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Receiving push-notifications from smartphone games reduces students learning performance in a brief lecture: An experimental study

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ABSTRACT

Many university students use mobile phones during study tasks for unrelated activities. It is known that using social networking while studying reduces the learning performance. The objective of the present study was to investigate whether using smartphone games during a lecture reduces the learning performance, and whether this is influenced by receiving push notifications. Ninety-three students were randomized to three conditions: In two gaming conditions (G), participants played a custom-made gaming-app (20 s) at 2-min intervals while watching a video mimicking a lecture. In one subgroup (GN+), the game app sent push notifications; in the other (GN-), no notifications were sent. Participants in the control group (C) watched the lecture without playing. Subsequently, participants answered multiple choice questions and estimated their own quiz performance. Comparing the quiz scores and subjective performance estimates of the three groups showed that the learning performance in GN+ was lower than in C ($d = 0.51$); no other differences were observed. Participants' subjective performance estimations remained unaffected by the experimental condition. Possible implications of the divergence of the subjective estimate and objective performance are discussed, as well as limitations, such as the low complexity of the game used and the short lecture duration, not reflective of typical lectures.

1. Introduction

In some lectures one may get the feeling that part of the students are only physically present: the gaze is fixed on laptop or smartphone (Gehlen-Baum & Weinberger, 2014). Nearly all (96%) German university students own a smartphone (VuMa, 2019). Thus, the question whether smartphones interfere with university students' learning is highly relevant. One study found that 64 percent of students were using mobile devices in parallel to the lectures: 52 percent of the observed use was deemed independent of the lectures (e.g. gaming or watching a video), 30 percent was related to the lecture content (e.g. looking up a technical term) and 18 percent was classified as inconclusive (Gehlen-Baum & Weinberger, 2012). The use of mobile devices during a lecture had negative effects on the (self-rated) understanding of course material or overall course performance (Fried, 2008; Gehlen-Baum & Weinberger, 2012; Kraushaar & Novak, 2010). In a similar vein, self-report studies also found negative relationships between the use of social networks and the grade point average (e.g., Karpinski, Kirschner, Ozer, Mellott, & Ochwo, 2013; Rosen, Mark Carrier, & Cheever, 2013). Experimental studies, investigating actual student performance are scarce. In a previous study, we investigated the possible disruptive effects of the use of a custom-made smartphone gaming app while reading a text (Graben, Doering, & Barke, 2021). We did not find any significant differences in reading time or quiz performance between participants who repeatedly used a gaming app while reading and participants who did not. Given the previous research on interruptions on learning performance (Conard & Marsh, 2014; Kuznekoff & Titsworth, 2013; Oulasvirta & Saariluoma, 2004), this result was unexpected. One possible explanation that could not be addressed within the previous study, was that participants did perhaps not miss any information during the game because they had stopped reading to play and then started reading again at the same point in the text. However, in the context of lectures, there is no chance to stop or rewind when interruptions occur. In a Canadian study (Wood et al., 2012), an experimental group using a smartphone (texting, emailing, MSN messaging and Facebook) and three control-groups (enforced paper-and-pencil note-taking, enforced word-processing note-taking and a natural use of technology condition) took a 15-item quiz after a 20 min lecture presentation and all of the

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control groups fared better than the group using social networks on the smartphone during the lecture. These results have been replicated with different experimental designs (Conard & Marsh, 2014; Dietz & Henrich, 2014; Gupta & Irwin, 2016). The cited studies have in common that the distraction consisted of communication via the smartphone, rather than gaming. However, smartphone gaming is widespread: Every fourth German Internet user plays video games on the smartphone every day (Ipsos, 2016). These games may also lead to frequent interruptions while learning because of game-inherent mechanisms: In many popular gaming apps, the user has a limited amount of 'energy' to play which only allows a few actions before the user has to wait for a recharge (e.g., *Harry Potter: Hogwarts Mystery*™ requires one energy unit every 4 min). In some other games, rewards occur on a regular time rate (e.g. in *Hay Day*™, wheat can be harvested after 2 min or carrots after 10 min). Most gaming apps send so-called 'push-notifications' to call the users' attention to these events and to motivate the users to turn their attention to the game again. Depending on the user's phone settings, push notifications can be audio or vibration signals, which interrupt other activities. Such notifications can be turned off in the phone's or app's user-settings. Even if the user deactivates the notifications, it is still possible to be aware of these time rates and to continue playing accordingly in order not to miss any game events or rewards. Relative to the main activity (e.g. studying), the push notification can be seen as externally generated interruption, the monitoring of the intervals without push notifications can be regarded as internally generated self-interruption.

Interruptions are generally detrimental to the main task that is being interrupted (Couffe & Michael, 2017; Trafton & Monk, 2007). The exact 'costs' to the main task depend on several factors, such as the nature of the tasks, motivational aspects (Gupta & Irwin, 2016) and the locus of the interruption - processing time of the main task was longer when the interruptions were internally rather than externally generated (Katidioti, Borst, Van Vugt, & Taatgen, 2016). The authors explain the increased processing time by the additional cognitive load required for the decisions to change tasks. However, in a natural office environment, participants return later to the main task in case of external interruptions. Cades, Werner, Boehm-Davis, and Arshad (2010) assume that it is more difficult to return to the main task when there is a lack of control over the timing of the interruption to pace the activities accordingly.

It is not yet known whether playing mobile games while attending lectures can have disruptive effects, and the extent to which receiving push notifications plays a role in this. In the present study, we examined the effects of a standardized smartphone game on students' performance when watching a brief lecture-like video that – like a real lecture – could not be paused by the students, but proceeded regardless of their activity. We investigated whether the concurrent use of the gaming app once with and once without push notifications resulted in performance differences by examining three groups: (1) one group watched the lecture-line video without interruptions of the mobile game (C); (2) the second group watched the video, played the mobile game, and received push notifications from the game (GN+); (3) the third group watched the video, played the mobile game, but did not receive push notifications (GN-). Group 2 and 3 together will be referred to as the 'gaming group (G)'. Performance was operationalized as the score in a quiz testing the participants' understanding and retention of the information contained in the video.

The objective of the present study was to investigate whether using smartphone games during a lecture reduces the learning performance and whether receiving push notifications has an impact on the learning performance. We tested the following hypotheses:

(1a) Students' learning performance is lower in the gaming group (G) than in the control group (C).
(1b) Students' learning performance is lower in the group receiving push notification (GN+) than in the control group (C).
(1c) Students' learning performance is lower in the group not receiving push notifications (GN-) than in the control group (C).
(2) Students' learning performance differs between the groups with (GN+) and without push notifications (GN-).

2. Method

2.1. Ethics

The study was approved by the internal review board of Philipps-University Marburg (approval ID: 2019-70k). It was conducted in accordance with the Declaration of Helsinki (World Medical Association, 2013) and participants received full information about the study and provided informed consent. Participants were able to earn course credits by participating.

2.2. Participants

A student sample was recruited online through a university research participation system and via a university-wide email list. All students of a Marburg University with age over 18 years and unrestricted abilities of seeing, hearing and movement of the fingers were permitted to participate. The sample size was determined with reference to comparable studies (Conard & Marsh, 2014; Dietz & Henrich, 2014; Wood et al., 2012) that examined the effect of texting or Facebook use during a lecture-style video and used sample sizes ranging from $n = 21$ to $n = 56$ per group. Informed consent was provided by 98 participants. After three participants were excluded due to technical difficulties and two because they failed to follow the instructions, 93 participants remained for analysis. The majority were women (73.1%). The mean age was 22.8 $\pm$ 3.8 years and the mean school-leaving grade 1.8 $\pm$ 0.7 (possible range: 0.7 [best] to 4.0 [worst]). Although this was not an inclusion criterion, all participants reported owning a smartphone.

2.3. Procedure

The study was conducted in a behavioural laboratory at Marburg University. After they had provided informed consent, the participants were allocated randomly to one of the three experimental groups (push notifications GN+, no push notifications GN-, control C). They familiarized themselves with the game by playing a demo-version on the provided smartphone. Subsequently, they provided demographic information, rated their prior knowledge regarding the topic of the video (i.e. the Tau-Ceti system), and completed the questionnaires using the online survey software *SoSci Survey* (SoSci Survey GmbH, Munich, https://www.soscisurvey.de).

The participants were then asked to watch a video on the Tau-Ceti system and informed that their learning performance would be tested afterwards. Participants in the gaming groups (GN+ and GN-) watched the video while they played the smartphone game for 20 s every 2 min. They received the instruction that both tasks (watching the video and gaming) were important and they should try to do as well as possible in both of them. Participants in the control group (C) watched the video without playing the game.

After the video, all participants completed the quiz and provided information about their motivation, their subjective performance and their typical smartphone use.

2.4. Material

2.4.1 Video and pilot testing

As study task, we selected a video that was similar in structure, perspective and complexity to a typical lecture. The topic was selected to be unfamiliar to most participants to ensure that any knowledge had to be gained from the video. To choose the topic, we conducted a pilot study, in which 15 students of psychology at Marburg University were asked to indicate their knowledge of three topics on a six-point rating scale (0–5). For the 'Tau Ceti system', the pilot test participants indicated no prior knowledge (0 ± 0). Based on this result, we decided to use a video from the series α-Centauri ('Was ist nur mit dem Tau-Ceti-System los?' - 'What's going on in the Tau Ceti System?') of the educational channel *BR-alpha* of the *Bayerischer Rundfunk* (Bavarian broadcasting company). In the video, the astrophysicist Prof. Dr. Harald Lesch gives a 15-min lecture about the Tau Ceti System (a star-system, 11.9 light-years away). The video showed the speaker, a coloured background, an empty blackboard and an old school desk.

2.4.2 Demographic information and prior knowledge regarding the lecture topic

Participants provided information on sex, age, their first language, the subject studied and the semester and their grade in the German school leaving certificate (Abitur: the university entry requirement). In order to assess their prior knowledge of the topic of the video, we asked the participants to rate how much they know about the Tau-Ceti system and six distractor topics (cinema, methane hydrate, fracking, low-energy houses, neopterans and forest owls) on a six-point scale (0 = "I do not know anything about this topic", 5 = "I know everything about this topic").

2.4.3 Quiz

Participants' learning performance about the video content was tested with a knowledge test in multiple choice format. The quiz consisted of 16 questions with four answer options (one correct answer and three distractors). Participants could not skip questions. The number of correctly answered questions (quiz-score: maximum 16, minimum 0) indicated the learning performance. The quiz was pilot tested with regard to the scores students would achieve without watching the video. A group of n = 29 psychology students (mean age: 21.2 ± 1.1 years, sex: 82.8% women) took the quiz and scored 4.5 ± 1.7 points, which is close to the score of 4, representing a performance at chance level.

2.4.4 Smartphone game

In order to ensure that the gaming app was standardized and novel to all participants, the first author (KG) programmed a custom app (see Fig. 1) that was easy to use. The app was programmed with the MIT App Inventor (Massachusetts Institute of Technology, Massachusetts, USA) and installed on a smartphone (Huawei P8 lite 2017) provided to all participants for the duration of the experiment. The participants' task was to use a finger to drag a penguin-figure across the screen to collect statically displayed fish while avoiding the figure of a polar bear that moved randomly across the screen. The score of collected fish was displayed at the top of the screen. Touching the polar bear resulted in a loss of all fish collected and the score was reset to nil. The game could only be played for 20 s at a time. Then a black screen appeared for at least 2 min. Once the 2 min were over, the participants could resume gaming by touching the black screen. Depending on the condition, the end of the 2 min waiting period was signalled by a short signal (vibration and a beep (GN+)), or not announced (GN-).

2.4.5 Motivation check

After watching the video and again after taking the quiz, the participants were asked how motivated they were to do well in completing the preceding experimental activity (playing the game, watching the video, taking the quiz), how interested they were in the respective activity and how much fun it was. After the quiz, participants were also asked to estimate how well they did in answering the video-related questions. At the end of the experimental part, participants in the gaming group indicated how well they believed to have done in the game and how much they had felt disturbed by the app while watching the video. All questions were rated on a six point scale (1 = "not at all", 6 = "very much").

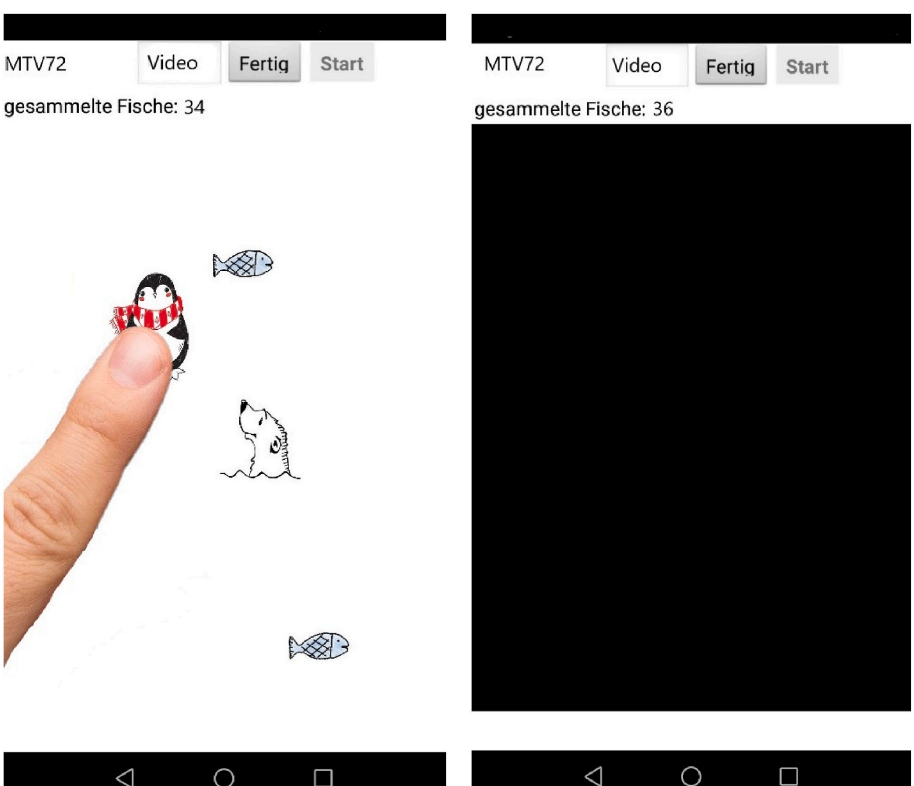

Fig. 1. Screenshots of the smartphone game. Left panel: gaming screen with finger moving the penguin. Right panel: waiting screen. 'Gesammelte Fische': number of fish collected; 'fertig': finished.

2.4.6 Smartphone use

To assess problematic smartphone use, Participants completed the German version of the *Problematic Use of Mobile Phones* (PUMP) scale (Graben, Doering, Jeromin, & Barke, 2020; Merlo, Stone, & Bibbey, 2013). The PUMP has a 5-point scale (1 = "strongly disagree" to 5 = "strongly agree") on which the participants rate their agreement with 20 statements about possible thoughts, feelings, and behaviours related to problematic smart phone use. The original PUMP scale showed good internal consistency ($\alpha = 0.94$), as mirrored in the present study ($\alpha = 0.90$).

Participants also indicated whether they owned a smartphone (mobile phone with internet access), a cell phone (mobile phone without internet access) or no mobile phone at all. They estimated their typical daily usage time (minutes) on the mobile phone and how often they would typically interrupt their studies on their own initiative with their mobile phone (count), and how often interruptions occurred as a reaction to notifications initiated by the phone (count).

2.5. Data analysis

The randomization with regard to basic variables (age, Abitur school leaving grade, problematic smartphone use patterns, previous knowledge of the Tau Ceti System and interest in it, and the motivation to perform well in the quiz) was tested with one-way ANOVAs. Sex differences between the groups were examined with a χ^2 test. Outliers in the quiz performance in the experimental task (±1.5 SD) were identified (4 participants: two in group C [n = 29], one in GN+ [n = 30] and one in GN-[n = 30]) and removed from further analysis.

The hypotheses were tested by planned contrasts. Hypothesis 1 was tested by comparing group C with the overall group G and the subgroups GN+ and GN- with one-tailed *t* tests for independent samples; Hypothesis 2 by comparing the subgroups GN+ and GN- with a two-tailed *t* test. We calculated the same contrasts for the participants' self-rated performance. As a measure of the effect size, Cohen's *d* was calculated.

All analyses were computed with SPSS version 21.0.0 (IBM, Meadville, USA).

3. Results

The three experimental groups did not differ in any of the basic variables (see Table 1 for a full characterization). Generally, participants were highly motivated to perform well in the quiz (5.00 ± 0.84; scale 1 to 6) and the gaming app (4.80 ± 1.13; scale 1 to 6).

3.1. Performance regarding the gaming app

The groups GN+ and GN- showed no differences in the performance of the gaming app (see Table 2 for a full characterization) except for time needed to return to the game after the 2 min breaks: In the GN- group, participants started later to play again (first touch of the screen) [$t(58) = -5.42$, $p < .001$, $d = 1.40$].

Participants felt moderately (4.2 ± 1.4, 1 = 'not at all'; 6 = 'very much') distracted by the gaming-app while watching the lecture video. No significant difference between the two gaming groups (GN+, GN-) was observed [$t(58) = 0.18$, $p = .859$, $d = 0.048$]. How much the participants felt distracted by the game did not correlate with the achieved quiz-scores ($r = -0.22$, $p = .870$).

3.2. Quiz performance

3.2.1 Objective quiz performance

The planned comparisons showed no group differences between the whole gaming group G and the control group C [one-tailed *t* test: $t(87) = 1.590$, $p = .051$, $d = 0.36$]. The control group outperformed the group receiving push message GN+ [one-tailed *t* test: $t(57) = -1.937$, $p = .029$, $d = 0.51$], but not the group monitoring the time for gaming by themselves GN- [one-tailed *t* test: $t(57) = -0.898$, $p = .187$, $d = 0.23$] (see Fig. 2). There were no performance differences between the two gaming groups GN+ and GN- [two-tailed *t* test: $t(58) = -0.900$, $p = .372$, $d = 0.23$] (Table 3).

3.2.2 Subjective quiz performance

The subjective performance did not differ between the groups (see Table 3) with all $t < 0.506$ and all $p > .28$.

4. Discussion

With this study, we present the first experiment to investigate whether the parallel use of smartphone gaming apps disturbs students' learning performance when watching a lecture-like video and whether this is affected by the settings of push notifications. We found that students receiving push notifications alerting them to the game showed reduced learning performance compared to the non-gaming control group.

The results extend our previous research (Graben et al., 2021), in which we used the same variation of gaming and control, when students were reading a text: we did not find group differences of quiz performance or net reading time. In that study, we surmised that students were able to compensate for potential negative gaming effects because they did not miss any information when simply pausing their reading. This compensatory effort should not be possible with regard to the present design, where the lecture continues regardless. This consideration was borne out for the students who were externally interrupted during the lecture by the push notification, but not for the students who chose the time of interruption for themselves. However, we did not find any performance differences between of the two gaming groups (with and without notifications). In our study, push notifications (i.e. externally generated disruptions) and participant's own time monitoring (i.e.

Table 1
Characterization of control variables with their mean and standard deviation per group, F and *p* value for the control group (C), the gaming group without Notifications (GN-) and the gaming group with Notifications (GN+).

	C		GN-		GN+		F(2,88)	*p*
	M	SD	M	SD	M	SD		
Age	23.3	5.0	21.3	2.5	22.9	3.6	2.123	.126
Abitur school leaving grade	1.9	0.7	1.8	0.7	1.7	0.7	0.456	.635
PUMP score	44.7	12.2	46.4	11.1	48.7	10.6	0.927	.400
Previous knowledge of video topic	0.0	0.0	0.0	0.2	0.0	0.2	0.483	.619
Interest in the video	4.3	1.2	4.4	1.4	3.9	1.4	1.235	.296
Motivation for the quiz	4.9	1.0	5.1	0.7	5.1	0.8	0.575	.565
Motivation for the game	/	/	4.7	1.1	4.9	1.2	0.205	.652
Usage of Smartphone per day (min)	140.0	93.7	166.8	75.1	161.2	74.2	0.887	.416
Number interruptions per day without notifications	7.5	6.0	10.5	9.4	13.1	13.0	3.279	.052
Number interruptions per day because of notifications	9.4	11.9	15.0	19.2	9.2	9.9	1.580	.212

Note: PUMP: Problematic Use of Mobile Phones Scale (Graben et al., 2020).

Table 2
Characterization of game performance in the gaming group with their mean and standard deviation per group for the gaming group (G) and the subgroups without notifications (GN-) and with notifications (GN+). On the right calculation of *t* tests for GN+ and GN-.

	G		GN-		GN+		*t* test GN- vs. GN+		
	M	SD	M	SD	M	SD	*t*(58)	*p*	*d*
Fishes per round	30.24	7.00	29.81	8.29	30.68	5.37	−.49	629	−0.13
Number of played rounds	5.80	0.60	5.83	0.46	5.83	0.65	.00	1.00	0.00
Collisions with the polar bear per round	0.15	0.19	0.17	0.21	0.14	0.16	.62	.541	0.16
First touch of the screen per round (milliseconds)	3285.17	3417.26	5250.25	3947.37	1320.09	432.19	−5.42	< .001	1.40

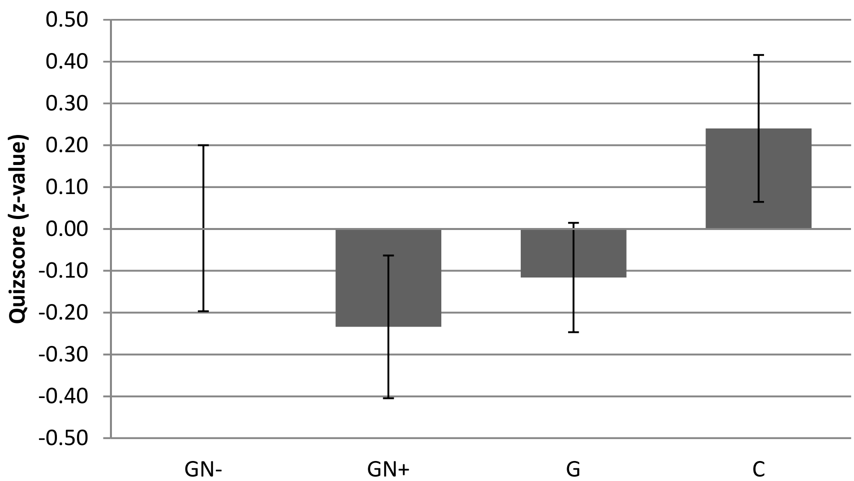

Fig. 2. z-transformed quiz scores for the gaming subgroups GN- and GN+, the complete gaming group (G) and the control group (C). Error bars show standard errors. Note: The z-value for GN- was 0.

Table 3
Characterization of quiz performance in the gaming group with their mean and standard deviation per group for the control group (C), the gaming group (G) and the subgroups without notifications (GN-) and with notifications (GN+).

	G		C		GN-		GN+	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Quiz score	12.47	2.00	13.17	1.87	12.70	2.15	12.23	1.85
Subjective quiz performance	3.60	1.05	3.72	1.16	3.63	1.16	3.57	0.94

internally controlled disruptions), seemed equally (non-)disruptive in comparison to each other, but significant group differences between GN+ and C were found (medium effect size). This corresponds to previous research (Cades et al., 2010), which suggests that control about the time of interruption may lead to a quicker return to the main task – and in our case may ensure that less information is missed. So push messages inviting the user to play a game during a lecture may be an impediment to attending to the lecture and reproducing its content. Note however, that in this study only an immediate recall was tested by the quiz. It is possible – (such an investigation would be an important line in future research) that the gaming also may have an impact on a later recall of the lecture material by impeding the encoding. A later recall would mimick more closely the student situation with an exam later in the course.

Despite the objective performance difference between C and GN+, the participants themselves did not notice a subjective performance difference. This result is a cause for concern, because if people themselves are not able to assess whether their smartphone use impacts their performance, this information will not available to them in their decision whether to use smartphone games during lectures or not.

In the present study, special emphasis was placed on a high internal validity. Firstly, the game used was completely new to the participants, although the attractiveness of self-chosen games would be much higher (presumably making them more disruptive). Higher previous investment of time, energy or money in an (Internet) game leads to further investment and increased playtime (King & Delfabbro, 2014), which is called the 'sunk cost' effect (Arkes & Blumer, 1985). In our study, however, none of the participants had ever before played the game for the sake of greater experimental control.

Secondly, all participants used the same smartphone. Previous research found that people feel psychological involvement towards their own mobile phone (Fullwood, Quinn, Kaye, & Redding, 2017; Walsh, White, & Young, 2010). Using their own phone in a real lecture may induce students to pay more attention to the smartphone (and therefore a disruptive effect would be more likely). However, we wanted to ensure an equal starting point.

The performance loss in the group receiving the push notifications was observed despite these factors that may promote an underestimation of the effect. This performance loss is the more notable, since in our study the video may have differed with respect to "real lectures", in that the information in the video was conveyed by means of speaking only (as in a traditional lecture), whereas in the case of most current lectures, additional information is presented visually in form of presentation slides or whiteboard writing. In the Tau Ceti video, it would theoretically have been sufficient to listen (like in a podcast) without watching. Also in other aspects, the video used here differs from a real lecture: the participants could not take notes, which would have certainly supported the learning, the lecture was significantly shorter than a real lecture and the motivation might have been lower due to the lack of grade pressure.

Many students are used to doing other things with a low cognitive load at the same time while listening to a lesson (Götz, Frenzel, & Pekrun, 2007) such as doodling or knitting. Research suggests that such tasks, especially doodling, may have even positive consequences on concentration and learning (Andrade, 2010; Tadayon & Afhami, 2017). The cognitive effort required for the game used in our experiment was not very high, yet the students in the push condition suffered a performance loss. This points to the importance of the source of interruption (externally vs. internally generated). In addition, it remains open what impact more complex games may have, in which reading is an important part of the game (e.g. *Episode*™, *My Story*™, *Lonewolf*™) or those requiring computations (e.g. *Sudoku*).

In addition, the experimental video lasted only 15 min, whereas a standard lecture in Germany has six time the length, i.e. 90 min. It is known that people are able to allocate more of their cognitive resources to tasks when challenges or stressors appear, which helps with short-term performance (Crawford, LePine, & Rich, 2010; Widmer, Semmer, Kälin, Jacobshagen, & Meier, 2012). It is possible that the duration of the experimental video fell within the time frame in which such compensatory effort could be maintained. In a longer time frame this increased use of cognitive resources tends to produce faster mental fatigue (Crawford et al., 2010; Widmer et al., 2012) which is known to reduce working memory performances (Borragán, Slama, Bartolomei, & Peigneux, 2017; Faber, Maurits, & Lorist, 2012). In a standard-length lecture, the performance loss observed in our experiment, is therefore likely to be even higher.

To sum up, despite a relatively low involvement in the game (due to its novelty for the participants) and low attachment to the smartphone (as it was not their own), the low complexity of the game and the brief and mostly audio-centred lecture, a disruptive effect of parallel gaming was observed for the group receiving push notifications. This is even more notable when considering the characteristics of the study participants. All participants in our study were already used to such interruptions since all of them owned a smartphone. Evidence suggests that training reduces interruptive effects. Hess and Detweiler (1994) showed that after two training sessions with interruptions, the interruptions lost some of their detrimental effect. Further, our sample consisted of participants who were not only highly motivated but also high achievers (mean school-leaving grade 1.8 ± 0.7). Research at four English schools, where a general smartphone ban was introduced, showed that less-able or less motivated learners are more negatively affected by smartphone-use while learning: Especially weaker pupils profited from the ban. Their performance improved by 14% while the mean improvement across all pupils was only 6% (Beland & Murphy, 2016). It can be assumed that our high achieving sample experienced a smaller negative effect of parallel smartphone use than a less able or more heterogeneous sample.

On the basis of existing research (Fried, 2008; Gehlen-Baum & Weinberger, 2012; Kraushaar & Novak, 2010), we also expected to find a difference between the group that could watch the video without distraction and the gaming group as a whole, which played the smartphone in parallel. This effect did not reach significance, even though the effect size ($d = 0.36$) for the contrast would be classified as a small-to-medium effect. Probably the size of this effect was reduced involuntarily by our experimental design with aimed at maximizing internal validity (use of a study smartphone, simplicity of the game, unfamiliarity of the game, etc.) and the aforementioned characteristics of the sample (high achievers, used to interruptions by smartphones, etc.).

4.1 Limitations

Our results should be interpreted in the light of some limitations. Firstly, in order to increase the internal validity, participants did not use their own smartphones, sacrificing a certain amount of external validity. Secondly, most of the participants were psychology students (58%) with very good Abitur school leaving grades. Since psychology in Germany is a restricted study course that only students belonging the top tier of academic achievement can choose, they are not be representative of the general population of university students and tend to be academically very able and highly motivated. Thus, they may also be more capable of compensating the detrimental effects of mobile phone use in the context of a lecture. Thirdly, the lecture was very brief: we do not know whether in a longer lecture the missed material would accumulate and lead to an even more pronounced effect or whether longer lectures may facilitate compensating for missed information by staying longer on one topic. Fourthly, the game was rather simple in order to be new to everyone, fast and easy to learn; for the same reason, it may have only needed few cognitive resources.

4.2 Directions for future research

Future research should build on this study increasing external validity: Investigated samples should include more representative student samples with a broader range of academic ability. The lecture should be modified for a greater ecological validity by increasing its length and using the customary visual material, such as slides. The attractiveness of the game could be increased if participants were able to use their own preferred games, in which they may be much more highly invested, e.g. when having spent time previously achieve high scores. In addition, the respective attractiveness of the game and the lecture should be varied systematically in order to investigate variations of the learners' (relative) motivations.

5 Conclusion

This study investigated the potential detrimental effects of using an easy gaming app on learning material that was presented in a lecture-type video. University students showed reduced objective learning performance when push notifications regarding game availability were turned on, yet their subjective performance ratings remained oblivious to this reduction. When the push notifications were turned off, no negative effects on the subjects' learning performance due to parallel play of a smartphone game were observed.

Disclosure of interest

The authors do not have any conflicts of interest to report.

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