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

DISSERTATION

Effects of Rest on Learning Processes

zur Erlangung des akademischen Grades
Doctor of Philosophy (PhD)
im Rahmen des
International Graduate Program „Medical Neurosciences“

vorgelegt der Medizinischen Fakultät
Charité – Universitätsmedizin Berlin

von

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aus Kunming, China

Datum der Promotion: 09.12.2016

Effects of Rest on Learning Processes

Abstract

Introduction: Learning processes are often interrupted by breaks filled with diverse activities in everyday life. The influence of such break activities on different learning types, however, remains to be explored.

Methodology: To investigate the effects of different break activities on different learning-associated tasks (auditory and visual learning, working memory and habitual and goal-directed reinforcement learning), young adults were exposed to breaks involving (*i*) open eyes resting, (*ii*) listening to music and (*iii*) playing a video game.

Results: The studies showed that playing a video game during a break enhanced visual learning but reduced auditory learning and the *n*-back working memory performance over time compared to eyes-open resting and listening to music. Interestingly, the degree of working memory impairment was correlated with high levels of daily mind wandering and a low self-reported ability to concentrate. Low working memory capacity was also associated with reduced reliance on goal-directed learning after video gaming versus music.

Conclusions: These results suggest that the influence of breaks on learning depend on the specific learning process and the type of break. These findings can help to inform the structure and content of break activities during everyday learning contexts.

Wirkungen von Pausen auf Lernprozesse

Zusammenfassung

Einleitung: Lernprozesse werden häufig durch Pausen unterbrochen, die mit diversen Aktivitäten des alltäglichen Lebens gefüllt werden. Der Einfluss der Pausen-Gestaltung auf die unterschiedlichen Lern-Arten ist bisher noch nicht erforscht worden.

Methodik: Die Effekte unterschiedlicher Pausen-Gestaltung auf unterschiedliche Lern-Arten (auditives und visuelles Lernen, Arbeitsgedächtnis, zielgerichtete und habituelle Entscheidungsfindung) wurden erfasst. Dazu sollten junge Erwachsene in den Lernpausen (*i*) mit geöffneten Augen ruhen, (*ii*) Musik hören oder (*iii*) ein Videospiel spielen.

Ergebnisse: Die Studie konnte zeigen, dass das Spielen von Videospielen während einer Pause das visuelle Lernen im Vergleich zu den anderen Pausen-Aktivitäten verbesserte, jedoch negative Auswirkungen auf das auditive Lernen hatte; mit zunehmender Dauer nahm auch die Leistung des *n*-back Arbeitsgedächtnisses ab. Interessanterweise war die Beeinträchtigung des Arbeitsgedächtnisses mit einem hohen Grad des Gedanken-Abschweifens und selbst beschriebener, geringer Konzentrationsfähigkeit verbunden. Eine niedrige Kapazität des Arbeitsgedächtnisses korrelierte zudem mit einer geringeren Ausprägung zielgerichteten Verhaltens nach Pausen mit einem Videospiel, verglichen mit Pausen nach Musik.

Schlussfolgerung: Diese Ergebnisse deuten darauf hin, dass der Einfluss von Pausen auf das Lernen vom jeweiligen Lernprozess und der Pausen-Gestaltung abhängig ist und dass die Struktur und der Inhalt der Pausen-Aktivitäten im Kontext des alltäglichen Lernens wichtig sind.

Abbreviations

AIC	Akaike information criterion
AVLT	Auditory verbal learning test
BIC	Bayesian information criterion
DMW	Daily mind wandering
GD	Goal-directed learning
HB	Habitual learning
MAP	Maximum a posteriori
min	Minute
MWQ	Mind wandering questionnaire
VAS	Visual analog scales
vs.	Versus

List of figures and tables

The figures and tables listed here refer to each study, respectively. The Figure 1 "General mechanism of break actions on learning" in the section of "4.6 Conclusions" shows an overview of key findings in three studies.

Study 1: Differential effects of music and video gaming during breaks on auditory and visual learning. doi:10.1089/cyber.2015.0140.

Study 2: Differential effects of wakeful rest, music and video game playing on working memory performance in the *n*-back task. doi: 10.3389/fpsyg.2015.01683

Study 3: Music and video gaming during breaks: Influence of habitual versus goal-directed decision making. doi: 10.1371/journal.pone.0150165

1 Introduction

Taking a break from learning is common in our daily life. Breaks are often filled with different activities, which range from wakeful resting, listening to music to more popular behaviors such as using social media and playing video games. Such break activities may help to encode, consolidate and retrieve information and to prepare for upcoming tasks.[1, 2] The exact effects of different break activities on subsequent learning and memory performance remain to be explored.

Main functional types of learning are: (*i*) explicit learning, e.g. of a word list, and (*ii*) habitual and goal-directed reinforcement learning. Generally, task performance can be affected by reduced attentional control, e.g. due to “mind wandering”,[3] potentially due to limited resources[3] and control failure[4] during mind wandering. In this context, Thomson and co-workers[5] proposed the “resource-control” theory, suggesting that as executive control fades over time, resource distribution favors mind wandering, which, in turn, decreases performance. With respect to habitual and goal-directed reinforcement learning, habitual learning is associated with the simple repetition of rewarded actions, on the other hand, the actions of goal-directed learning are guided by a learned environmental model.[6] Computational models have described habitual behavior as fast and automatic (model-free) and goal-directed behavior as slow and deliberative (model-based).[6] To support this distinction, goal-directed learning is particularly impaired under competing cognitive demands, with the degree of impairment interacting with baseline working memory capacity.[7] On the other hand, Economides and co-workers[8] showed that working memory load does not impair goal-directed behavior in participants with sufficient prior training on the task.

What do we know about the impact of different break activities on learning? Playing video games is popular with people of all age groups, while the question whether adolescents should play video games between learning periods has sparked considerable debate.[9] Playing video games can enhance learning on several dimensions including spatial cognition, processing speed, task switching and decision making,[9] while video gaming has also been associated with negative outcomes, such as inducing stress, disturbing performance and concentration.[9] Wakeful resting rather than playing video games has been suggested to be a more effective intervention connected to enhanced learning.[10] Resource theory implies that the ability of an intervention to afford performance recovery is higher if there is little overlap between the intervention and the specific processing resources of the primary task.[10] A passive wakeful rest may thus help with consolidation and preparation of upcoming tasks by protecting from incoming interference,[1, 2] thereby boosting learning—at least over the short term. Other common break activities, such as listening to music, have been linked to the enhancement of cognitive performance specifically in the auditory domain, but not in the visual domain,[11] suggesting a specific effect of music on phonological loops but not on the visuospatial sketchpad.[12]

What do we know about the utility of breaks on short- and long-term learning? A short-term learning boost could be useful in some everyday situations, but it would be much more valuable if it lasted longer. The spacing of rest periods is essential to obtain maximum learning efficiency, particularly with respect to explicit learning.[1] Evidence shows that episodic buffers can relate phonological and visuospatial short-term memory to long-term learning.[12] Indeed, Dewar and co-workers[1] found that 10 minutes (min) of wakeful resting after explicit learning enhanced both short- and long-term memory after 7 days. Thus, post-learning resting may be highly beneficial if one wishes to retain new information over the long term.[2]

The objectives of this thesis are:

(i) To explore the mechanism of how different learning-associated tasks respond to the exposure of different break activities

(ii) To find out if and to what extent a change in learning performance has taken place

(iii) To contribute to effective management of different break actives during learning

The main hypotheses are:

Different break activities significantly affect different learning-associated tasks. Specifically, actively playing a popular video game could affect auditory and visual learning differentially compared to passive eyes-open resting and listening to music. The project also explored whether different breaks have different effects on working memory performance over time and whether this is be linked to mind wandering,[13] and assessed whether different break activities and their respective effects on working memory have a significant influence on habitual versus goal-directed learning.

2 Methodology

In this section, only the main methods which related to the key findings are summarized; for more details, see the methods sections of all three publications listed in the section of “Print copies of selected publications”.

Right-handed healthy native German participants were recruited through advertisements in Berlin. Participants were screened for major psychiatric disorders (SCID-I screening questionnaire) and underwent neuropsychological testing. Social and demographical data, video gaming and music listening habits were gathered. The project was approved by the Ethics Committee of Charité — University Medicine Berlin and was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. Participants were given detailed information and provided fully informed written consent.

A within-subjects design was used in each study. The presentation order of the different testing task versions in each study and the order of the different break activities were counterbalanced across participants. Participants were randomly assigned to one of the presentation and break orders.

2.1 Study 1: Auditory versus visual learning task

To evaluate the effects of different break activities on auditory and visual learning, 46 participants were exposed to *both* auditory and visual learning break activities. In order to increase statistical power and to further explore effects of stimulus modality, another 11 participants were recruited for auditory learning only, and another 16 participants for visual learning only.

Three parallel word lists (A, C, D) of a German language auditory verbal learning test (AVLT) were used. For auditory learning, each list was played with a digital record by a German native speaker. For visual learning, words were presented on a screen. The experiment included two testing sessions: *Session 1*. Participants engaged in three rounds of word list learning with break activities. Every such round consisted of: (*i*) an auditory presentation of the word list including 25 nouns with instructions to remember as many of the words as possible for subsequent immediate recall; (*ii*) free recall of that word list (this learning and recall process was repeated three times); (*iii*) an 8:30 min break; and (*iv*) free recall of that word list again. *Session 2*. Seven days later after *Session 1*, participants were again asked to freely recall all words from the three wordlists and then recognize those words from a recognition wordlist, which included the original words intermixed with semantically similar words. The general procedure is depicted in *Publication 1* (see there Figure 1).

2.2 Study 2: *N*-back working memory task

To evaluate the effects of different break activities on working memory, 35 participants were recruited.

The *n*-back task was used with two memory loads (*2*- and *3*-back). Participants performed 12 blocks of *n*-back task (randomly alternating between *2*- and *3*-back) with six blocks of each memory load condition. In the *2*-back condition, participants were required to press a response button if the current stimulus (target) was identical to the stimulus presented two trials ago. In the *3*-back condition, participants had to match the stimulus presented 3 trials ago. Each *n*-back block consisted of 20 numeric stimuli (single digit from 0 to 9) with five targets. The stimulus was presented visually in a randomized sequence, one at a time. All participants began with a two block training session that consisted of 20 trials for each memory load before they engaged in an 8:30 min break and then started the main task. The task and testing procedure are depicted in *Publication 2* (see there Figure 1A and 1B).

Immediately after every *n*-back task, participants were asked to rate their ability to concentrate on the *n*-back task by using visual analog scales (VAS). Their daily mind wandering (DMW) was assessed based on the self-report Mind-Wandering Questionnaire (MWQ).

2.3 Study 3: Two-step habitual versus goal-directed learning task

To evaluate the effects of different break activities on habitual versus goal-directed learning, 33 participants were recruited.

The two-step task was based on the task established by Daw and co-workers[6] (see *Publication 3*, Figure 1). The task consisted of two subsequent steps, each demanding a choice between two stimuli. In step 1, participants were presented with two stimuli. The choice from step 1 probabilistically determined which one (of two) new sets of options (each with two probabilistically rewarded choices) will be presented; participants were then presented with this new pair of stimuli in step 2. The final choice in step 2 was either rewarded with money or not. Prior to the experiment, participants were informed that the reward probabilities in step 2 would change, but those controlling the transitions from step 1 to step 2 would remain fixed and be primarily associated with one or the other of the step 2 sets of options. Participants underwent 50 practice trials with a separate set of stimuli before starting the main task.

2.4 Selection of break activities

To evaluate the effects of different break activities on various learning tasks, participants were instructed to engage in "eyes-open resting" (rest quietly with their eyes open), "listening to music" (Mozarts "Sonata for Two Pianos in D Major, KV. 448 — Allegro con spirito" over headphones) and "playing a video game" (play the "Angry Birds" video game, www.angrybirds.com, on a laptop computer) during an 8:30 min break. In the literature, ranges from 5 to 20 min have been reported for break duration;[1] The here chosen 8:30 min break duration was based on the length of the piece of music and was well within the range of the previous studies.[1] For the specific reasons to choose Mozarts Sonata and "Angry Birds" video game, see the section of "Break activity scenarios" in *Publication 1*.

In total, all three break activities were applied in *Study 1* and *2*, while only music and game conditions were applied in *Study 3* (due to the complex study design of the two-step task):

(i) *Study 1*: The 8:30 min break followed the encoding phase of a verbal learning task. Task performance was assessed immediately after the break and again after 7 days.

(ii) *Study 2*: The 8:30 min break followed the training phase (consisted of two blocks of *2*-back and two blocks of *3*-back tasks) of the *n*-back task.

(iii) *Study 3*: The 8:30 min break took place for three times (i.e. once before and twice during the main task after one and two thirds of the task duration respectively).

2.5 Data analysis

R version 3.1.0 statistical language (www.r-project.org) was used for data analysis. Multilevel regression models were estimated using the *lme4* linear mixed effects package. Model comparisons were performed based on log-likelihood ratios, using the Akaike information criterion (AIC), and the Bayesian Information Criterion (BIC). For statistical tests of fixed effects parameters, the Satterthwaite approximation was used as implemented in the *lmerTest* package. Differences were considered “significant” at $p < 0.05$ and “highly significant” at $p < 0.001$. Regression coefficients β were reported to estimate the effect sizes of each independent variable in the fitted model.

2.5.1 Study 1: Mixed-effects models and models comparison

Including all 46 participants for pooled analysis, a linear mixed-effects model was conducted in which the dependent variable was the percentage of correctly recalled as well as recognized (i.e. recognized and correctly identified) items (words) after a 7-day delay.

For fixed effects, the study used the predictors *response type* (recall vs. recognition), *stimulus modality* (visual vs. auditory), *break activity* (rest, music and game), as well as all interactions between these factors. In addition, random participant intercepts and slopes for the three main effects were included.

2.5.2 Study 2: Mixed-effects models and models comparison

A linear mixed-effects model was constructed to evaluate whether different break activities had an influence on overall memory performance and on performance changes over time. The data was averaged within each of six blocks of consecutive trials (each containing 20 trials). The difference between hit and false alarm rate was used as the dependent variable for these analyses.

For overall memory performance, the study used the predictors *memory load* (*2*- vs. *3*-back) and *break activity* (rest, music and game) as well as their interaction as fixed effects. In addition, random participant intercepts and slopes for the two main effects were included.

For analyzing the performance over the course of the task, the same analysis as for overall memory performance was used, except that the predictor *block* (via a linear effect for blocks 1 to 6 [mean-centered]) as a fixed effect as well as random slopes and correlations for the block-effect were added to separately assess the effects of *block* and *break activity* in the *2*- and *3*-back tasks.

Last, to investigate the effects of mind wandering and self-reported ability to concentrate on break-induced changes in memory performance, the average score of the self-report MWQ and the VAS question were added to the best fitting model.

2.5.3 Study 3: Computational modelling of habitual vs. goal-directed learning

The computational dual-control model by Daw and co-workers[6] was adapted to analyze the behavioral choices in the experiment. The implementation is described in detail by Schad and co-workers.[14] Following Otto and co-workers,[7] the model was parameterized to assess separate weights for habitual versus goal-directed learning.

The model contains seven free parameters: (*i*+*ii*) α, learning rate for the first (α_1) and the second (α_2) step; (*iii*) λ, the reinforcement eligibility parameter, which determines the relative degree by which second-step reward prediction errors update first-step model-free (habitual) values; (*iv*) β_2, the inverse temperature parameter that controls how deterministic choices are at the second step; (*v*+*vi*) separate weights for model-free and the model-based learning that reflect contributions of habitual (β_{HB}) versus goal-directed (β_{GD}) learning to choice; (*vii*) p, first-step choice perseveration or stickiness. For bounded parameter estimation and due to the normal distribution assumption in statistical testing, bounded model parameters to an unbounded scale were transformed via a logistic transformation [x' = log(x/(1-x))] for parameters α and λ, and via an exponential transformation [x' = exp(x)] for parameter β. Individual model parameters were estimated via a Bayesian fitting procedure.

Linear mixed-effects models were used in order to regress individual maximum a posteriori (MAP) parameter estimates on the fixed effects predictor break condition (music versus gaming) and on random participant intercepts. Differences in model parameters between experimental conditions were interpreted as evidence that the experimental manipulation affected learning during task performance in a way that can be understood as a change in this specific learning parameter (for a similar approach see e.g., Otto and co-workers;[7] Schad and co-workers[14]).

To test whether break effects impair model-based control in individuals with a low baseline working memory capacity, the fixed-effect interaction between *break activity* (music versus gaming) and *Digit Span* (as a proxy for working memory capacity) as a fixed-effect was added into the model.

3 Results

The results are described in detail in those three publications which listed in the section of "Print copies of selected publications". Here, only the key findings are summarized.

3.1 Study 1: Gaming impaired auditory but enhanced visual learning

In verbal learning task, the main finding was that *stimulus modality* interacted with *break activity* ($\beta = 3.5$, $t = 3.65$, $p < 0.001$), affecting long-term recall and recognition regarding verbal learning performance. As shown in *Publication 1* (see Figure 2), a short active gaming exposure after the encoding phase reduced long-term auditory learning performance but enhanced visual learning performance compared to listening to music and eyes-open resting.

3.2 Study 2: Working memory performance gradually decline after gaming

In the working memory task, actively playing a video game during a break had no influence on overall task performance compared to eyes-open resting ($\beta = -2.4$, $t = -1.08$, $p = 0.29$) and listening to music ($\beta = 0.4$, $t = 0.19$, $p = 0.85$). However, after video gaming, participants' task performance was gradually declining over the course of the *3*-back task, compared to eyes-open resting ($\beta = -3.1$, $t = -2.33$, $p = 0.02$) and listening to music ($\beta = -2.9$, $t = -2.20$, $p = 0.03$). The interaction between *block* and *break activity* is depicted in *Publication 2* (see there Figure 3). Interestingly, this effect was associated with increased daily mind wandering and a decreased self-reported ability to concentrate. A significant three-way interaction between *break activity*, *block* and self-reported daily mind wandering ($\beta = -2.7$, $t = -1.96$, $p = 0.05$) suggested that the impairment of task performance over time after gaming was particularly prominent in participants scoring high in daily mind wandering ($p = 0.002$; in *Publication 2*, see in Figure 4A). Similarly, a significant three-way interaction involving participants' ability to concentrate on the task after the break ($\beta = 3.6$, $t = 2.7$, $p = 0.007$) indicated a larger decline of task performance over time after gaming in less concentrated participants ($p =.02$; in *Publication 2*, see Figure 4B).

3.3 Study 3: Gaming reduced goal-directed learning in low working memory individuals

In the reinforcement learning task, video gaming during a break, compared to listening to music, reduced reliance on goal-directed learning (β_{GD} parameter) in individuals with a rather low working memory capacity (i.e. Digit Span score; $b = -0.41$, $SE = 0.22$, $df = 31$, $t = -1.87$, $p = 0.04$), while leaving habitual learning undisturbed, as shown in *Publication 3* (see there Figure 2). These results complement the observations in *Study 2* that video gaming reduced working memory performance in the *3*-back task over time compared to listening to music (see *Publication 2* for more details) and suggest that gaming may interfere with working memory resources needed for goal-directed planning.

4 Discussion

4.1 Is auditory learning impaired after gaming in accordance with feature overwriting theory?

The feature overwriting theory has been suggested to address the role of interference in explicit learning.[15] When the interference shared some features with target items in the memory, the ability to learn target items was worse compared to the other items. A memory buffer is suggested to retain recent auditory information, including a number of features (e.g. frequency-specific components of a sound), and the auditory information is integrated in a contextual model of the recent auditory environment. The memory buffer is continuously updated by incoming auditory information. The occurrence of auditory information containing novel features therefore requires the model to be updated, whereas auditory information consisting of repeated features contributes rather less to the model-building process (only adapting the "shared-feature" at certain frequencies). Simple repetitions of a previously experienced feature, therefore, would lead to adaptation rather than overwriting. However, if a salient feature occurs (e.g. during video gaming) that resembles a previously learned "standard-feature", it can interfere with the "standard-feature" and thus disrupt task performance.

In *Study 1*, compared to the other break activities, after gaming participants performed the auditory learning task significantly worse than the visual learning task in recall and recognition after 7 days. This might be because auditory learning operates via feature-overwriting, as discussed above.[15] Emotionally salient gaming sounds as well as changes in timbre and pitch could have affected the phonological loop during the consolidation phase and thus reduced retrieval performance of auditory words.[15] Differing from music, gaming sounds are designed to actively engage the players' attention. During the "Angry Birds" game, participants hear the 'bang' and 'laughing' sound every time they hit the target. Such sounds may enable participants to connect with the game yet interfere with the task performance. At the same time, video gaming compared to other break activities had a trend to promote visual learning. This is consistent with previous findings that the salient visual objects of video games may enhance visual task performance.[9]

4.2 How do working memory performance, mind wandering and break activity interact?

After participants played the "Angry Birds" game, their task performance gradually declined over the course of the *3*-back task, compared to task performance after eyes-open resting and listening to music. Video gaming has been found to be reliably associated with an enhancement of visual attention[9] and increased visual attention induced by gaming may have helped participants to better maintain task-relevant information at the beginning of the *n*-back task. Thus, participants started out with a strong task performance after gaming, which gradually decreased over time. In support of this interpretation, immediately after every *n*-back task session, participants reported that subjectively they had less ability to concentrate on the task after playing a video game compared to listening to music, shown in *Publication 2* (Figure 2). This may reflect a gradual depletion of cognitive resources that are necessary for working memory performance.[10] Importantly, we found that this gradual performance decline after gaming was closely related to mind wandering: it was strongest in individuals with a high propensity to mind wandering in their daily life, and in those individuals with low levels of self-reported ability to concentrate. This result is consistent with previous reports of enhanced frequency and deeper levels of mind wandering after prolonged task execution[13] and with the "resource-control" framework of mind wandering,[5] suggesting that executive control over the content of thoughts is impaired after prolonged task execution, leading to intrusions of task-unrelated thoughts.

In the present study, mind wandering mediated a performance decline specifically after playing computer games, but not after resting or listening to music. Based on resource-control theory, computer gaming may effectively interact with cognitive resources even during the break, involving continued engagement of executive resources and their continued depletion over time, leading to mind-wandering-associated performance deficits. Listening to music or resting, on the contrary, could effectively interrupt external task-performance, and may thus support recovery of executive resources. In summary, the results show that mind wandering and reduced self-reported ability to concentrate were associated with declining performance in high working memory load conditions after spending time with video games rather than music or rest during learning breaks.

4.3 How does a negative effect of gaming on working memory processes in goal-directed control take place?

Taxing executive resources can impair goal-directed choice particularly in individuals with low baseline working memory capacity, but often has little effect in high working-memory individuals.[7] It was found in *Study 2* that video gaming compared to listening to music reduced working memory performance over time (see *Publication 2* for more details). In line with this finding, gaming reduced reliance on goal-directed learning in low working-memory individuals, suggesting that gaming interferes with working memory resources needed for goal-directed planning. Gaming may thus have rather subtle interfering effects on executive functioning: during reinforcement learning, individuals with high levels of executive resources appear to be able to compensate for these effects and maintain high levels of goal-directed control, while individuals whose executive resources are limited are not be able to guard against such negative influences and show a decline in goal-directed planning.

How may such an influence of gaming on working memory processes in goal-directed control be moderated by additional factors? *Study 2* showed that the detrimental influence of gaming on working memory was associated with mind wandering and impaired concentration (see *Publication 2* for more details), suggesting that these factors may also contribute to the present findings. As an additional possible explanation, the sound of a video game could disturb the players' concentration on learning and induce stress while gaming.[9] Such stress effects may tax cognitive resources and consequently inhibit more sophisticated ways of goal-directed learning but spare more parsimonious habitual learning.[7] Thus, participants might not integrate the information of each step into a cohesive model in order to optimize choice selections, which may contribute to the negative effects on goal-directed choice.

4.4 Critical review

How reliable are the results obtained from the project? The different samples and specific experimental procedure may limit the reliance and reproducibility of the results. For instance, other groups of participants with different age ranges and education levels may provide different findings. The samples did not allow a valid comparison of gamers and non-gamers, musicians and non-musicians and the relatively small sample size limits generalizability and requires independent replication.

Additionally, other music or games types (e.g. self-preferred selections of music and game) and more complex learning tasks may result in different findings. The approach of this project was selected to assess ecologically salient break activities as an initial test of the potential break effects on learning performance. The exact mechanisms by which eyes-open resting, listening to music, and gaming might exert their effects on learning, such as cognitive resources and control depletion, were not manipulated. Moreover, it is still unknown if potential transfer effects affect learning performance over a longer period of time. Therefore, further research is warranted.

Currently, it is still unclear whether breaks directly act on learning performance or whether learning performance is subject to indirect interaction processes together with emotional and cognitive functions. For example, differential break effects on learning performance might have resulted from participants' emotional states (i.e. arousal, mood, enjoyment). The contribution of emotional states could be validated by acquiring reliable physiological response (e.g. heart rate and skin conductance) and behavioral data during breaks and learning.

Future studies are needed to illuminate the nature of the interplay between break activities, cognitive function and task performance. As an example of mind wandering, the self-reported measures of mind wandering and self-reported ability to concentrate were obtained retroactively in order not to disturb participants' engagement with the respective break activities. However, it may be preferable to use real-time experience sampling, such as the thinking content scale of the Dundee Stress State Questionnaire, self-catch task-unrelated thought as well as intermittent thought probes to assess mind wandering during breaks and the learning tasks.

The observed behavioral patterns can provide some insight into the mechanisms of break actions on learning, however, the current investigations only provide limited information, since there may be further uncharted effects of break activity on learning in the brain functional and physiological levels.

4.5 Future work and applications

Despite the shortcomings discussed above, this project can contribute to our knowledge by showing that certain types of break activities may be detrimental to certain types of learning, while being beneficial to others. This may inspire future studies to define the working modes of other common break activities and other learning tasks, especially looking not only for the potentially negative effects of media use, but also for enhanced learning and productivity. It is also necessary to investigate how mixtures of various media use and multitasking habits in everyday life influence one another and thereby affect our learning performance.

Research in neuroscience, psychotherapy, and education could benefit from this project. It may help to develop better procedures for rest and recuperation and prevent young adults from potential over-reliance on media use. It can help in the development of recommendations for parents, who have to decide whether they should ban their children from playing video games in between learning or whether they can tolerate or even encourage them to play. On the other hand, it can help guide further research into the usage of video gaming in young adults and adolescents, who try to relax between learning sessions. Young adults have to choose optimal break activities to enable them to consistently perform academic and cognitive tasks at high levels.

Moreover, it would be interesting to integrate the current findings with real-world applications. From an industrial perspective, the break and rest structure and culture within a company can be investigated to optimize employees' performance and well-being at work. The following questions can be set: How often do employees take breaks in different functional positions; what do they currently do, what would they like to do, and what would be best for them to do during their breaks? How should company culture and the structure of the workplace be designed (in regards to official breaks) to facilitate optimal performance of employees on all levels of organization? In the long term, a cross-cultural study could be implemented to investigate differences and similarities in policies and organization within a company that is established in different countries.

4.6 Conclusions

Taking a short break from learning is known to have beneficial effects on task performance.[1, 2] This project identified common mechanisms underlying specific breaks actions that promote or reduce learning performance. Our behavioral analyses showed that different break activities (i.e., eyes-open resting, listening to music and playing a video game) were shown to have an impact on different types of learning. The following learning-associated tasks were significantly affected: auditory vs. visual learning, working memory and habitual vs. goal-directed reinforcement learning. To better understand break effects on learning via brain functions, functional imaging and additional physiological variables such as skin conductance and heart rate are required.

Figure 1 depicts a potential mechanism of break effects on learning based on the results of this work. During a break, playing the "Angry Birds" video game compared to listening to Mozart's Sonata KV. 448 can promote visual learning (see *Publication 1*) via potential stimulation of the visual network via salient visual objects in the game.[9] In the working memory task, these visual objects may help to increase visual attention and to maintain task-relevant information at the beginning of the working memory task (see *Publication 2*); however, this rather strong initial performance gradually decreased over time (see *Publication 2*). Interestingly, this decline was associated with mind wandering and impaired concentration (see *Publication 2*), which may support the "resource-control" framework.[5] Consistent with this finding, gaming reduced reliance on goal-directed choice in low working-memory individuals, suggesting that gaming can interfere with working memory resources needed for goal-directed learning (see *Publication 3*). Also, the sound of a video game may induce stress while gaming,[9] which can tax cognitive resources and consequently inhibit more sophisticated ways of goal-directed learning while sparing more parsimonious habitual learning.[7] Furthermore, such emotionally salient gaming sounds may interfere with the phonological loop and ultimately reduce auditory learning, altogether providing evidence for a hypothetical concept named "feature overwriting".[15] Figure 1 is a simplified model of the effects.

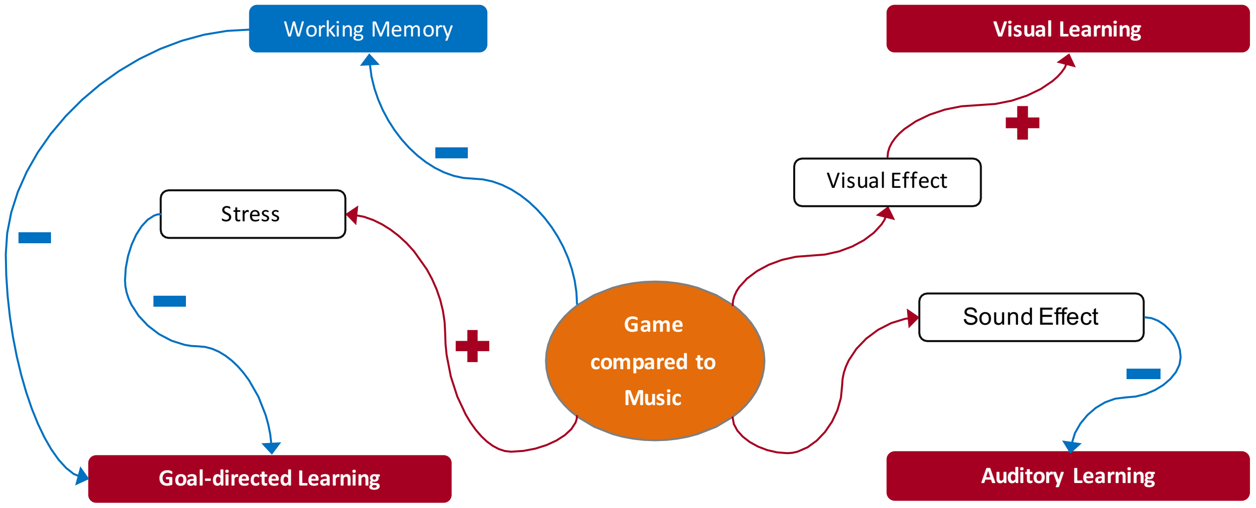

Figure 1 General mechanism of break actions on learning.
The diagram illustrates possible ways of break actions, which have an influence on auditory and visual learning, working memory and goal-directed learning.

Studying break actions on learning is a first step to further explore the complexity of underlying mechanisms in learning. This project gives first insight into breaks' multifaceted influences on different learning types, which can inspire further work in this direction. An overall picture may thus be generated from investigations providing more puzzle pieces to decipher the challenge of the effects of breaks, thus different break actives can be used to optimize performance.

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Affidavit

I, Shuyan Liu certify under penalty of perjury by my own signature that I have submitted the thesis on the topic "Effects of Rest on Learning Processes". I wrote this thesis independently and without assistance from third parties, I used no other aids than the listed sources and resources.

All points based literally or in spirit on publications or presentations of other authors are, as such, in proper citations (see "uniform requirements for manuscripts (URM)" the ICMJE www.icmje.org) indicated. The sections on methodology (in particular practical work, laboratory requirements, statistical processing) and results (in particular images, graphics and tables) correspond to the URM (s.o) and are answered by me. My contributions in the selected publications for this dissertation correspond to those that are specified in the following joint declaration with the responsible person and supervisor. All publications resulting from this thesis and which I am author of correspond to the URM (see above) and I am solely responsible.

The importance of this affidavit and the criminal consequences of a false affidavit (section 156,161 of the Criminal Code) are known to me and I understand the rights and responsibilities stated therein.

Date Signature

Declaration of any eventual publications

Shuyan Liu had the following share in the following publications:

Publication 1: **Liu, S.**, Kuschpel, M.S., Schad, D.J., Heinz, A., Rapp, M.A. Differential effects of music and video gaming on auditory and visual learning. Cyberpsychology, Behavior, and Social Networking. 2015
Impact Factor: **2.188 (2015/2016)**
Contribution in detail: Conceived and designed the experiments, performed the experiments, acquired, analyzed, and interpreted data, drafted the manuscript and made critical revision of the manuscript and correspondence to reviewer comments.

Publication 2: Kuschpel, M.S., **Liu, S.**, Schad, D.J., Heinzel, S., Heinz, A., 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: **2.463 (2015/2016)**
Contribution in detail: Conceived and designed the experiments, performed the experiments, acquired, analyzed, and interpreted data, drafted the manuscript and made critical revision of the manuscript and correspondence to reviewer comments.

Publication 3: **Liu, S.**[†], Schad, D.J.[†], Kuschpel, M.S., Rapp, M.A.[†], Heinz, A[†]. Music and video gaming during breaks: Influence of habitual versus goal-directed decision making. PLoS ONE. 2016
Impact Factor: **3.057 (2015/2016)**
Contribution in detail: Conceived and designed the experiments, performed the experiments, acquired and interpreted data, drafted the manuscript and partly wrote in response to reviewers' comments.

Signature, date and stamp of Prof. Dr.med. Dr.phil. Andreas Heinz

Signature of Shuyan Liu

Print copies of selected publications

Publication 1: **Liu, S.**, Kuschpel, M.S., Schad, D.J., Heinz, A., Rapp, M.A. Differential effects of music and video gaming during breaks on auditory and visual learning. (2015) Cyberpsychology, Behavior, and Social Networking. 18, 647-653. doi:10.1089/cyber.2015.0140.

IMPACT FACTOR (2015/2016): 2.188

Publication 2: Kuschpel, M.S., **Liu, S.**, Schad, D.J., Heinzel, S., Heinz, A., Rapp, M.A. Differential effects of wakeful rest, music and video game playing on working memory performance in the *n*-back task. (2015) Frontiers in Psychology. 6. doi: 10.3389/fpsyg.2015.01683.

IMPACT FACTOR (2015/2016): 2.463

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IMPACT FACTOR (2015/2016): 2.188

https://www.ncbi.nlm.nih.gov/pubmed/26448497

http://dx.doi.org/10.1089/cyber.2015.0140

Publication 2: Kuschpel, M.S., **Liu, S.**, Schad, D.J., Heinzel, S., Heinz, A., Rapp, M.A. Differential effects of wakeful rest, music and video game playing on working memory performance in the *n*-back task. (2015) Frontiers in Psychology. 6. doi: 10.3389/fpsyg.2015.01683.

IMPACT FACTOR (2015/2016): 2.463

https://www.ncbi.nlm.nih.gov/pubmed/26579055

http://dx.doi.org/10.3389/fpsyg.2015.01683

Publication 3: **Liu, S.**†, Schad, D.J.†, Kuschpel, M.S., Rapp, M.A.†, Heinz, A†. Music and video gaming during breaks: Influence of habitual versus goal-directed decision making. (2016). PLoS ONE. 11, e0150165. doi: 10.1371/journal.pone.0150165.

IMPACT FACTOR (2015/2016): 3.057

https://www.ncbi.nlm.nih.gov/pubmed/26982326

http://dx.doi.org/10.1371/journal.pone.0150165

Curriculum vitae

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

My CV will not be published in the electronic version of my PhD thesis due to data privacy.

Complete list of publications

I Publications in peer-reviewed journals:

1. **Liu, S.**[†], Schad, D.J.[†], Kuschpel, M.S., Rapp, M.A.[†], Heinz, A[†]. Music and video gaming during breaks: Influence of habitual versus goal-directed decision making. (2016). PLoS ONE. 11, e0150165. doi: 10.1371/journal.pone.0150165. **IMPACT FACTOR 3.057**

2. Kuschpel, M.S., **Liu, S.**, Schad, D.J., Heinzel, S., Heinz, A., Rapp, M.A. Differential effects of wakeful rest, music and video game playing on working memory performance in the *n*-back task. (2015) Frontiers in Psychology. 6. doi: 10.3389/fpsyg.2015.01683. **IMPACT FACTOR 2.463**

3. **Liu, S.**, Kuschpel, M.S., Schad, D.J., Heinz, A., Rapp, M.A. Differential effects of music and video gaming on auditory and visual learning. (2015) Cyberpsychology, Behavior, and Social Networking. 18, 647-653. doi:10.1089/cyber.2015.0140. **IMPACT FACTOR 2.188**

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II Newsletter without peer review process:

1. **Liu, S.** Life as a game. (2015) Charité Medical Neurosciences Newsletter. 8(2), 22.

2. **Liu, S.** The secrete of beauty. (2015) Charité Medical Neurosciences Newsletter. 8(2), 13.

3. **Liu, S.** Culture smart and science intelligent. (2014) Charité Medical Neurosciences Newsletter. 7(4), 9.

4. **Liu, S.** Sex similarities and gender differences. (2014) Charité Medical Neurosciences Newsletter. 7(3), 8.

IMPACT FACTOR of the journal is obtained from: http://www.bioxbio.com/if/

as of October 2016

Acknowledgements

My family has been supportive throughout this process, as they are in all aspects of my life. I want to thank all of my family, as they have paved the road for me. I would like to thank the financial support given by China Scholarship Council (grant 201208080013) and the kind coordination of Qi Dong, Feng Jiang, Yunhua Lou and Hui Zhang at the Abteilung für Bildungswesen der Botschaft der Volksrepublik China in der Bundesrepublik Deutschland.

I would like to thank my research team. I thank Prof. Andreas Heinz who offered me this opportunity to conduct this dissertation in his scientific research family. I will be eternally grateful to him, who trusted me throughout my PhD work and helped me enormously with his excellent ideas and invaluable personal support. A special thank you goes to Prof. Michael A. Rapp for his guidance to conduct experiments and address problems, the patience, helpfulness as well as showing me the great entertainment of science. He has contributed through constructive criticism to improve the quality of this work considerably. I also would like to thank Maxim S. Kuschpel for the pleasant cooperation. Daniel J. Schad and Stephan Heinzel I thank in particular for the continuous assistance in the data analysis.

I feel incredibly lucky to have had the chance to work with other members from the “Emotional Neuroscience”, “Learning and Cognition” and “Berlin Center for Advanced Neuroimaging” research groups at the Charité–Universitätsmedizin Berlin. For example (listed in alphabetical order by last name), Anne Beck, Katrin Charlet, Lorenz Deserno, Robin Frank, Eva Friedel, Claudia Gählsdorf, Maria Garbusow, Alexander Genauck, Tobias Gleich, Sabrina Golde, Andrea Hassenpflug, Claudia Hägele, Stefan Hetzer, Quentin J.M. Huys, Elisabeth Jünger, Yvonne Kamm, Jürgen Keller, Stefan Koch, Christian Labadie, Chantal Patricia Mörsen, Dirk Mülle, Stephan Nebe, Britta Neumann, Anne Pankow, Sören Paul, Patricia Pelz, Simone Penka, Lydia Romund, Florian Schlagenhauf, Miriam Sebold, Nina Romanczuk-Seiferth, Michael Smolka, Andreas Ströhle, Jean Wendt and Torsten Wüstenberg. I thank Ralf Ansorg, Filiz Celiker, Sarah Kümmel, Jana Lüdtke, Rebekka Maaz, Sabine Nawrotzki, Doreen Reinker, Jeniffer Sabisch, Duygu Sarigül, Lutz Steiner and Patricia Welk for administrative support. I thank you all including those people who were not mentioned by name here, but have had a great positive influence on this work. Last, but foremost, I would like to thank all subjects who participated in my study.

Thank you!