousing information is processed and prioritized faster. When it comes to formal learning environments, arousal is also found to increase memory (e.g., Buchanan, Etzel, Adolphs, & Tranel, 2006; Cahill, Babinsky, Markowitsch, & McGaugh, 1995; Cahill & McGaugh, 1995; Nielson, Yee, & Erickson, 2005). Kensinger and Corkin (2004) revealed that words are remembered better in arousing states, especially when attention is limited due to a secondary task. By using the attentional blink paradigm, Anderson and Phelps (2001) showed that a target item is better remembered when a second item is arousing rather than calming. Falk and Gillespie (2009) reported that more aroused visitors of an exhibition were better in memory and attitudes. The influence of misinformation is also found to be less detrimental when learners are in a higher state of arousal (Brainerd, Holliday, Reyna, Yang, & Toglia, 2010). In terms of metacognition, Ochsner (2000) revealed that high-arousal words elevated rates of remembering judgements relative to low-arousal words. Highly arousing materials also lead to an increased memory performance, more confident metacognitive judgements, and more positive affect in a learning environment (Bradley, Greenwald, Petry, & Lang, 1992).

In a multimedia learning environment, high arousal states of learners, for instance, induced by video clips, were found to foster learning performance indicated by a recall test as well as motivation and mental effort ratings, in contrast to low aroused learners (Chung, Cheon, & Lee, 2015). The results were explained with the limited capacity model of motivated mediated message processing (LC4MP; Lang, 2006). According to this theory, learners' motivation to process information is both aversive and appetitive. If an emotional stimulus is presented, its emotional tone (either valence or arousal) can activate motivational systems, which in turn assign meaning to the presented stimulus (opportunity or threat). In conclusion, multimedia learning materials, which trigger different states of arousal, might determine how information is received, encoded, and stored. According to Strain, Azevedo, and D'Mello (2013), the border between appetitive and aversive behaviour triggered by arousal is fluid. Moreover, there are two hypotheses of how people react to an arousing stimulus: the *alarm hypothesis* and the *alert hypothesis*.

The alarm hypothesis is based on results that show that higher states of arousal will be appraised as problematic resulting in negative affective states (e.g., Schwarz, 2011) and increased heart rates (HRs; Nielson et al., 2005). This can lead to avoidance achievement goals (Pekrun, Elliot, & Maier, 2009) and decreased learning performance (e.g., Eysenck, Derakshan, Santos, & Calvo, 2007; Zeidner, 2007). In contrast, the alert hypothesis explains higher states of arousal as an indicator for alert, engaging, and interesting tasks, which trigger positive emotions (Strain et al., 2013), facilitate decision making (Carpenter, Peters, Västfjäll, & Isen, 2013), enhance problem solving (e.g., Fredrickson, 2001; Isen, 2004), and improve learning (Zeidner, 2007). In contrast, too high states of arousal have been identified as rather leading to alarming states while increasing false memories (Brainerd et al., 2010).

In conclusion, there might be an optimal range of arousal, which is not too low (no activation) and not too high (avoidance behaviour) but instead activates learners. This inverted U-shaped curve of the interaction between learning and states of arousal is also formulated within the Yerkes–Dodson law (Yerkes & Dodson, 1908; see Figure 1).

This law might explain how arousal and learning performance are intertwined (Baldi & Bucherelli, 2005) and why too high states of arousal might even worse learning (McGaugh, 2006). These results can explain possible differences in the cognitive processing of information. However, this study was not aimed at finding the optimal range of arousal but rather at finding out how an increase in a learner's arousal might affect his or her cognitive processes and learning performance. Nonetheless, in multimedia settings, the arousal of learners is typically low so that an increase in the activation of learners normally should lead to an increase in cognitive processing and learning.

In order to increase a learner's arousal in experimental settings, different methods were used (e.g., sports activities; Wegner & Giuliano, 1980; or autobiographical recall; Jallais & Gilet, 2010). In educational settings, these methods are often short termed or distract learners from their main goal of, for instance, reading new information. Therefore, methods like listening to a false HR (Strain et al., 2013) might be a sufficient method to maintain a high state of arousal without consuming too many resources (in contrast to dual-task

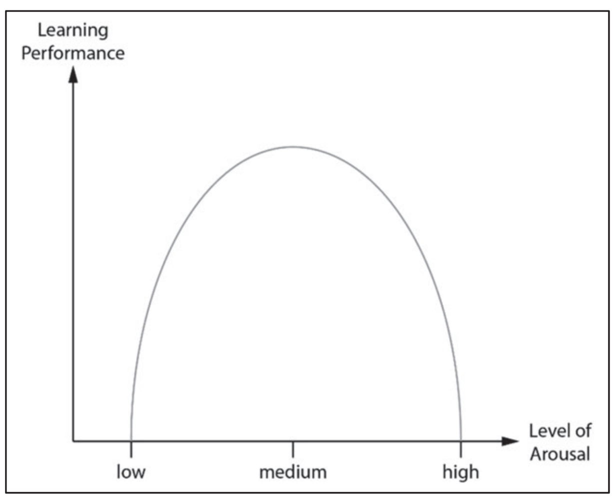

FIGURE 1 Schematic visualization of the Yerkes–Dodson law (Yerkes & Dodson, 1908)

paradigms). These methods were used in several experiments in order to evaluate the influence of activation levels on cognitive processes like perception and attention (Borkovec & Glasgow, 1973; Karsdorp, Kindt, Rietveld, Everaerd, & Mulder, 2009; Strain et al., 2013). This experiment tried to use this method as an induction method for arousal levels in the sense of a higher activation of learners.

2.4 | Research questions and hypotheses

This study tried to identify if an increased state of arousal might help to diminish the cognitive costs of included seductive details. First, both higher states of arousal and the exclusion of seductive details were supposed to enhance learning based on previous literature (e.g., Chung et al., 2015; Rey, 2012).

> **H1.** *Learners with a higher arousal achieve higher learning scores than do less aroused learners.*

> **H2.** *Learning materials with seductive details lead to a worse performance of learners than do materials without seductive details.*

However, the attention-focusing effect of arousal might not only help to increase learning performance through affective processes but also highlight relevant information in a learning environment. For example, Easterbrook (1959) revealed that arousal-enhanced attention eliminated the processing and storage of irrelevant information (Brainerd et al., 2010). As seductive details are defined as rather irrelevant for learning and these details are found to distract attention, arousal is assumed to moderate this effect through two possible mechanisms: (a) an increase of attentional resources and (b) a reduction of a (cognitive) processing of irrelevant information. Moreover, additional attention resources could help to cope with the huge cognitive demands of splitting attention between relevant and irrelevant information in a learning material with learning and seductive detail texts. As arousal might also help to focus on relevant information, learning performance should additionally be enhanced and the seductive detail effect should be further reduced. In order to examine these theoretical assumptions, the following hypothesis was formulated:

> **H3.** *Higher states of arousal diminish the seductive detail effect in contrast to lower states of arousal.*

Based on the results of previous studies, both seductive details and different states of arousal were shown to affect cognitive and physiological measurements (e.g., Nielson et al., 2005; Park et al., 2011; Schneider et al., 2016), which will also be analysed in this study in order to gain insights in possible cognitive and affective mechanisms. As the effects of seductive details and arousal on learning performance are mainly explained by cognitive processes, this study aimed at analysing the mediational effect of all cognitive load types (see Figure 2).

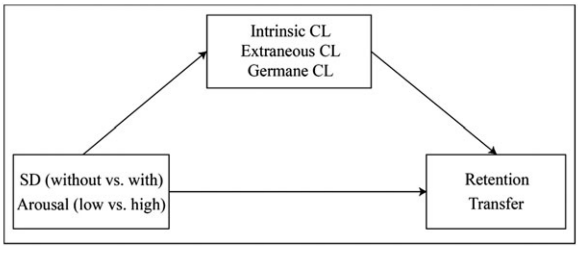

FIGURE 2 Hypothesized mediation on the effect of the inclusion of *SD*s and arousal differences on the retention and transfer scores by intrinsic CL, extraneous CL, and germane CL. CL, cognitive load

3 | METHOD

3.1 | Prestudy

For the evaluation of the seductive details, which can be used in the main study, a prestudy was conducted (N = 39, 16 females, M_{age} = 22.55, SD_{age} = 2.67). Participants rated 15 textual seductive details, via an online survey, regarding their *interestingness* and *relevance to the learning text* using a 7-point Likert scale (1 = *not at all interesting* [relevant], 7 = *very interesting* [relevant]) after reading an excerpt of the text. All seductive details and their scores in interestingness and relevance to the text are listed in Table 1. In consequence, sentences that were high in interestingness scores and low in relevance scores were chosen as seductive details for the main study.

3.2 | Participants and experimental design

Overall, 100 university students (72 females), registered for communication and media studies, participated in the experiment. Students had a mean age of 22.8 years (SD = 3.8) and were either bachelor (74%) or master students. Their effort was compensated with a financial compensation of €6 (41%) or course credits. Most participants (97%) were native speakers, whereas the other 3% spoke the required language for a minimum of 3 years.

All participants were randomly assigned to one of four conditions of a 2 (with vs. without seductive details) × 2 (lower vs. higher false HR) between-subjects design (25 participants per condition). In detail, students listened to preset audio files with different HR (normal HR vs. increased HR) in order to achieve different states of arousal (lower vs. higher arousal) during the learning phase. Moreover, students received different learning texts either with or without seductive text passages. Thus, the first experimental group received seductive details and listened to a higher HR, and the second group had seductive details and a lower HR audio. The third group was assigned to the condition without seductive details and listened to higher HR, whereas the fourth condition consisted of an environment without seductive details and a lower HR audio.

3.3 | Materials and apparatus

A self-made website featuring six texts about the topic "sleep" was used as the learning material. The content covered the topics of the circadian rhythm (e.g., morningness and eveningness), electroencephalography (EEG; as an example for measuring brain activities during the sleep), the sleep's influence on learning (e.g., the computation of semantic knowledge during the first 4 hr of sleep), and the

TABLE 1 Mean values of seductive details ratings on interest and relevance to the text

		Interestingness		Relevance to the text	
No.	Content of seductive detail	*M*	*SD*	*M*	*SD*
1	**Dolphins do not have a REM sleeping phase. It is most likely that this phenomenon was adapted during evolution, because dolphins are only able to breathe above the waterline.**	5.29	1.11	3.14	1.22
2	The risk to suffer from depression is four times higher for people who do not sleep well than for people who sleep well.	5.71	0.95	5.43	1.13
3	When most of the people are waken up during the first 2 SWS sleeping phases, they claim that they did not sleep, although they did not respond to any signals during this time.	5.29	1.25	4.29	1.98
4	Some medicine causes a higher repetition of nightmares.	5.57	0.79	5.00	1.73
5	Elderly people, women, or people who consume a great amount of cigarettes, coffee, or alcohol often suffer from insomnia (sleeplessness).	4.57	1.13	3.43	1.51
6	People who suffer from schizophrenia show the same symptoms of noctambulism as do healthy people.	5.57	0.98	3.71	1.60
7	**The less you sleep, the more genes are controlling your weight.**	5.29	1.25	3.29	1.60
8	Men drive more often in a dozily mood than do women. The risk of falling asleep while driving is twice as high for men as for women.	5.43	0.98	5.00	1.63
9	Sleeplessness can be a reason for overweight, caused by a released hormone that stimulates the feeling of hunger and increases this feeling by 25%.	6.00	1.00	4.29	1.50
10	**People who have problems breathing properly during their sleep are more likely to suffer from cancer.**	5.86	1.21	3.29	1.38
11	In the first 2 years of their first newborn child, the parents lose 6 months of sleep.	5.57	1.40	5.00	1.41
12	According to studies, the main reason for the short of sleep is the 24-hr reachability of the Internet.	5.43	1.13	4.71	1.60
13	Five minutes after getting up, almost 50% of the dreams are forgotten. After 10 min, already 90% are lost.	5.71	1.11	3.29	1.70
14	**Snoring and dreaming at the same time are not possible.**	5.86	0.69	3.71	1.80
15	**400 years ago, sleeplessness was used to enforce death penalty. It took 3 weeks until the convict died of sleeplessness.**	5.43	0.79	3.00	1.53

Note. Scales ranged from 1 to 7 with higher ratings indicating higher interestingness or relevance to the text. Seductive details are translated from German into English. Seductive details, which are printed in bold, were selected for the main study. REM: rapid eye movement; SWS: slow-wave sleep.

consequences of sleep deprivation (e.g., the lack of concentration and disorientation) based on cognitive and biological textbooks (Breedlove, Rosenzweig, & Watson, 2007; Purves et al., 2008). The text on each web page consisted of a mean length of M = 147 (SD = 47.3) words and was presented on a separate website displaying a headline, the learning text, a "read" button. In addition, one seductive text passage was placed beneath each text in both groups with seductive details (for an example of the structure of a web page, see Figure 3). In sum, all texts without seductive details consisted of 897 words, and all texts with seductive details 968 words (i.e., 8% more words). Seductive details were chosen as described in the prestudy.

In order to change participants' affective state of arousal, the sound of a heartbeat, differing in its rate, was used. Providing false biofeedback like heartbeats has been recognized as an effective method for alternating participants' arousal by being less learning invasive and more continuous than other manipulation methods are (Luft & Bhattacharya, 2015; Strain et al., 2013). Therefore, two sound files with a pulse of 70 or 90 bpm were created. These frequencies are supposed to induce a lower (70 bpm) and higher arousal (90 bpm) according to mean scores of previous literature (e.g., Borkovec & Glasgow, 1973; Karsdorp et al., 2009; Strain et al., 2013). Audio files had a runtime of 60 s and were looped via PHP code. These audio files were invisibly included into the learning web pages (background windows) so that learners were not distracted by the display of the audio controls.

3.4 | Tasks and measures

3.4.1 | Knowledge scores

Participants' prior knowledge about the topic sleep was measured by three self-developed questions (α = 0.87): (1) "Mention all phases of sleep which are known to you!" (2) "What is sleep deprivation?" and (3) "Note consequences of sleep deprivation!" For each question, a maximum of one point could be reached, whereas Question 1 was divided into 0.2 point steps for each phase, whereby students only need to name one correct answer in Questions 2 and 3 to reach one point. Answers were corrected on the basis of a predefined answer list by three raters, resulting in a good interrater reliability for all items (κ = 0.97).

Moreover, learning outcomes were measured by a self-developed posttest containing 16 multiple-choice questions with four preset answer possibilities. The test consisted of eight retention (α = 0.71) and eight transfer questions (α = 0.80). Both the retention and transfer questionnaires are displayed in the Appendix. For all retention questions, students had to retrieve information that was explicitly named in the learning material (Mayer, 2014). In terms of transfer questions, students had to apply gained knowledge to a new problem (Mayer, 2014).

3.4.2 | Affect measures

In order to measure arousal, the translated version of the Activation–Deactivation Adjective Check List (Imhof, 1998) was used, consisting of 20 adjectives divided into two dimensions: (a) *energy* with the subdimensions energy (e.g., full-of-pep) and (b) tiredness (reversed;

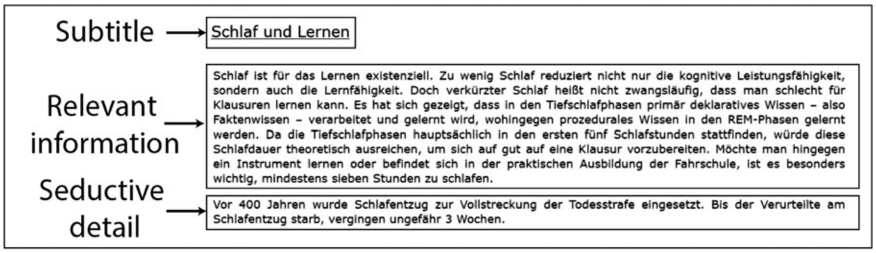

FIGURE 3 Example of the structure of a learning web page in the experiment

e.g., drowsy) and *tension* with the subdimensions tension (e.g., clutched-up) and calmness (reversed;e.g., placid). Answers were given via a 4-point scale ranging from 1 (*strongly disagree*) to 4 (*strongly agree*). In order to measure valence, two valence items from the Positive Activation, Negative Activation, and Valence in experience sampling studies Short Scale (Schallberger, 2005) were included. Participants were asked to indicate their level of agreement for each item on a 7-point bipolar Likert scale ranging from "−3" (i.e., "*satisfied*" and "*happy*") to "+3" (i.e., "*dissatisfied*" and "*happy*").

3.4.3 | Electro-dermal activity and heartbeat frequency

Electro-dermal activity (EDA) and heartbeat frequency were continuously and simultaneously recorded during learning with the Empatica WristBand E4 (Garbarino, Lai, Bender, Picard, & Tognetti, 2014). This band was placed on the wrist of the nondominant hand. Data were collected four times per second. For each learner, mean values (less a baseline measurement of 10 s) for both the EDA and heartbeat frequency data were calculated. Higher scores of physiological measures like EDA were also shown to be an indicator of an increased cognitive load of learners (Setz et al., 2010).

3.4.4 | Cognitive load scores

Although there is evidence that a two-factorial approach (ICL and ECL) is a sufficient approach in explaining demands on learners' resources without redundancy (Kalyuga, 2011), latest measures of cognitive load still relied on the three-factorial model. In conclusion, the 10-item questionnaire (Leppink, Paas, Van der Vleuten, Van Gog, & Van Merriënboer, 2013; 10-point scale; ranging from 0, *not at all*, to 10, *completely agree*) measuring cognitive load was included measuring all three concepts of cognitive load in order not to miss the GCL concept in the measurement of cognitive load. As this questionnaire was only provided in English, we used a translated version of this questionnaire by Schneider, Nebel, Beege, and Rey (2017). In detail, the subscales are ICL (three items; α = 0.81,e.g., "The topics covered in the activity were very complex"), GCL (four items; α = 0.82, e.g., "The activity really enhanced my understanding of the topics covered"), and extraneous cognitive load (three items; α = 0.75, e.g., "The instructions and explanations during the activity were very unclear").

3.5 | Procedure

Participants were tested in single-person sessions and were randomly assigned to one of the four experimental conditions by drawing lots. All parts of the experiment were computer based using 4 × 2.8 GHz workstation PCs, 24-in. displays (resolution, 1,920 × 1,080 pixels), and commercial headphones. At the beginning, participants were told to follow the on-screen instructions of the programme (i.e., instructions how to fill in the questionnaires). All questionnaires were displayed in full-screen mode, so participants could not be distracted by any other software. Participants were tested regarding their prior knowledge. Besides, the first measurement of all affect scales was conducted (baseline measurements). After that, participants were instructed to wear the Empatica wristband. For manipulation purposes, participants were told that this wristband is capable of providing real-time biofeedback. In order to achieve baseline measurements, students were told to wait 10 s after the successful calibration in order to calibrate the system, although the wristband already tracked data. This time was used to balance the prior levels of the learners' states of arousal. After this, they were told to wear headphones, which purportedly played their synchronized pulse. Dependent on the experimental group, participants always listened to a looped pulse with either 70 or 90 bpm of a looped heartbeat. Participants were then instructed to navigate through the websites. Time on task protocols were created automatically. At the end of the learning pages, the participants were shown a picture that instructed them to turn off their wristbands. After that, participants were advised to remove their headphones and the wristband and to proceed with the next set of questionnaires in the following order: affect and cognitive load as well as both learning scores. At the end, the participants were asked to provide demographic information. Overall, the entire study took between 35 and 45 min.

4 | RESULTS

Descriptively, students took between 12 and 18 min for the learning web pages (M = 899.15 s, SD = 106.67). Moreover, participants were low in prior knowledge (M = 0.86 points; SD = 0.92). Difference scores were calculated for the energy, tension, and valence measurements (i.e.; after-measurement minus baseline measurement). In addition, a multivariate analysis of variance showed that there were no significant main or interaction effects for the independent variables seductive details and level of false HR in terms of age, gender, study subject, and time on task (ps > 0.05). All descriptive results for the dependent variables by the experimental groups are displayed in Table 2. In the analyses of data, multivariate analyses of covariance (MANOVAs) and univariate analyses of covariance were conducted with the presence of seductive details (yes vs. no) and level of false HR (lower vs. higher) as between-subject factors. Predefined test

TABLE 2 Descriptive results (means and *SDs*) of all measures by experimental group

	Groups							
	Without seductive details Slow heart rate (*N* = 25)		Fast heart rate (*N* = 25)		With seductive details Slow heart rate (*N* = 25)		Fast heart rate (*N* = 25)	
Measure	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Energy difference	−0.11	0.39	0.14	0.39	−0.20	0.32	0.12	0.31
Tension difference	0.05	0.27	−0.06	0.27	0.02	0.25	0.05	0.40
Valence difference	0.02	0.70	0.32	1.02	0.20	0.65	−0.02	0.96
Learning: Prior knowledge	0.76	0.93	0.72	0.84	0.96	0.84	0.84	1.11
Learning: Retention	25.88	2.54	25.88	2.68	22.76	2.17	26.28	2.41
Learning: Transfer	23.72	2.21	23.96	2.23	20.24	2.80	24.44	2.71
Intrinsic cognitive load	5.16	1.56	4.25	1.74	5.24	1.40	4.73	1.79
Extraneous cognitive load	2.75	1.26	2.48	1.22	4.36	1.33	2.83	0.88
Germane cognitive load	7.04	1.42	7.04	1.09	6.74	1.52	7.36	1.40
Electro-dermal activity difference	0.42	0.68	0.54	0.93	1.37	1.02	0.62	0.81
Heart rate difference	4.79	13.30	9.22	12.33	9.01	10.62	7.95	10.95
Time on task (in seconds)	905.60	99.74	902.00	112.24	918.88	113.22	870.12	101.15

Note. Affect difference scores ranged from −6 to 6. Prior knowledge scores ranged from 0 to 3. Retention and transfer scores ranged from 0 to 32 points. Cognitive load scores ranged from 1 to 10.

assumptions are only reported if significant violations occurred. Follow-up analyses are only reported when main or interaction significant effects were found in the multivariate analyses.

4.1 | Manipulation check

Prior to the main analyses, differences in the assessment of affect were analysed as a manipulation check. For this, a MANOVA was conducted with the energy difference, tension difference, and valence difference as dependent variables. Significant main effects were found for level of false HR, Wilk's Λ = 0.85, $F(3, 94) = 5.57$, $p = 0.001$, $\eta_p^2 = 0.15$, but neither for the presence of seductive details, Wilk's Λ = 0.99, $F(3, 94) = 1.17$, $p = 0.81$, $\eta_p^2 = 0.01$, nor for the interaction, Wilk's Λ = 0.97, $F(3, 94) = 1.06$, $p = 0.37$, $\eta_p^2 = 0.03$. A follow-up analysis of variance (ANOVA) for level of HR reveals only a significant effect for energy, $F(1, 96) = 16.39$, $p < 0.001$, $\eta_p^2 = 0.15$. Students with fast false HR revealed higher difference scores of energy than did students with slower false HR (see Table 2). In conclusion, the method to induce arousal via two levels of false HR can be seen as confirmed, because energy levels increased with higher HR, whereas tension and valence assessments were not affected.

4.2 | The effects of false HR and seductive details on learning

In order to analyse possible differences for all learning scores, a MANOVA, with the retention and transfer scores as dependent variables, was conducted. Significant main effects were found for level of false HR, Wilk's Λ = 0.76, $F(2, 95) = 15.25$, $p = 0.004$, $\eta_p^2 = 0.24$, and for seductive details, Wilk's Λ = 0.86, $F(2, 95) = 7.80$, $p < 0.001$, $\eta_p^2 = 0.14$. There was also a significant interaction, Wilk's Λ = 0.78, $F(2, 95) = 13.35$, $p < 0.001$, $\eta_p^2 = 0.22$.

A first follow-up ANOVA for the presence seductive details reveals significant effects for retention, $F(1, 96) = 7.67$, $p = 0.007$, $\eta_p^2 = 0.07$, and transfer, $F(1, 96) = 8.99$, $p = 0.003$, $\eta_p^2 = 0.09$. Students with seductive details revealed lower scores of retention and transfer than did students without seductive details. Descriptive results are displayed in Table 2. A second follow-up ANOVA for level of false HR shows significant effects for retention, $F(1, 96) = 12.84$, $p = 0.001$, $\eta_p^2 = 0.12$, and transfer, $F(1, 65) = 19.69$, $p < 0.001$, $\eta_p^2 = 0.17$. Students with a higher false HR revealed higher retention and transfer scores than did students with a lower false HR. A closer look at the interaction of seductive details and level of false HR reveals a significant effect for retention, $F(1, 96) = 12.84$, $p = 0.001$, $\eta_p^2 = 0.12$, and for transfer, $F(1, 96) = 15.66$, $p < 0.001$, $\eta_p^2 = 0.14$. The significant interactions are shown in Figures 4 and 5. Under lower

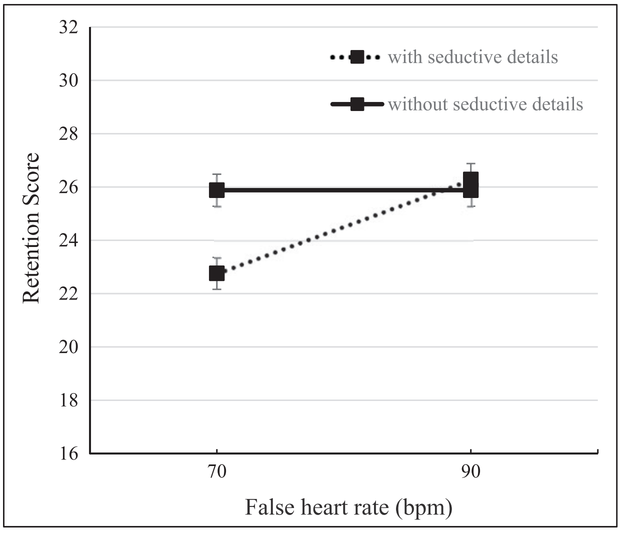

FIGURE 4 Mean retention scores and corresponding standard errors by experimental group. Retentions scores range from 0 to 32 (16 points represent 50% guess probability)

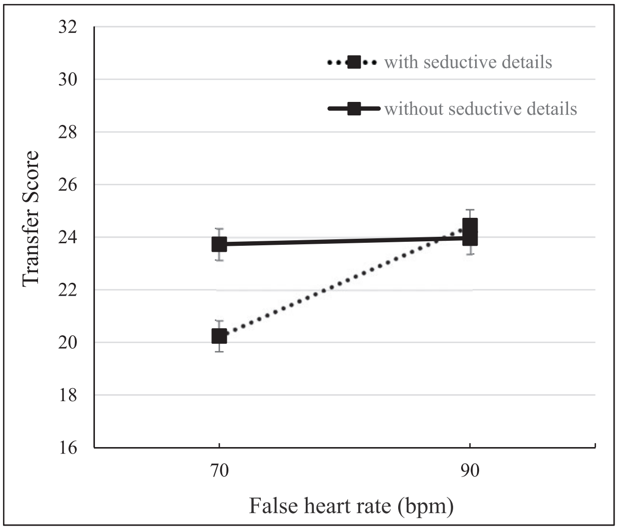

FIGURE 5 Mean transfer scores and corresponding standard errors by experimental group. Transfer scores range from 0 to 32 (16 points represent 50% guess probability)

false HR conditions, seductive details were shown to decrease learning in contrast to a material without seductive details, whereas this effect disappeared under a higher false HR conditions. These results confirm H1, H2, and H3.

4.3 | The effects of false HR and *SD* on cognitive load

An interesting question is if differences in the level of false HR and the presence of seductive details influence the assessment of cognitive processes. For this, a MANOVA was conducted with ICL, ECL, and GCL scores as dependent variables. Significant main effects were found for level of false HR, Wilk's $\Lambda = 0.86$, $F(3, 94) = 5.21$, $p = 0.001$, $\eta_p^2 = 0.14$, and for seductive details, Wilk's $\Lambda = 0.85$, $F(3, 94) = 5.74$, $p = 0.002$, $\eta_p^2 = 0.16$. In addition, a significant interaction was revealed, Wilk's $\Lambda = 0.91$, $F(3, 94) = 3.29$, $p = 0.024$, $\eta_p^2 = 0.10$.

A follow-up ANOVA for the presence of seductive details revealed only a significant effect for ECL, $F(1, 96) = 17.11$, $p < 0.001$, $\eta_p^2 = 0.15$. Students with seductive details assessed a higher ECL than did students without seductive details (see Table 2). A second ANOVA for the level of false HR showed a significant effect for ECL, $F(1, 96) = 14.43$, $p < 0.001$, $\eta_p^2 = 0.13$, and a significant effect for ICL, $F(1, 96) = 4.70$, $p = 0.033$, $\eta_p^2 = 0.05$. Students with a lower false HR assessed a higher ECL and a higher ICL than did students with a higher false HR (see Table 2). In addition, there was a significant interaction effect for ECL, $F(1, 96) = 7.14$, $p = 0.009$, $\eta_p^2 = 0.07$. The interaction is shown in Figure 6. Again, a higher false HR diminished the ECL-inducing effect of seductive details, which was found for the lower false HR conditions.

4.4 | The effects of false HR and *SD* on physiological measures

For two participants, psychological data could not be computed because of technical defects. First, an ANOVA was conducted with the EDA difference scores as dependent measure. The analysis revealed a significant effect for seductive details, $F(1, 94) = 8.43$, $p = 0.005$, $\eta_p^2 = 0.08$. Moreover, a significant interaction effect could be revealed, $F(1, 94) = 6.36$, $p = 0.013$, $\eta_p^2 = 0.06$. The interaction effect of level of false HR and seductive details on EDA is displayed in Figure 7. Although seductive details led to higher scores of EDA under lower false HR conditions in contrast to a material without seductive details, this difference disappeared under higher false HR conditions. Second, an ANOVA was conducted with the HR difference scores as dependent measure. Here, no significant effects could be revealed.

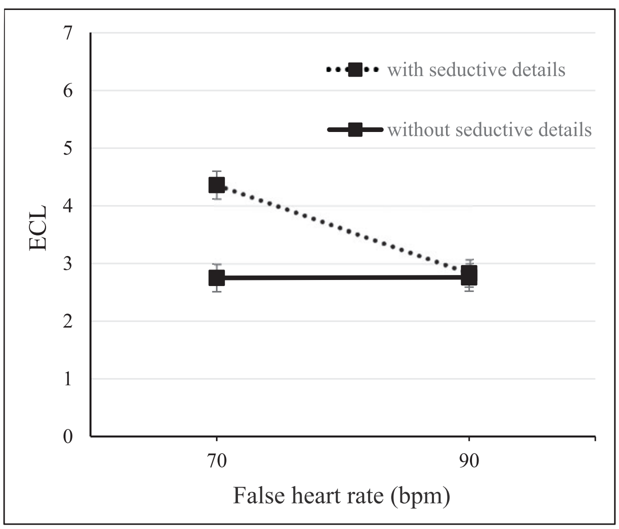

FIGURE 6 Mean ECL scores and corresponding standard errors by experimental group. ECL scores range from 0 to 7. ECL, extraneous cognitive load

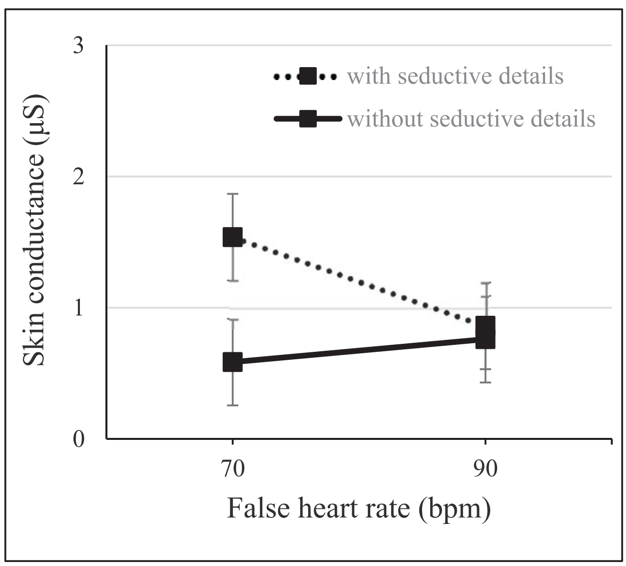

FIGURE 7 Mean skin conductance scores and corresponding standard errors by experimental group

4.5 | Mediation analysis

After demonstrating the effects of *SD*s and arousal on learning performance as well as cognitive and physiological measures, the effects of all presupposed mediators (ICL, ECL, GCL) were analysed. In order to check the collinearity of all constructs (Hayes, 2009), correlations among all dependent and independent were calculated (see Table 3). As all mediators need to significantly correlate with either retention or transfer, only ICL and ECL were included in the mediation analysis of *SD*s and arousal on retention and transfer. No outliers were detected for the dependent variables. A series of regression analyses based on the PROCESS macro (Hayes, 2013) were run, whereby only significant mediation analyses were reported.

The results show five significant mediation models (see Table 4). The indirect effects were calculated by using a bootstrapping procedure with k = 5,000 trials, because this test should be preferred in contrast to the Sobel test (Hayes, 2009).

As a result, the effect of the presence of *SD*s on retention was mediated by ECL. The indirect effect explains 65% of the total effect. The effect of the presence of *SD*s on transfer was also mediated by ECL with a 63% explanation rate. In contrast, ICL did not significantly explain variance of the total effect of *SD*s on both retention and transfer.

In addition, the effect of arousal differences on retention was mediated by ICL (27% explanation of the total effect). In contrast, the effect of arousal on transfer was not mediated by ICL. Both the effect of arousal on retention (55% explanation rate) and the effect of arousal on transfer (50% explanation rate) were mediated by ECL.

5 | DISCUSSION

According to Harp and Mayer (1998), seductive details play a crucial role in the deterioration of a learner's performance because such details consume too many cognitive resources, which cannot be used to process learning-relevant information, and, thus, overload a learners' working memory capacity. At first glance, the present study was able to replicate this assumption by revealing that seductive text passages decreased both retention and transfer learning performance in contrast to a learning text without seductive details. An enlargement in the learners' perception of ECL and an increase in their EDA scores in the groups with seductive details additionally emphasized the learning-inhibiting effect of seductive details—a result that is in line with previous research (Wang & Adesope, 2017). Also in accordance with previous findings (Brainerd et al., 2010), the playback of higher false HR (in contrast to lower false HR) was connected with higher states of arousal and an increase in the learners' retention and transfer performance. In consequence and based on the Yerkes–Dodson law, the induced higher arousal in this study was in the range of an optimum of arousal states. An increase in the level of a false HR did also result in a decrease of the learners' perceptions of ECL and ICL. As ECL and ICL can be seen as constant when only looking at differences in the manipulation of the false heartbeat, the reduction of both load types might arise from the increase of more cognitive resources. In this case, the invested cognitive load is in relation to the free cognitive resources lower than in the case of a lower arousal. This underlines the assumption that the total amount of cognitive resources increased with a higher arousal, because the content and the design of the learning material, which are theoretically connected with ICL and ECL (Sweller et al., 2011), did not change. In this vein, measured HRs of learners were not significantly changed. A reason might be that an increased arousal is not always affecting physiological measure like HRs if the stimulus is not additionally changed in its valence (Bonnet & Arand, 1997).

Interestingly, an interaction effect for the retention performance showed that the seductive detail effect could only be verified for lower false HR conditions, whereas for higher false HR conditions, no differences occur. According to Park et al. (2011), seductive details do not hamper learning if enough cognitive resources were available. In conclusion, ways of making additional cognitive resources available, like increasing learners' states of arousal, were found to counter the seductive detail effect.

A closer look at the mediation analyses showed that the negative effect is mainly explained by an increase of ECL. This result mirrors the statements of the CLT, which postulates that extraneous (irrelevant) learning materials lead to an increase in this type of CL. In contrast, an increase in the learners' states of arousal leads to a decrease in their assessment of ECL and, in part, their assessment of ICL. These decreases finally lead to an increase in the learning performance. This result shows that an increase in arousal might be able to request more

TABLE 3 Correlations between the independent variables (IV), dependent variables (DV), and possible moderators of the present experiment

Variables	1	2	3	4	5	6	7
1. Seductive details (IV)	—						
2. States of arousal (IV)	0.000	—					
3. Retention (DV)	−0.243*	0.315**	—				
4. Transfer (DV)	−0.253*	0.375***	0.325**	—			
5. Intrinsic cognitive load	0.085	−0.215*	−0.281**	−0.066	—		
6. Extraneous cognitive load	0.356***	−0.327**	−0.327***	−0.352***	0.310**	—	
7. Germane cognitive load	0.004	0.115	0.176*	0.045	−0.211*	−0.191	—

Note. Seductive details with 0 = without *SD*s and 1 = with *SD*s. States of arousal with 0 = low arousal and 1 = high arousal.

*p < 0.05.

**p < 0.01.

***p < 0.001.

TABLE 4 Overview on all regression analyses and indirect effects of the significant mediation analyses

Model no.	IV	DV	M	Regression analyses *a*	*b*	*c*	*c′*	Indirect effect *ab/c*	*SE*	95% CI
1	Seductive detail	Retention	ECL	$\beta = 0.98$ $t = 3.78$ $p < 0.001$	$\beta = -0.66$ $t = 3.26$ $p = 0.002$	$\beta = -1.36$ $t = 2.49$ $p = 0.015$	$\beta = -0.71$ $t = 1.27$ $p = 0.207$	−0.650	0.321	[−1.403, −0.140]
2	Seductive detail	Transfer	ECL	$\beta = 0.98$ $t = 3.78$ $p < 0.001$	$\beta = -0.65$ $t = 2.98$ $p = 0.004$	$\beta = -1.50$ $t = 2.59$ $p = 0.011$	$\beta = -0.87$ $t = 1.45$ $p = 0.149$	−0.633	0.356	[−1.472, −0.089]
3	Arousal	Retention	ICL	$\beta = -0.71$ $t = 2.18$ $p = 0.032$	$\beta = -0.66$ $t = 3.26$ $p = 0.022$	$\beta = 1.76$ $t = 3.29$ $p = 0.001$	$\beta = 1.49$ $t = 2.78$ $p = 0.006$	0.268	0.156	[0.078, 0.617]
4	Arousal	Retention	ECL	$\beta = -0.90$ $t = 3.43$ $p = 0.009$	$\beta = -0.61$ $t = 3.09$ $p = 0.003$	$\beta = 1.76$ $t = 3.29$ $p = 0.001$	$\beta = 1.21$ $t = 2.23$ $p = 0.028$	0.550	0.272	[0.108, 1.171]
5	Arousal	Transfer	ECL	$\beta = -0.90$ $t = 3.43$ $p = 0.009$	$\beta = -0.55$ $t = 2.67$ $p = 0.009$	$\beta = 2.22$ $t = 4.00$ $p < 0.001$	$\beta = 1.72$ $t = 3.02$ $p = 0.003$	0.498	0.299	[0.041, 1.183]

Note. Seductive details with 0 = without *SDs* and 1 = with *SDs*. States of arousal with 0 = low arousal and 1 = high arousal. *a*: regression from IV to M; *ab/c*: indirect effect size; *b*: regression from M to DV; *c*: regression from IV to DV; CI: confidence interval based on bootstrapping (k = 5,000); DV: dependent variable; IV: independent variable; M: mediator; *SE*: standard error of the effect size based on bootstrapping (k = 5,000).

cognitive resources. Although both the "real" ICL and ECL of the learning materials did not vary during the experiment, learners assessed their demands to be smaller than those of students with a lower arousal.

One explanation might be seen in the consideration of cognitive resources. As supposed, an increased false HR did not only lower the assessment of ECL in learners—a hint towards an increased access to cognitive resources—but also erase the effect of increased ECL scores for seductive text passages. The increase in ECL for learners with a higher false HR and seductive text passages was also combined with an increase in the EDA scores. The supposedly additional attentional resources for learners might have helped to cope with the additional information of the seductive detail passages or, at least, might have helped to assess seductive passages more accurately and concentrate on learning-relevant information.

6 | IMPLICATIONS, LIMITATIONS, AND FUTURE DIRECTIONS

The results of this study reveal that research on seductive details has to examine moderators like differences in a learner's state (Schneider et al., 2016) carefully in order not to generalize possible negative effects. Moreover, it is particularly important to increase the effort of examining the interplay between cognitive resources and demands in this research field. When possible boundary conditions of seductive details like a learners' state of arousal are identified, the positive effects of seductive details (e.g., an increase in the situational interest of learners) can be used to design effective learning environments. Another major implication of this study can be found in the results of different states of arousal. The use of the false HR feedback method seems to produce reliable differences in the learners' states of arousal. These results also emphasize the importance of a close examination of the interplay between differences in arousal, cognitive resources, and learning outcomes.

In this context, arousal-enhancing features of a learning environment like music or videos should be examined more closely in order to stimulate learners by enhancing their states of arousal. As these environments might also differ in their complexity of information transfer, future research on learners' emotional states in general should more closely examine the effects of different states of arousal in learners on their performance in complex learning situations. In accordance with the Yerkes–Dodson law (Yerkes & Dodson, 1908), the positive relation between higher states of arousal and an increase in learning can be limited until a defined border where the costs of an increase in arousal do not equal the cognitive benefits. Future research should focus on the full range of arousal. Moreover, research on the influence of seductive details should continue its examination of moderators in general and emotional states of learners in particular. As the presented results are not replicated with another group of participants or in other learning contexts, future studies are needed.

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APPENDIX. OVERVIEW OF THE USED RETENTION AND TRANSFER TASKS

Retention test

1. Which types of waves can be distinguished in electroencephalography (EEG)?

a. Alpha waves
b. Omega waves
c. Delta waves
d. Beta waves

2. What is specific for the rapid eye movement (REM) sleeping phase?

a. It is characterized by waves with high frequency and low amplitude.
b. It is characterized by waves with low frequency and high amplitude.
c. The systemic muscular system is relaxed and does not work.
d. The eyes move quickly, but the respiration is regular.

3. Which symptoms characterize sleep deprivation?

a. Hallucinations
b. Concentration difficulties
c. Nausea
d. Joint pain

4. Which sleep phases do exist?

a. Slow-wave sleep phase
b. Slow-eye movement phase
c. Rapid-wave sleep phase
d. Rapid eye movement phase

5. Which of the following sentences are valid?

a. Declarative knowledge is primarily consolidated during REM phases.
b. A shortened sleeping time of 5 hr has no negative impact on the consolidation of procedural knowledge.
c. A shortened sleeping time of 5 hr has no negative impact on the consolidation of declarative knowledge.
d. Procedural knowledge is primarily consolidated during the first slow-wave sleep (SWS) phase.

6. Which of the following statements regarding sleep of Germans are correct?

a. German habitants sleep 7 hr and 14 min on average.
b. 14.1% of the Germans usually sleep 9 hr.
c. 6.6% of the Germans are comfortable with 5 hr of sleep.
d. The majority of the Germans sleep about 8 hr on average.

7. Which of the following statements about circadian rhythms (CRs) are right?

a. The rhythm has a periodic length of 12 hr.
b. Humans can be divided into more than two types of sleep–wake rhythm.
c. The CRs are dependent on the surrounding light spectrum.
d. The CR is anchored biologically in the brain.

8. Which of the following statements about the topic sleep are correct?

a. Eight hours of sleep is the recommended and ideal length of sleep.
b. The characteristic of one's chronotype can be modified by personal habits.
c. Sleep deprivation is an acknowledged sickness.
d. The first 5 hr of sleep is enough for test preparation.

Transfer questions

1. A graduate gets a post in a big project. Every morning at 7 a.m., the team of the project meets for deploying the tasks of the day. After a few months, the graduate gained weight and suffers more frequently from racing heart. Why is that?

a. The graduate is a morning type and therefore goes too late to bed.
b. The graduate is an evening type and gets up too early.
c. The graduate is an evening type and goes to bed too late.
d. The graduate is a morning type and goes to bed too early.

2. A student has passed the theoretical examination for his driver's license 1 year ago but failed in the practical examination repeatedly. Which of the following sleep patterns could be the cause of this problem?

a. The student has a very restless sleep with many nightmares and awakens frequently.
b. The student uses to sleep just for a few hours and does not achieve longer sleeping phases.
c. The student falls asleep very late.
d. The student uses to sleep more than 9 hr a day.

3. Which of the following images depict the results of an EEG measurement? (Take care of the physical units)

Four pictures of measurements displayed.

4. Which of the marked point of times represents a REM sleeping phase?

Four labelled diagrams displayed.

5. With the help of your knowledge about frequencies and amplitudes of EEG waves, please mark all correctly labelled wave types

Four labelled diagrams displayed

6. Regarding the study about sleep deprivation, in which of the following situations could sleep deprivation be obstructive?

a. Playing Lotto
b. Decision of the course of studies or job
c. Find the way out of a labyrinth
d. Decision in the construction of a house

7. Which of the following matches between performance types and chronotypes are correct?

Four labelled diagrams displayed

8. Which chronotypes do exist?

a. Morning type
b. Evening type
c. Night type
d. Midmorning type