Aus der Klinik für Psychiatrie und Psychotherapie Campus Mitte
der Medizinischen Fakultät Charité – Universitätsmedizin Berlin

DISSERTATION

The influence of different break activities on working memory and other cognitive functions

zur Erlangung des akademischen Grades
Doctor medicinae (Dr. med.)

vorgelegt der Medizinischen Fakultät
Charité – Universitätsmedizin Berlin

von

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Datum der Promotion: 04.03.2022

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ZUSAMMENFASSUNG

Einleitung: Lernvorgänge im Alltag werden häufig durch geplante und ungeplante Pausen unterbrochen. Pausen erlauben es, sich zu erholen, Informationen zu verarbeiten und Gedächtnisinhalte zu festigen. Insbesondere in Bezug auf den Einfluss vom Inhalt der Pausenaktivitäten auf den Lernerfolg gibt es noch zahlreiche offene Fragen, ob und wie verschiedene Aktivitäten nützlich, oder hinderlich dabei sind, Gelerntes zu behalten und Erholung zu gewähren oder zu behindern.

Methodik: In vier Experimenten haben wir den Einfluss von drei Pausenaktivitäten: Ruhen mit offenen Augen, Musik hören und Videospielen auf die Leistung junger, durchschnittlich 25-jähriger Menschen, bei verschiedenen Aufgaben untersucht. Im ersten Experiment untersuchten wir die Auswirkungen der verschiedenen Pausen auf das Arbeitsgedächtnis mittels einer n-back Aufgabe. Im zweiten Experiment ergänzten wir diesen Versuchsaufbau um fMRI Messungen, während der n-back Aufgabe. Im dritten Experiment prüften wir, anhand einer 2-step Aufgabe, ob die gewählten Pausen sich auf die Fähigkeit zum zielgesteuerten, modell-basierten Lernen auswirken würden. Schließlich, untersuchten wir im vierten Experiment deren Auswirkungen auf das Lernen und Wiedererkennen von Wörtern im Verbalen Lern- und Merkfähigkeitstest.

Ergebnisse: Wir fanden eine von den Pausenaktivitäten abhängige Ausprägung des Lernerfolgs, wobei sich das Videospielen, im Vergleich zu Musik und Ruhen mit offenen Augen, zumeist hinderlich auswirkte. So störte das Videospielen im ersten Experiment, insbesondere bei Menschen, die sich leicht in Gedanken verlieren, die Leistung bei der n-back Arbeitsgedächtnis Aufgabe, steigerte die Herzfrequenz und verringerte den subjektiv empfundenen Entspannungs- und Erholungseffekt der Pause im zweiten Experiment, mit entsprechenden Auswirkungen auf die Arbeitsleistung und kongruent, möglicherweise durch die fehlende Erholung, verringerter Aktivierung der supplementär-motorischen Rinde (SMA) im fMRI. Im dritten Experiment waren Probanden mit einer geringeren Arbeitsgedächtnis-Kapazität, nach dem Videospielen weniger dazu in der Lage, gezielt modell-gesteuert zu lernen, und im vierten Experiment, verbesserte Videospielen zwar das Erinnern an visuell präsentierten Wörter, störte jedoch die Erinnerung an gehörtes Material. Unsere Ergebnisse könnten eine Relevanz haben für Eltern, wie auch möglicherweise für klinische Forschung, welche sich mit (Online) Videospielabhängigkeit beschäftigt.

ABSTRACT

Introduction: Learning activities in everyday life are often interrupted by planned and unplanned breaks. Breaks enable relaxation, information processing and memory consolidation. There are still many open questions, whether and how the content of breaks enhances or diminishes task performance, memory and recuperation.

Methods: In four experiments we evaluated the influence of three break activities: open eyes resting, listening to music and playing a videogame on the performance of young, on average 25-year-old subjects in various tasks. In our first experiment we looked at the influence of our chosen breaks on working memory performance in an n-back task. In the second experiment we added fMRI scanning during the n-back task. In the third experiment we used a two-step task, to evaluate whether the different breaks would have a measurable influence on goal-directed, model-based learning. And finally, we looked at the influence of our breaks on verbal learning and recognition in a verbal-learning and memory task.

Results: We found that task performance varied with break activity and that playing a video game during the break, as compared to listening to music or open eyes resting, was mostly detrimental to task performance. In the first experiment, videogaming lowered working memory performance, especially in subjects prone to mind-wandering, it also pushed up heart-frequency and diminished subjective feelings of relaxation and recuperation during the break, which again led to lower working memory performance and, possibly because of diminished recuperation, a congruently reduced supplementary motor area activation (SMA) in fMRI scanning. In the third experiment, videogaming caused subjects with a lower baseline working memory, to be less able to apply model-based, goal-directed learning strategies. In the fourth experiment, videogaming did enhance verbal memory for visually presented material, but disturbed the ability to recall and recognize material, that has been presented in an auditory way. Our results could be relevant to parents, as well as to clinical research dealing with (online) videogame addiction.

1. INTRODUCTION

People, especially young people often spend time with learning and acquisition of new knowledge. In between these activities, breaks filled with different activities take place. We wanted to look at the effect of gaming, rest and music during breaks on different kinds of learning and memory.

When we began our studies in 2013, restful breaks had already been known to provide relief from fatigue (Edlund, 2010), help to process information, to form and consolidate new memories (Dewar, Alber, Butler, Cowan, & Della Sala, 2012) and enhance performance (Tambini, Ketz, & Davachi, 2010), while listening to music had been linked to diverse effects, like augmented memory function (Jakobson, Lewycky, Kilgour, & Stoesz, 2008), better spatial reasoning (Rauscher, 2002) and enhanced cognitive abilities (Jausovec, Jausovec, & Gerlic, 2006). Findings with video games had been more varied, with some studies finding that video games promote learning (Bavelier & Davidson, 2013) and that expert video game players often outperform non-gamers specifically on working memory tasks (Boot, Kramer, Simons, Fabiani, & Gratton, 2008), but other studies suggesting that videogames impair concentration (Bavelier et al., 2011; Lipscomb & Zehnder, 2004) and induce physiological stress (Hébert, Béland, Dionne-Fournelle, Crête, & Lupien, 2005). Learning depends on memory, which has been subdivided into long-term and short-term memory, or working memory, with the latter showing strong correlations with intellectual aptitudes (Cowan, 2008). Working memory is most often conceptualized as a combination of visual, auditory and general information storage and their manipulation by central executive functions (Baddeley, 2011), which are vulnerable to fatigue (Gergelyfi, Jacob, Olivier, & Zénon, 2015), for example by the mechanism of mind-wandering (Schad, Nuthmann, & Engbert, 2012).

Because we expected gaming to deplete executive resources and impair concentration, we decided to look at the effects of different breaks on a working memory task, first outside (Publication 1) and later inside (Publication 2) an fMRI scanner. In the past, impaired concentration had been directly linked to mind-wandering (Smallwood & Schooler, 2006) and the amount of mind-wandering was found being influenced by the pleasantness of a task and by fatigue (Kane et al., 2007). Mind-wandering was found to decreased task attention (Allan Cheyne, Solman, Carriere, & Smilek, 2009) and lowered working memory (McVay & Kane, 2010). Two different theories, an increased demand for cognitive resources (Smallwood & Schooler, 2006), also called the "resource" theory, on the one hand and an executive "control failure" (McVay & Kane, 2010) on the other hand, were theorized to lead to these effects of mind-wandering. A “resource-control” synthesis was proposed by (Thomson, Besner, & Smilek, 2015), combining both “resource” (Smallwood & Schooler, 2006) and “control-failure“ (McVay & Kane, 2010) to explain how mind-wandering might impair performance over time. Mind-wandering has been found to reduce performance in both high- as well as low demand tasks (Thomson, Seli, Besner, & Smilek, 2014), which also fits the levels-of-inattention hypothesis (Schad et al., 2012) suggesting that an increased duration of cognitive depletion by a task can not only induce quantitatively more mind-wandering but also a qualitative shift the nature of mind-wandering or inattention to deeper levels.

A third experiment (Publication 3) was concerned with the possible effects that different break activities might have on decision making and cognitive balance between different decision-making strategies. The thought, that gaming might deplete attentional and executive resources led us to use a 2-step task to explore this hypothesis (Wunderlich, Smittenaar, & Dolan, 2012). Decision making is thought to rely on a habitual, retrospective system and a goal-directed, prospective system (Daw, Gershman, Seymour, Dayan, & Dolan, 2011; Dolan & Dayan, 2013). In an experimental setting these can be described as model-free and model-based. These systems are complementing each other (Friedel et al., 2014), because successful behavior regulation needs to be governed by past experience as well as future expectations (Daw et al., 2011). Successful operation of these systems depends on cognitive abilities, with working memory being crucial (Daw, Niv, & Dayan, 2005; Dolan & Dayan, 2013; Huys et al., 2012; Keramati, Dezfouli, & Piray, 2011; Schad et al., 2014) . Higher working memory capacity enhances goal-based decision making (A. R. Otto, Raio, Chiang, Phelps, & Daw, 2013b), especially coupled with higher processing speed, while processing speed also interacts with habitual choice in an inverted U-type fashion, with the moderate processing speeds showing the greatest propensity for strong reliance on habitual choice (Radenbach et al., 2015). Greater verbal knowledge and executive resources also benefit model-based choice (A. Ross Otto, Skatova, Madlon-Kay, & Daw, 2014). Acute and chronic stress impairs both systems (Radenbach et al., 2015).

A fourth experiment (Publication 4) was designed to probe the influence of gaming, music and restful breaks on verbal learning, restful breaks had already been shown to be beneficial to short- and long-term memory (Dewar et al., 2012) and we were curious whether gaming and listening to music would affect learning success, possibly through interfering with the phonological loop or the visuo-spatial sketchpad (Baddeley, 2011).

2. METHODS

We requested and received approval for all experiments from the Ethics Committee of the Charité-Universitätsmedizin Berlin. All participants in the following studies were provided information about the experiment in writing and in person before the start of the experiments and gave informed written consent. We used a within subject design for all experiments. Each participant went through all experimental conditions in a randomized and counterbalanced order. Randomization was accomplished by means of a list randomizer (Haahr, 2013).

2.1 PUBLICATION 1: DIFFERENTIAL EFFECTS OF WAKEFUL REST, MUSIC AND VIDEO GAME PLAYING ON WORKING MEMORY PERFORMANCE IN THE N-BACK TASK

We recruited 35 righthanded native German speakers (18 female, mean age 24,51 years). Subjects were screened for psychiatric disorders with a SCID-1 screening questionnaire. Demographical data (age, years of education), as well as experience with and habitual consumption of music and video games were collected, also familiarity with the specific game and music used in our research was queried. Subjects underwent a neuropsychological test battery measuring variables that had earlier been shown to have an effect on memory performance: cognitive speed (Wechsler, 1997), verbal knowledge (Lehrl, 2005), verbal memory (Morris et al., 1989), verbal working memory (Wechsler, 1997), semantic verbal fluency (Isaacs & Kennie, 1973) and executive function (Army Individual Test Battery, 1944). Daily mind wandering was accessed as a trait with the Mind-Wandering-Questionnaire (MWQ) (Mrazek, Phillips, Franklin, Broadway, & Schooler, 2013).

After screening and neuropsychological assessment , participants were familiarized with the n-back task (J. D. Cohen et al., 1994), implemented via Presentation© software (Version 10.81, 2004, Neurobehavioral Systems Inc., Albany, CA, USA). The n-back task is designed to give a continuous load on working memory by forcing participants to always match the currently shown stimulus to a continuously changing series of previously shown stimulus. Subjects have to press a button as soon as the current stimulus matches one of the previously seen stimuli. The further back subjects have to search for a match of the current stimulus, the higher the load on working memory. Our version of the n-back task consisted of digits from 0-9 presented on the screen and had already been utilized in previous research. Stimulus duration was set for 500 ms and the interstimulus interval for 1000 ms. Only 2-back and 3-back memory loads were used because lower memory loads encountered ceiling effects in young adults (Heinzel et al., 2014a; Heinzel et al., 2014b; Heinzel et al., 2014c). In a 2-back task, subjects had to correctly press a button, when the current symbol matched the one presented 2 trials ago. Analogously in the 3-back task the stimulus from 3 trials ago had to be matched. We used a repeated measures design. Subjects did 12 blocks of 2-back and 3-back tasks, in a random counterbalanced order with 6 blocks of each condition. Each block had 20 trials. Participants were first introduced to the task with two blocks of training, one for each condition. After training, participants engaged in an 8:30 minutes break filled with either eyes open resting, listening to music or gaming. See publication 1, page 4 for a visualization of the procedure.

For the listening to music condition, we selected Mozart's "Sonata for Two Pianos in D in Major, KV.448 – Allegro con spirito" because it already had been used in previous cognitive research (Rauscher, 2002; Thompson, Schellenberg, & Husain, 2001). For the game intervention condition, we chose the popular video game "Angry Birds" [Rovio Entertainment 2013] mostly because it too had been used in previous research (Ferreira, Lopes, & Santos, 2013). Effective break durations in the literature were described to range from 5-20 minutes (Dewar et al., 2012; Travis, 1937), and we chose to use the length of the musical piece (8:30 minutes) as our break duration. During the rest condition, participants were instructed to just do nothing in particular, while remaining seated. Immediately after every break participants were instructed to rate the difficulty of the break, their concentration during the break and their enjoyment of the break using visual analog scales (VAS) (Bond & Lader, 1974).

The main n-back task consisted of different sequences of 2-back and 3-back blocks in equal proportion. N-back sequences as well as break activities were counterbalanced with a latin square by one experimenter. The other experimenter blindly and randomly assigned subjects to one of the sequences by means of a list randomizer. After each task sequence we queried participants ability to concentrate on the task and the amount of their thinking about the task while on the break using VAS.

2.2 Publication 2: Short-term effects of video gaming on brain response during working memory performance

We recruited 27 righthanded healthy German subjects (13 female, mean age 24,88 years). Before the first fMRI session participants were tested with our standard neurophysiological battery of tests, demographic information was collected and music and gaming habits were explored as described in the methods of publication 1. Subjects also practiced 2-back and 3-back conditions outside the scanner. 2-back practice was used to make the transition to 3-back easier. After practice, participants proceeded to scanning. To create a contrast between focused attention and working memory utilization, we used a 0-back condition and a 3-back condition. In a 0-back condition, participants had to press a button whenever a 0 appeared on the screen. In the 3-back condition, subjects had to press a button, when the current symbol matched the one shown 3 symbols ago. We again used a repeated measures, within-subject design, and each participant was tested three times during three weeks, at matching times of the day and matching weekdays. See publication 2, page 4 for a visualization of the procedure.

Scanning consisted of a structural T1 scan, a subsequent break filled with gaming, music or rest, we utilized the same rest, music and game conditions as in publication 1, a rating of their level of tension/relaxation on a VAS and then the fMRI n-back task. During the fMRI session, heart rate data was acquired through photoplethysmography sampling at 50 Hz. Immediately after the n-back, subjects were debriefed with a structured interview rating the task difficulty, their ability to concentrate on as well as their motivation to excel at the task. fMRI data was collected at the BCAN (Berlin) with a Siemens 3T Magnetom TIM-Trio MRI scanner and a 12-channel head coil. Built in auto align following T1 scanning was used to achieve bicommissural plane alignment. Parameters for functional, echoplanar imaging (EPI) were: repetition time (TR) = 2000 ms, echo time (TE) = 30 ms, matrix size = 64x64, voxel size = 3x3x3 mm, 33 slices.

2.3 Publication 3: Music and video gaming during breaks: influence on habitual versus goal-directed decision making

We recruited 33 righthanded healthy native German subjects in Berlin (17 female, mean age 24,6 years) and performed the same screening and information collection, already described in the method section of publication 1. We used a two-step Markov decision task designed to discriminate model free and model based contributions to decision making (Wunderlich et al., 2012). The experimental task consisted of two steps. See publication 3, page 5 for a visualization of the task. In the first step, two images were presented to participants and they had to choose one of them. Each of the first images led to two different sets of paired images in a probabilistic (70/30) fashion. In the second step, the subject again had to choose between the two images of the second set. Each image in the second step had a hidden reward probability, that fluctuated over the course of the experiment. In the case of triggering a reward, participants were shown the stimulus picture and the image of a coin. When no reward was triggered, only the stimulus picture was shown. To avoid possible interactions with the content of our break condition and to increase difficulty, we used simple black and white stimulus pictures instead of the original complex and colorful pictures. We tried to enhance motivation by informing the subjects that the highest scoring participants would be presented with a gift at the end of the experiment. Before the experiments, subjects were instructed on the nature of the task and practiced 50 trials with an alternative set of images. After practice, participants were randomized to engage in a break of either listening to music or playing a game. The same music and game were used as in the previous publications. After the break, the main experiment featured 201 trials of the two-step task with additional breaks of the assigned condition (music, rest or game) after trial 67 and trial 134. Subsequently subjects performed the same experiment with another version of the two-step task and the other break conditions. After task performance, participants were asked to rate their perception of task difficulty and ability to concentrate using VAS.

2.4 Publication 4: Differential effects of music and video gaming during breaks on auditory and visual learning

We recruited 46 right-handed subjects (24 females, mean age 24,59 years). Participants were asked to participate in two sessions. In the first session, participants first performed the same screening and information collection, already described in experiment one. Then the subjects proceeded to learn (encode) three lists of words. Each list was presented for three consecutive times. Each word was presented for 2 seconds, either through an audio file recorded by a German native speaker, or by a screen presentation with Microsoft PowerPoint 2010. We utilized an expanded 25-words lists auditory verbal learning test (AVLT) (Elmer, Burkard, Renz, Meyer, & Jancke, 2009; Helmstaedter, Lendt, & Lux, 2001), as we encountered ceiling effects in our pilot studies. Immediate recall attempts for 180 seconds after each presentation for 180 seconds helped strengthen the encoding, all answers were recorded by a digital audio recorder to secure accuracy. Going through the list thrice, subjects were instructed to take a break with either gaming, listening to music or having a quiet rest, we utilized the same music and game as in experiment one. Immediately after every break, participants were instructed to rate the difficulty of the break, their concentration during the break and their enjoyment of the break using VAS. Exactly seven days later, participants were scheduled for the second session and were asked to first recall as many words as possible from the lists of the first sessions. Afterwards they were presented a mixed list of 132 words with the task to recognize as many of the 75 words that were part of the learned material. See publication 4, page 3 for a visualization of the procedure.

3. Results

3.1 Publication 1: Differential effects of wakeful rest, music and video game playing on working memory performance in the n-back task

The data of all 35 subjects were used in the analysis. In the best fitting linear mixed effect model, the effects of memory load (2- vs. 3-back), break activity and their interactions were estimated as fixed effects. Random intercepts and slopes were estimated but gave no reliable improvement in model fit. Overall n-back task performance after game, music and rest was not statistically different at the 5% significance level (p=0,09 for music vs rest, p=0,29 for game vs rest, p=0,85 for game vs music). Break activities also did not interact with memory load (p=>0,64). Evaluating the time course of task performance, we found that in the 3-back task, subjects´ performance decreased more rapidly after gaming, than after rest (p=0,02), and after music (p=0,03). This effect could not be found in the 2-back task (all ps greater than 0.21). There were no significant correlations with the neuropsychological test scores and habits after Bonferroni correction for nine statistical comparisons (all ps <0,06 with a significance level of p = 0,006). Exploring our data on daily mind wandering (DMW) and the self-reported ability to concentrate (VAS) we found progressive impairment of 3-back task performance in participants with high DMW scores (p = 0.002) but no impairment of subjects scoring low in the DMW (p = 0.06). Subjects who reported not being able to concentrate well on the VAS, suffered from a proportionally larger decline in test performance over time (p = 0.02). We also found that subjects with higher levels of mind wandering reported lower ability to concentrate (Pearson r = 0.301, P <0.05, one-tailed). Neuropsychological test scores did not correlate with either concentration, or DMW.

3.2 Publication 2: Short-term effects of video gaming on brain response during working memory performance

The data of 24 subjects was used. Data of three subjects was excluded because of excessive interscan motion (one subject) and n-back performance at chance level (two subjects). The behavioral data and VAS questionnaires of the remaining subjects were analyzed with SPSS statistics version 24, utilizing ANOVA with Bonferroni corrections for multiple testing. Main effects of break activities were analyzed with linear mixed-effects models using R system for statistical computing version 3.3.2 (www.R-project.org). fMRI data was analyzed using SPM 12 (http://www.fil.ion.ucl.ac.uk/spm, Welcome Department of Imaging Neuroscience, London, UK). Data was put through slice repair and hit motion correction. All functional data was normalized into the standard MNI Atlas space. Data was smoothed within 8 mm full width at half maximum (FWHM) gaussian kernel, a high pass filter (128s) was applied. Imaging data was analyzed with a general linear model (GLM). We contrasted 0-back and 3-back blocks, separately for each break activity, against the resting baseline (fixation cross). Cues, responses and motion correction data were entered as regressors of no interest. Whole brain activity was analyzed using a working memory mask derived from a meta-analysis of 901 working memory experiments (http://neurosynth.org). A Monte Carlo simulation correction (10,000 iterations) was used. Only clusters with a minimum size of 63 voxels that yielded a cluster-level FWE threshold of p <0.05 were considered. Analyzing the VAS ratings, we found only one result that was statistically distinguishable from zero at the 5% level: subjects rated themselves as 12% more relaxed after listening to music, as compared to gaming (p=0.009). Physiologically, subjects showed a slightly higher heart rate while playing video games, compared to listening to music (p = 0.04), and compared to rest (p=0.06). There was no behavioral effect of breaks on overall n-back performance (all ps >0.40), but 3-back performance was significantly influenced by relaxation levels (p=0,014), and an analysis of the interaction between break activities and relaxation levels showed that subjects rated themselves more relaxed after music (p=0,03) and rest (p=0,07) compared to gaming. Adding heart-rate data, we found that higher heart rate during gaming versus listening to music might have contributed to this effect (p=0.06), though this effect did not hold for gaming versus rest (p>0.61). In our analysis of fMRI data, no blood oxygen level dependent (BOLD) responses for any combinations of break activity and memory load survived cluster-correction. We did however observe a significantly decreased activation in the bilateral supplementary motor area (SMA) after gaming, compared to listening to music. This result did not hold true for gaming vs. rest and music vs. rest.

3.3 PUBLICATION 3: MUSIC AND VIDEO GAMING DURING BREAKS: INFLUENCE ON HABITUAL VERSUS GOAL-DIRECTED DECISION MAKING

The data of all 33 subjects was included in the analysis. Observed 2-step data was analyzed using a computational dual-control model by Daw and colleagues (Daw et al., 2011), as previously done by Schad and colleagues (Schad et al., 2014). Theoretical maximum a posteriori (MAP) outcomes computed by the model were tested against the actual individual subject data using linear mixed-effects modes implemented in R (R Development Core Team, 2013). Because of previous reports that subjects with low baseline working memory capacity might be particularly prone to detrimental influences (Kuschpel et al., 2015; A. R. Otto et al., 2013b; Smittenaar, FitzGerald, Romei, Wright, & Dolan, 2013) we added working memory as measured by Digit Span in neuropsychological testing to our analysis. Testing of VAS questionnaires was done in SPSS statistics version 18 (SPSS Inc., Chicago, IL, USA). We used paired t-tests for pairwise comparisons and Bonferroni corrections when utilizing multiple testing. We did not find an overall influence of gaming vs. music on the ratio of model-based vs. model-free learning (p=0.14). Next, we tested whether an effect could be found, when also taking into account working memory capacity. We found that gaming, compared to music, reduced model-based learning in subjects with low working memory capacity, as measured by the Digit Span Score (p=0,04), but did not affect model-based control in subjects with a large Digit Span score (p=0.76). We replicated previous findings (Schad et al., 2014) that high cognitive speed, as accessed by the Digit Span Score, was associated with increased model-based choice (p= 0,03). In the VAS scores, the only finding with a significance level at 5% was that subjects enjoyed gaming 21% more than listening to music ($p<0.001$).

3.4 Publication 4: Differential effects of music and video gaming during breaks on auditory and visual learning

The data of all 46 participants was pooled in a linear mixed-effects model of response type (recall vs. recognition), stimulus modality (visual vs. auditory) and break activity (music vs. rest, game vs music + rest) using the lme4 package (Bates, Maechler, Bolker, & Walker, 2014) and the stats package in R v3.1.0 (R Development Core Team, 2013). No reliable improvement in model fit was found by adding random slopes for high-level interactions of main effects ($p>0{,}465$). Based on the best fitting model, we found that after gaming, visual memory recall performance was better when compared to the performance after both music and rest combined, while auditory recall performance was worse ($\beta=3{,}5$, $t=3{,}65$, $p<0{,}001$). Repeating the analysis with recognition, we also found that gaming (vs music + rest) boosted visual recognition while weakening auditory recognition ($\beta=2{,}2$, $t=2{,}89$, $p<0{,}004$). Neuropsychological test data and personal gaming and music habits were added to the analysis but no relevant correlations were found after Bonferroni correction. VAS ratings of the task difficulty, concentration on the task and enjoyment were analyzed with a repeated measures analysis of variance (ANOVA). Differences were considered statistically distinguishable from zero at the 5% level ($p<0{,}05$ two sided). There were no distinguishable differences of the difficulty of visual and auditory tasks and the level of concentration of the participants after gaming, music or rest (all $p>0.153$) but participants enjoyed gaming more than listening to music ($p<0{,}001$).

4. Discussion

In our research we found differential, though mostly negative results of playing video games during breaks. Exposure to highly salient stimuli had previously been shown to decrease performance in a 3-back working memory task (Helton & Russell, 2011), possibly by depletion of central resources. And while depletion of central resources was demonstrated to be relieved by restful breaks, breaks were less effective, if break activities utilized the same resources as the main experimental task (Helton & Russell, 2015). In our first working memory experiment, subjects' performance in a 3-back task, decreased more rapidly after gaming, compared to a quiet rest or listening to music. Crucially, this performance decline was strongest in subjects with an already elevated propensity for mind-wandering in daily life, and subjects with already low self-reported levels of concentration. This is congruent with findings of deeper levels (Schad et al., 2012) and higher frequency (Thomson et al., 2014) of mind-wandering after strenuous task performance and fits the "resource-control" framework of mind-wandering (Thomson et al., 2015). It also could explain why mind-wandering mediated the performance decline after gaming, but not after music and rest. Because game production is usually commercially motivated, games try to use very salient audio-visual stimuli to engage and hold the players attention, as well as trigger emotions (Anderson, 2012; Kim & Lee, 2013; Bavelier et al., 2011), possibly leading to deeper mind-wandering, which would explain their decremental effects on working memory, as mediated by changes in attention or emotions (Choi et al., 2013; Bergmann, Rijpkema, Fernandez, & Kessels, 2012). In our second working memory study we found that, compared to listening to music, an increased heartrate during gaming and lowered relaxation levels after gaming led to a decreased 3-back performance. And while Mozarts Sonata KV.448 has been specifically found to induce relaxation (Dastgheib et al., 2014), games usually are specifically designed to arouse, engage and motivate players (Kim & Lee, 2013), which might – as an unintended side effect - markedly tax the central executive resources of gamers. The lowered SMA activity in fMRI scanning during the 3-back task after gaming, compared to music might be interpreted in this context (Ahmed & de Fockert, 2012). The potential for depletion of central executive and working memory resources by the complex and engaging audio-visual nature of games was also relevant for our third experiment. There, taking into account working memory capacity, we found that low baseline working memory capacity predisposed subjects to use less model-based learning after gaming, compared to music. Subjects with high working memory were not affected. This adds to previous findings showing that depletion of executive resources impairs goal-directed choice particularly in subjects with low working memory (A. R. Otto et al., 2013b; Smittenaar et al., 2013). We know that goal-directed thinking and behavior are reliant on readily available central-executive resources and processes (Balleine & O'Doherty, 2009; Daw et al., 2005; Keramati et al., 2011) and that for instance working memory and processing speed mediate moment to moment choices between model-based and model-free behavior (Schad et al., 2014). Gaming might have taxed or impeded these resources and processes in various ways, like increasing stress levels (Arnsten, 2009; Bavelier et al., 2011; Hébert et al., 2005; Lipscomb & Zehnder, 2004; Schwabe & Wolf, 2009), mind-wandering or other changes in attention or emotion. Finally, in the fourth study we found that playing video games enhanced long-term recall and recognition in verbal learning, when the verbal learning material was presented visually. These positive effects of gaming on visual memory performance are consistent with previously published findings that salient visual stimuli might enhance visual tasks (Green & Bavelier, 2003, 2012). We also hypothesized that there might be a connection to positive affect states, like joy and interest (Fredrickson, 2001), which are known to enhance learning (LaBar & Phelps, 1998). In our study this might have been reflected in the higher reported enjoyment after playing the game, as compared to quiet rest or listening to music. But here again, we found detrimental effects of gaming when subjects were asked to memorize verbal material presented non-visually through headphones. When information was presented in this way, participants remembered less material, when they interrupted the learning activity with gaming, instead of taking a rest or listening to music. This result might be connected to functional and capacity differences in the different memory systems (M. A. Cohen, Horowitz, & Wolfe, 2009), which make auditory memory more vulnerable to feature override (Oberauer, 2009) and interference (Mercer & McKeown, 2010) through salient signals.

In Summary, our findings point to differential (Liu et al., 2015) but mostly detrimental (Kuschpel et al., 2015; Liu et al., 2019; Liu, Schad, Kuschpel, Rapp, & Heinz, 2016) effects of gaming on central executive resources in general and working memory in particular, especially in subjects with relatively lower baseline capacities. We are curious whether and how these findings will fit into the research that led to the inclusion of internet gaming disorder in the DSM-5 (American Psychiatric Association, 2013) and gaming disorder in the ICD-11 (World Health Organization, 2020).

Our studies do share several strong limitations: The average age of our participants gravitated around the twenty-five, thus limiting generalizability to younger or older age groups. Our sample sizes were small, which might lead to a failure of replication, which we experienced ourselves, with the two working-memory studies showing coherent but not identical results. We also relied on just one particular game and one particular piece of music, thus leaving the question whether other games or musical pieces would lead to different results. Because of the main two experimenters' inexperience with the methods, we only measured physiological responses in one study, thus limiting our ability to theorize about the contribution of stress and arousal to our results. Future studies might want to look at other types of games and music in a wider selection of age groups, as well as include more measurement of physiological responses.

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[auch Bestandteil der Dissertation]

EIDESSTAATLICHE VERSICHERUNG

„Ich, Maxim Kuschpel, versichere an Eides statt durch meine eigenhändige Unterschrift, dass ich die vorgelegte Dissertation mit dem Thema: The influence of different break activities on working memory and other cognitive functions/ Der Einfluss von verschiedenen Pausenaktivitäten auf bestimmte Aspekte des Lernens und des Gedächtnisses, selbstständig und ohne nicht offengelegte Hilfe Dritter verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel genutzt habe.
Alle Stellen, die wörtlich oder dem Sinne nach auf Publikationen oder Vorträgen anderer Autoren/innen beruhen, sind als solche in korrekter Zitierung kenntlich gemacht. Die Abschnitte zu Methodik (insbesondere praktische Arbeiten, Laborbestimmungen, statistische Aufarbeitung) und Resultaten (insbesondere Abbildungen, Graphiken und Tabellen) werden von mir verantwortet.

Ich versichere ferner, dass ich die in Zusammenarbeit mit anderen Personen generierten Daten, Datenauswertungen und Schlussfolgerungen korrekt gekennzeichnet und meinen eigenen Beitrag sowie die Beiträge anderer Personen korrekt kenntlich gemacht habe (siehe Anteilserklärung). Texte oder Textteile, die gemeinsam mit anderen erstellt oder verwendet wurden, habe ich korrekt kenntlich gemacht.

Meine Anteile an etwaigen Publikationen zu dieser Dissertation entsprechen denen, die in der untenstehenden gemeinsamen Erklärung mit dem Erstbetreuer, angegeben sind. Für sämtliche im Rahmen der Dissertation entstandenen Publikationen wurden die Richtlinien des ICMJE (International Committee of Medical Journal Editors; www.icmje.og) zur Autorenschaft eingehalten. Ich erkläre ferner, dass ich mich zur Einhaltung der Satzung der Charité – Universitätsmedizin Berlin zur Sicherung Guter Wissenschaftlicher Praxis verpflichte.

Weiterhin versichere ich, dass ich diese Dissertation weder in gleicher noch in ähnlicher Form bereits an einer anderen Fakultät eingereicht habe.

Die Bedeutung dieser eidesstattlichen Versicherung und die strafrechtlichen Folgen einer unwahren eidesstattlichen Versicherung (§§156, 161 des Strafgesetzbuches) sind mir bekannt und bewusst.“

Datum Unterschrift

Anteilserklärung an den erfolgten Publikationen
Maxim Kuschpel hatte folgenden Anteil an den folgenden Publikationen:

Publikation 1: Kuschpel, M. S., Liu, S., Schad, D. J., Heinzel, S., Heinz, A., and Rapp, M. A., Differential effects of wakeful rest, music and video game playing on working memory performance in the n-back task, Frontiers in Psychology, 2015, Impact Factor: 2.843 (2015)
Beitrag im Einzelnen: Mitarbeit an Design und Aufbau der Versuche (Mitwirken am Design der Experimentalbedingungen, insbesondere Aussuchen des Spiels, Design der Anweisungen an die Probanden), Mitarbeit an der Durchführung der Versuche und der Datenaufzeichnung und

Sammlung (Die Versuche, Datenaufzeichnung und Datensammlung wurden arbeitsteilig 50/50 mit Dr. Shuyan Liu durchgeführt), Mitarbeit an der Analyse der Daten (Übertragen und Aufarbeitung der Rohdaten in Excel für Auswertung in SPSS und R durch Dr. Liu), Mitarbeit an der Interpretation der Daten (gemeinsam mit dem restlichen Team), Mitarbeit an der Ausarbeitung des Manuskripts (Dieses Paper wurde durch Dr. Liu und mich im Tandem geschrieben, eine genaue Zuordnung einzelner Textpassagen ist nicht möglich, da die Texte viele Male hin und her gingen), Mitarbeit an der Revision des Manuskripts (mit dem Rest des Teams), Mitarbeit an der Beantwortung von Reviewer Kommentaren (mit dem Rest des Teams).

Publikation 2: Liu, S., Kaufmann, C., Labadie, C., Ströhle, A., Kuschpel, M. S., Garbusow, M., Hummel, R., Schad D. J., Rapp, M. A., Heinz, A., Heinzel, S. (2019). Short-term effects of video gaming on brain response during working memory performance. PLoS ONE, 14(10)
Beitrag im Einzelnen: Mitarbeit an Design und Aufbau der Versuche, Mitarbeit an der Durchführung der Versuche und der Datenaufzeichnung und Sammlung (Die Versuche, einschliesslich der fMRI–Scans im BCAN, der Datenaufzeichnung und Datensammlung wurden arbeitsteilig 50/50 mit Dr. Shuyan Liu durchgeführt, habe mir dafür den Status „Advanced User“ erarbeiten müssen), Mitarbeit an der Revision des Manuskripts (mit dem Rest des Teams).

Publikation 3: Liu, S., Schad, D. J., Kuschpel, M. S., Rapp, M. A., and Heinz, A., Music and Video Gaming during Breaks: Influence on Habitual versus Goal-Directed Decision Making, PLoS ONE 11, 2016, Impact Factor: 3.234 (2016)
Beitrag im Einzelnen: Mitarbeit an Design und Aufbau der Versuche (Mitwirken am Design der Experimentalbedingungen, insbesondere Aussuchen des Spiels), Mitarbeit an der Durchführung der Versuche und der Datenaufzeichnung und Sammlung (Die Versuche, Datenaufzeichnung und Datensammlung wurden arbeitsteilig 50/50 mit Dr. Shuyan Liu durchgeführt), Mitarbeit an der Revision des Manuskripts (mit dem Rest des Teams).

Publikation 4: Liu, S., Kuschpel, M. S., Schad, D. J., Heinz, A., and Rapp, M. A., Differential Effects of Music and Video Gaming During Breaks on Auditory and Visual Learning, Cyberpsychology, Behavior, and Social Networking, 2015, Impact Factor: 2.182 (2015)
Beitrag im Einzelnen: Mitarbeit an Design und Aufbau der Versuche (Mitwirken am Design der Experimentalbedingungen, insbesondere Aussuchen des Spiels), Mitarbeit an der Durchführung der Versuche und der Datenaufzeichnung und Sammlung (Die Versuche, Datenaufzeichnung und Datensammlung wurden arbeitsteilig 50/50 mit Dr. Shuyan Liu durchgeführt), Mitarbeit an der Analyse der Daten (Übertragen und Aufarbeitung der Rohdaten in Excel für Auswertung in SPSS und R durch Dr. Liu), Mitarbeit an der Interpretation der Daten (gemeinsam mit dem restlichen Team), Mitarbeit an der Ausarbeitung des Manuskripts (Dieses Paper wurde durch Dr. Liu und mich im Tandem geschrieben, eine genaue Zuordnung einzelner Textpassagen ist nicht möglich, da die Texte viele Male hin und her gingen), Mitarbeit an der Revision des Manuskripts (mit dem Rest des Teams), Mitarbeit an der Beantwortung von Reviewer Kommentaren (mit dem Rest des Teams).

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Unterschrift, Datum und Stempel des betreuenden Hochschullehrers/der betreuenden Hochschullehrerin

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Unterschrift des Doktoranden/der Doktorandin

DRUCKEXEMPLARE DER AUSGEWÄHLTEN PUBLIKATIONEN

Publikation 1: **Kuschpel MS**, Liu S, Schad DJ, Heinzel S, Heinz A, Rapp MA. Differential effects of wakeful rest, music and video game playing on working memory performance in the n-back task. Front Psychol. 2015 Oct 30;6:1683. doi: 10.3389/fpsyg.2015.01683. PMID: 26579055; PMCID: PMC4626555. Impact Factor: 2.843 (2015)

Publikation 2: Liu S, Kaufmann C, Labadie C, Ströhle A, **Kuschpel MS**, Garbusow M, Hummel R, Schad DJ, Rapp MA, Heinz A, Heinzel S. Short-term effects of video gaming on brain response during working memory performance. PLoS One. 2019 Oct 10;14(10):e0223666. doi: 10.1371/journal.pone.0223666. PMID: 31600305; PMCID: PMC6786602. Impact Factor: 2.740 (2019)

Publikation 3: Liu S, Schad DJ, **Kuschpel MS**, Rapp MA, Heinz A. Music and Video Gaming during Breaks: Influence on Habitual versus Goal-Directed Decision Making. PLoS One. 2016 Mar 16;11(3):e0150165. doi: 10.1371/journal.pone.0150165. PMID: 26982326; PMCID: PMC4794202. Impact Factor: 3.234 (2016)

Publikation 4: Liu S, **Kuschpel MS**, Schad DJ, Heinz A, Rapp MA. Differential Effects of Music and Video Gaming During Breaks on Auditory and Visual Learning. Cyberpsychol Behav Soc Netw. 2015 Nov;18(11):647-53. doi: 10.1089/cyber.2015.0140. Epub 2015 Oct 8. PMID: 26448497. Impact Factor: 2.182 (2015)

Publikation 1: **Kuschpel MS**, Liu S, Schad DJ, Heinzel S, Heinz A, Rapp MA. Differential effects of wakeful rest, music and video game playing on working memory performance in the n-back task. Front Psychol. 2015 Oct 30;6:1683. doi: 10.3389/fpsyg.2015.01683. PMID: 26579055; PMCID: PMC4626555. Impact Factor: 2.843 (2015)

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LEBENSLAUF

Mein Lebenslauf wird aus datenschutzrechtlichen Gründen in der elektronischen Version meiner Arbeit nicht veröffentlicht.

KOMPLETTE PUBLIKATIONSLISTE

Kuschpel MS. Maintenance or Discontinuation of Antidepressants in Primary Care. N Engl J Med. 2021 Dec 30;385(27):2587. doi: 10.1056/NEJMc2117168. PMID: 34965348. Impact Factor: 91.245 (2020)

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Liu S, Kaufmann C, Labadie C, Ströhle A, **Kuschpel MS**, Garbusow M, Hummel R, Schad DJ, Rapp MA, Heinz A, Heinzel S. Short-term effects of video gaming on brain response during working memory performance. PLoS One. 2019 Oct 10;14(10):e0223666. doi: 10.1371/journal.pone.0223666. PMID: 31600305; PMCID: PMC6786602. Impact Factor: 2.740 (2019)

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DANKSAGUNG

Mein Dank gilt meiner Familie, meinen Freunden, und meinen Supervisoren, insbesondere Dr. Lutz Hörenz, Antje Kuschpel, Tanja Kuschpel, Sergej Kuschpel, PD Ernst Hermann und Dr. J. Philip Zindel – ohne Eure Unterstützung hätte ich die Doktorarbeit nicht erfolgreich beenden können. Mein Dank gilt auch der Charité für die Möglichkeit, Medizin zu studieren.

Mein Dank gilt Prof. Andreas Heinz, ohne seine Ideen und Wirken wäre diese Arbeit nicht zustande gekommen, Prof. Michael A. Rapp, Prof. Stephan Heinzel und Prof. Andreas Ströhle für ihre vielfältige Unterstützung und Prof. Shuyan Liu für die immer sehr angenehme und produktive Zusammenarbeit in unserem kleinen Team.

Mein Dank gilt ebenfalls und insbesondere allen Co-Autoren der Studien und dem gesamten Team der Charité Psychiatrie Mitte und dem BCAN.