Unfamiliar Contexts Compared to Familiar Contexts Impair Learning in Humans

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Abstract

Re-exposure to the context that information was learned in facilitates its memory retrieval. However, the influence of context changes on the ability to learn new information is less well understood, which the present work investigated in two experiments with healthy participants ($n = 40$ per experiment; 20 female). In experiment 1, participants learned a list of word-pairs (A-B) in the morning, after which their memory for the word-pairs was immediately tested. In the evening, they learned and were tested on a second non-overlapping list (C-D), either in the same context or in a different context than the first list (between-subjects). We found that new learning is enhanced in the same context, and that new learning in the other context was decreased compared to baseline. In experiment 2, participants were exposed to both contexts in the morning, but only learned word-pairs in one of them. In the second learning session in the evening, this familiarisation with the other context abolished differences between the same and other context group. These data point to context novelty interfering with new learning rather than context familiarity enhancing it. Importantly, the reduction of new learning in the other context in the first experiment, where the context was unfamiliar in both learning sessions, suggests mechanisms beyond attention processes that are bound by the novelty of the other context. Rather, the old context impairs the processing of the new context, possibly by biasing pattern completion and pattern separation trade-offs within the hippocampus.

Keywords: context-dependent, learning, memory, meta-cognition, familiarity

1. Introduction

Memory is sensitive to context, meaning that the environments learning and testing take place in affect memory performance (Smith & Vela, 2001). The pioneering work of Godden & Baddeley (1975), demonstrated that a mismatch between the context during learning and recall results in impaired memory performance (for recent replication attempts, see Murre, 2021; Shin et al., 2021). Since then, a considerable amount of research has investigated this contextual dependence of memory, referring to the phenomenon that retrieving information is easier in the same context it was encoded in (Cairney et al., 2011; McKenzie & Tiberghien, 2004; Smith, 1979; Smith et al., 1978). For these context effects to occur, the context does not need to be extrinsic (e.g. different rooms for learning and testing), but can also be intrinsic (e.g. differences in the participants' mood at encoding and retrieval, Bower et al., 1978; Robinson & Rollings, 2010). Smith (1979) demonstrated that the improvement in memory performance could not only be attributed to the reinstatement of the learning context at retrieval alone, but that familiarity with the retrieval context also contributed independently.

It is not clear whether context affects new learning in the same manner, i.e., whether new learning of information is enhanced when it is presented in a similar way as during the initial learning experience in this context. For example, Smith (1982) showed that changing contexts between learning different word lists increases new learning performance. However, different contextual features (e.g., location and appearance of the room, temporal separation) had different (positive or negative) effects on new learning in their study. On the other hand, Smith & Handy (2014) found that acquisition is improved when the same face-name pairs are repeatedly studied across several sessions in the same context. But at a later retrieval test (either without any context or in an entirely new context), memory performance was better for participants who had learned the face-name pairs in varying contexts, suggesting that repeated learning episodes in the same context accelerate acquisition, but learning in varying contexts produces more robust, decontextualised memories. Pastötter et al. (2008) let their

participants study two different word lists, separated by a mental context change (participants had to mentally project themselves to their parents' house), and found that the context change improved learning. However, in both studies, the learning episodes took place only minutes after each other, which means that they overlapped in their temporal context. These findings are contrasted by the experiments Cox & Fell (2020) report, where participants learned overlapping lists of word pairs (day 1: AB, day 2: AC). Each word pair was associated with a specific context (background image), and during new learning, the AC word pair was either presented in the same or a different context than the corresponding AB word pair. On the third day, memory for both the AB and the AC list was tested without any context. Under these conditions, new learning benefitted from overlapping contexts. It might be that matching contexts only benefit new learning when the learning episodes are already separated by other contextual features (e.g., time). Smith (1982) argues that contextual information during learning (e.g., spatial or temporal) may serve as landmarks, which can then be utilized during retrieval to separate the information learned in different contexts. When the learning episodes take place shortly after each other, other contextual features might be needed to separate the episodes. When the learning episodes already differ in their temporal context, additional differences in context might not provide any added value, but simply additional information that needs to be processed. We hypothesise that new learning will be impaired by mismatching contexts, if they are sufficiently separated in time (i.e., several hours). We suggest that the temporal distance between learning episodes suffices to yield the beneficial effects usually associated with context changes and that additional changes to the context are then detrimental.

There are further good theoretical reasons to believe that similar contexts can be beneficial for new learning. On the one hand, schemas have been shown to facilitate the assimilation of new congruent memories leading to superior new learning (Tse et al., 2007; van Kesteren et al., 2012), and schema memory can include contextual features of the learning situation (Ghosh & Gilboa, 2014). On the other hand meta-cognition, i.e., knowledge about cognitive processes and strategies to regulate one's problem solving and learning

(Flavell, 1979; Veenman et al., 2006), could additionally enhance new learning in familiar contexts. In this regards Hanczakowski et al., 2017 demonstrated that metacognition is sensitive to variations of the external context and showed that feeling-of-knowing judgments increase in familiar contexts.

In the present study, we prepared two different contexts to investigate their impact on new declarative learning after a delay. The contexts were designed to resemble a forest or a seaside environment, respectively, in two of our labs in different buildings on separate campuses. In the first experiment, participants learned word-pair lists in one of the contexts in the morning learning session and either returned to that same context or to the other context 12 h later in the evening to learn a novel list of word pairs. We predicted that learning in the same context would improve learning performance, which we confirmed in experiment 1. However, the benefit of matching contexts for new learning might be explained by the fact that participants in the same context condition were simply more familiar with the context by the second learning session. For example, when new learning occurs in a different context, some attentional resources might need to be spared to process the new context. To control for context familiarity, we conducted a second experiment, where participants were additionally familiarized to the other context during the morning, but crucially did not learn in that context.

2. Materials and Methods

2.1. Participants

Eighty participants completed the study in two separate experiments (40 per experiment; 20 = male, 20 = female). This sample size was determined by the usual sample size in comparable experiments (e.g., Murre, 2021, $N = 16$; Pastötter et al., 2008, $N = 48$; Cox & Fell, 2020, $N = 39, 43$, and 41), as well as available resources (Lakens, 2021). We conducted a sensitivity analysis to determine the smallest effect size we were able to detect with 80% power ($1 - \beta$) in our main analysis, an ANOVA on the first run of each session, with session (within-subjects; morning or evening) and context (between-subjects; same or different) as predictors. We used G*Power, version 3.1.9.7 (Faul, Erdfelder, Lang, & Buchner, 2007) to calculate the sensitivity for an α -level of 0.05, our total sample size of 40 (number of groups = 2, number of measurements = 2) and a correlation of .7 between repeated measures (the correlation between the morning and evening session was $r = .76$ for experiment 1, and $r = .72$ for experiment 2). This analysis (which crucially should not be confused with a post-hoc power analysis) revealed that the effect size we have 80% power to detect is $f = 0.18$ or larger, which we deemed sufficiently large to be of interest.

Participants were healthy, non-smoking, native German speaking men and women, age range between 18-30 years old (for demographic data, see Table 1). Before starting the study, all participants were pre-screened via e-mail by answering questions about their age, height, weight, and general health condition (confirming their age was between 18 and 30, their BMI below 26 and that they had no known chronic illness). If they met the initial criteria a more detailed telephone screening was used to confirm this information and exclude any participants with psychiatric, neurological, or endocrine diseases and participants who took regular/acute medication (except for oral contraceptives). The screening relied on a structured interview asking for current or past diagnosed conditions, and only healthy participants were included. In addition, participants who had participated in other experiments using word-pairs or had been in any of the buildings used for running the experiments were excluded. Furthermore, we ensured to only include participants reporting a normal sleep-wake cycle, no

shift work, night work or intercontinental flights (> 4 hours time difference) for at least 6 weeks before the experiments.

Table 1

M(SD) for demographic variables.

	same context		different context	
<i>Experiment 1</i>				
age	24.3	(3.29)	22.8	(3.04)
bmi	21.77	(2.50)	21.84	(1.55)
h of sleep	8.03	(0.97)	8.22	(0.44)
<i>Experiment 2</i>				
age	23.25	(2.79)	24.21	(3.12)
bmi	22.01	(1.69)	22.16	(1.70)
h of sleep	7.68	(0.71)	7.65	(0.73)

Included participants were instructed to keep a regular sleep schedule in the week before the experiment (approximately sleeping from 23:00 to 7:00 each night) and to go to bed at 23:00 the night before experiments. They were asked to get up at 07:00 on experimental days and, during these days, not to drink caffeine-containing drinks and not to consume alcohol starting one day before the experiment. Furthermore, participants were instructed not to sleep between the two experimental sessions. Adherence to these rules was assessed with a general questionnaire at the very beginning of each experimental session and experiments were aborted and rescheduled if gross deviation from this plan was found.

In experiment 2, in addition to the above-mentioned inclusion/exclusion criteria participants were also excluded if they were familiar with Persian or Arabic language used in the control task. The experiments were approved by the local ethics committee. We obtained written informed consent from all participants before their participation.

2.2. Experimental Contexts

The experiments took place in the two different contexts Seashore and Forest set up in testing rooms. Importantly these rooms were located in two different buildings located at different campuses roughly 1.5 km apart. The contexts consisted of distinct decorations (sand and

seashells vs. trees), pictures on the walls (beach vs. forest), background screens on the testing computer (beach vs. forest), relevant background noises (waves vs. birds) and odours (ice-cream vs. pine). Two female experimenters were consistently assigned to one of these contexts each and had to wear a coloured lab coat (red vs. green). Furthermore, one of the experimenters spoke German and the other spoke English to the participants.

2.3. Tasks

2.3.1. Word-pair learning Task

We used slightly associated word-pairs to test declarative learning performance in the two learning sessions. For this, we created two completely different lists of 120 word-pairs, which were similar in difficulty. The lists were assigned to the morning or the evening learning sessions using a balancing list. The learning procedure was designed to last approximately 90 minutes and word-pairs were presented on a computer screen for 2s each with a 1s inter-stimulus interval (ISI). A picture of pinecones or a picture of seashells was used as the background of word pairs for the two contexts respectively, which was shown for 15s before learning to familiarize the participants with it. During the learning session, the 120 word-pairs were repeated in three consecutive runs and each run was divided into three 40 word-pairs blocks. The word-pair blocks were presented in the same order across the three runs, but the block order was varied across participants. After each block there was a short self-paced break. After presenting each run of a word-pairs list the participant's memory was tested in a cued-recall procedure, which involved presenting only the first cue word of a pair and asking the participant to produce the second target word. In the forest context, participants wrote the target word on a piece of paper whereas, in seashore context, they said the target word out loud, which was documented by the experimenter in addition to recording their voice. The amount of correctly recalled word-pairs during each run of the cued-recall procedure was used as the measure of learning performance. The same procedure was followed in the evening session for learning the completely new list of 120 word-pairs. In the morning session, participants were informed that the cued recall procedure will be repeated in the evening session and were not informed of the new learning, which actually took place.

2.3.2. Letter counting task

In experiment 2, a letter counting task was additionally administered after the morning session of the word-pair learning task while participants were familiarised with the other experimental context. This task, where participants counted the letters of Persian words, was constructed to mimic the learning task in as many aspects as possible except for actual learning. The words were also presented in three runs and each run contained two different procedures. The first mimicked the learning procedure and presented 120 word-pairs per run in three blocks of 40. In this phase, participants were asked to continuously count and add up the letters of all the word pairs in one block, which were displayed for 4s each (1s ISI). During the short breaks they wrote down the total number of letters for all 40 word-pairs on a piece of paper in the Forest context or said it aloud to the experimenter in the Seashore context. The second procedure mimicked the cued retrieval procedure and presented 120 single words in blocks of 40 words. Here, participants had to count the letters of each word and immediately afterwards write the number down on a piece of paper or say it aloud to the experimenter depending on the context. Each word was displayed until participants answered. The letters used in these words were of course repeated, but each word was only shown once, which prevented learning in this task. We chose Persian words (which did not have any meaning for the participants), as this would prevent any implicit learning. As for the word-pair task, the sum of counted letters for each run was used for data analysis.

2.3.3. Control measures—vigilance, sleepiness, and mood ratings and test of encoding

Participant's sleepiness and mood were assessed using self-report measures. The Stanford Sleepiness Scale (Hoddes et al., 1973) measures subjective sleepiness with one item and eight answer options ranging from one = "Feeling active, vital, alert, or wide awake" to eight = "Asleep" (provided as an anchor). We assessed the participants' mood using the multidimensional mood questionnaire (Hinz et al., 2012) at two time points once in the morning session before starting the learning and once in the evening before starting new learning. This questionnaire produces the three scales Positive mood (high is positive), Tiredness (low is

tired), and Calmness (high is calm). Objective vigilance was additionally tested twice using the psychomotor vigilance task (Dinges & Powell, 1985). This 5-min version of the PVT required pressing a button as fast as possible whenever a bright millisecond clock presented on a dark computer screen started counting upward. After the button press, this clock displayed the reaction time. In both experiment 1 and 2, one participant was excluded from the PVT analysis due to technical problems during the task. General capabilities of long-term memory retrieval were tested using two rounds of a word generation task (Regensburger Word Fluency Task, WFT). In the first round, participants had to produce as many words as possible starting with the letter P and in the second round, they had to generate as many hobbies as possible during a time of 2 min each (Aschenbrenner et al., 2000). At the end of the experiment participants were asked if they had any idea about the aim of the study.

Figure 1. Procedure for experiment 1. Participants completed three runs of a word-pair learning task in the morning in one context (e.g. forest) and then completed three runs of the same word-pair learning task (with new words) in either the same context or a different context (e.g. seashore) in the evening.

2.4. Procedure

In experiment 1, participants visited the lab twice in one day (Figure 1). In the morning they visited one of the two contexts for the first time and in the evening they either revisited the familiar context (same context group) or visited a new context (other context group). The starting context was balanced across participants. The morning learning session lasted from 9:00 to 11:00 and the evening session from 21:00 to 23:00 resulting in a 10 hrs interval between sessions. In the morning session, participants had to fill in questionnaires (Stanford Sleepiness Scale (SSS), Multidimensional Mood Questionnaire (MDBF) and the arrival questionnaire) after their arrival to one of the contexts. After receiving the instruction of the word-pair task and practicing on an example with the experimenter, they learned the word-pairs in three runs. After each run, performance was tested in a cued recall procedure. Participants were informed that they should avoid to consciously rehearse the word-pairs. After finishing the word-pair learning task participants performed the vigilance task (PVT). Then participants left the lab to return for the evening learning session at 21:00 either to the same context or to the other context. When participants arrived, they filled in additional questionnaires (SSS, MDBF). Then they learned a completely new list of 120 new word-pairs using the same procedure as in the morning. After learning new word-pairs, participants had to perform the word fluency task (WFT) and the vigilance task (PVT).

Experiment 2 was designed to match experiment 1 as closely as possible. However, participants were additionally familiarized with the other context while performing a letter-counting task (Figure 2). In the morning, visits to the two contexts were balanced and they visited the first context from 8:30 to 10:30 and travelled to the second context via taxi to visit it from 10:45 to 12:30. The evening learning session was slightly postponed from 20:30 to 23:00 leading to a minimum of 8 hrs between the two learning sessions.

Figure 2. Procedure for experiment 2. Participants completed three runs of a word-pair learning task in the morning in one context (e.g. forest) and were then familiarised with the other context (e.g. seashore), where they had to complete a letter counting task. In the evening, they completed three runs of the same word-pair learning task (with new words) in either the same context the first word-pair task took place, or in a different context (e.g. seashore).

2.5. Data reduction and statistical analysis

Data were analysed using R, version 4.1.0 (R Core Team, 2021), with the tidyverse package collection, version 1.3.1 (Wickham et al., 2019), as well as the packages package afex, version 1.0-1, (Singmann et al., 2021) and effectsize, version 0.4.5 (Ben-Shachar, Lüdtke & Makowski, 2020). Statistical analyses generally relied on analyses of variance (R package afex, version 1.0-1, Singmann et al., 2021) including the repeated-measures factors Session (Morning Session vs. Evening Session), as well as the between-subjects factor Same/Different Context. We focused our main analysis on the first of the three runs in each session, because this is the only run that is not contaminated by effects of context on learning

performance carried over from the previous run. In run 2 and 3, where the word-pairs from run 1 are repeated, memory may be influenced by the learning and retrieval processes that occurred beforehand, since memory is tested after each run. For example, if memory is improved in the first run by occurring in the same context, then for subsequent runs it is harder to show gains in additional items as more difficult items remain and the ceiling of the task is closer. Whenever we compared the two experiments, we added the factor Experiment as predictor. Greenhouse-Geisser correction of degrees of freedom was applied where necessary. Significant interactions were followed up by lower-level ANOVAs and post hoc t-tests. During the review process, all data and analysis code can be accessed privately by the reviewers. Upon publication, all data and analysis code will be made publicly available at the PsychArchives of the Leibniz Institute of Psychology (ZPID) and will be accessible at a persistent DOI.

3. Results

3.1. Word-pairs

In experiment 1, an ANOVA over the first run (Figure 3 A) showed that participants learned significantly more word-pairs in the same context in the evening learning session (Session x Context interaction: $F_{(1,38)} = 10.63$, $p = .002$, $\eta_p^2 = .219$). There were no significant main effects of Context ($F_{(1,38)} = 2.41$, $p = .129$, $\eta_p^2 = .060$) or Session ($F_{(1,38)} = 0.55$, $p = .462$, $\eta_p^2 = .014$) on performance. Intriguingly, the participants in the same context group learned more word-pairs in the first run of the evening learning session compared to the morning learning session ($t_{(19)} = 2.47$, $p = .023$, $d_z = 0.55$, 95% CI [0.08, 1.04]), whereas participants in the different context group learned less word-pairs in the first run of the evening learning session compared to the morning learning session ($t_{(19)} = -2.16$, $p = .044$, $d_z = -0.48$, 95% CI [-0.96, -0.01]).

When participants were familiarised with the different context between sessions (experiment 2), an ANOVA (Figure 3 B) over the first run in each session showed no significant difference between the two context conditions (Context main effect: $F_{(1, 38)} = 0.01$, $p = .935$, $\eta_p^2 = <0.001$; Context x Session interaction effect: $F_{(1, 38)} = 0.05$, $p = .827$, $\eta_p^2 = 0.001$). Correspondingly, when comparing the two experiments we found that only in experiment 1 the different context negatively affected word-pair learning performance in the first run of the evening learning session (Experiment x Context x Session interaction: $F_{(1, 76)} = 4.10$, $p = .046$, $\eta_p^2 = 0.051$, Context x Session interaction: $F_{(1, 76)} = 5.53$, $p = .021$, $\eta_p^2 = 0.068$). Comparing the first run of the evening learning session across the two experiments (Figure 4), we found that participants learned less word-pairs in experiment 1 in the other context ($t(38) = -2.07$, $p = .045$, $d = -0.66$, 95% CI [-1.29, -0.01]), whereas learning was comparable in the same context ($t(38) = 0.42$, $p = .679$, $d = 0.13$, 95% CI [-0.49, 0.75]).

When extending the analysis to all three runs in each session, an ANOVA for experiment 1 (Figure 3C) likewise showed that participants learned significantly more word-pairs in the same context in the evening learning session (Session x Context interaction: $F_{(1,38)} = 6.38$, $p = .016$, $\eta_p^2 = .144$). In the same analysis we found that word pair learning improved across the three runs ($F_{(2,76)} = 857.05$, $p \leq .001$, $\eta_p^2 = .958$). All other factors did not significantly

affect performance (all $F \leq 2.77$, $p \geq .104$). An analysis of the separate sessions revealed that the benefit of the same context was only evident in the evening learning session ($F_{(1, 38)} = 4.43$, $p = .042$, $\eta_p^2 = 0.104$), but not in the morning learning session ($F_{(1, 38)} = 1.04$, $p = .313$, $\eta_p^2 = 0.027$).

Figure 3. The first two panels show the number of correctly recalled word-pairs in the same context condition versus the different context condition in the first out of three runs in experiment 1 (A), where participants were either exposed to the same or a different context during the evening session, and experiment 2 (B), where participants were additionally familiarized with the different context after the morning session. The results for an independent

t-test per session comparing the same versus different context condition are shown (asterisks indicate significance at $\alpha = .05$). The last two panels show the number of correctly recalled word-pairs across all runs in the morning versus evening session of experiment 1 (C) and experiment 2 (D). The results for a dependent t-test per context comparing the morning versus evening session per condition and run are shown (asterisks indicate significance at $\alpha = .05$). In all panels, the scattered points represent individual data points, randomly jittered across the x-axis. The lower and upper hinges of the boxplot correspond to the first and third quartiles (the 25th and 75th percentiles), and the middle line represents the median. The whiskers extend from the upper hinge to the largest value (no further than $1.5 \times$ inter-quartile range from the hinge) and from the lower hinge to the smallest value (no further than $1.5 \times$ inter-quartile range from the hinge). Data beyond the end of the whiskers are plotted in black (outliers). The larger diamonds indicate the mean.

In experiment 2 (context familiarisation), an ANOVA across all runs (Figure 1D) likewise revealed that participants improved their learning performance across the three runs ($F_{(1.47, 55.80)} = 676.10$, $p \leq .001$, $\eta_p^2 = 0.947$). However, there was no significant difference between the two contexts (Context main effect: $F_{(1, 38)} = 0.10$, $p = .759$, $\eta_p^2 = 0.003$; Context $\times$ Session interaction effect: $F_{(1, 38)} = 0.09$, $p = .769$, $\eta_p^2 = 0.002$). A comparison between the two experiments (Figure 4) showed a trend towards the different context negatively affecting word-pair learning in the evening learning session of experiment 1 (Experiment $\times$ Context $\times$ Session interaction: $F_{(1, 76)} = 3.35$, $p = .071$, $\eta_p^2 = 0.042$).

Figure 4. The number of correctly recalled word-pairs in experiment 1, where participants were either exposed to the same or a different context during the evening session, versus experiment 2, where participants were additionally familiarized with the different context after the morning session, for the first run of each session (morning and evening) and for both conditions (same and different context). The results for an independent t-test per session and condition comparing the first versus the second experiment are shown (asterisks indicate significance at $\alpha = .05$). The scattered points represent individual data points, randomly jittered across the x-axis. The lower and upper hinges of the boxplot correspond to the first and third quartiles (the 25th and 75th percentiles), and the middle line represents the median. The whiskers extend from the upper hinge to the largest value (no further than $1.5 \times$ inter-quartile range from the hinge) and from the lower hinge to the smallest value (no further than $1.5 \times$ inter-quartile range from the hinge). Data beyond the end of the whiskers are plotted in black (outliers). The larger diamonds indicate the mean.

3.2. Control measures

Descriptive statistics for the control measures for experiment 1 can be found in Table 2. There were no significant effects of Session, Context or their interactions on the number of lapses or reaction speed (mean 1/rt) in the psychomotor vigilance task (all $F \leq 2.73$, $p \geq .107$). Subjective sleepiness measured by the Stanford Sleepiness Scale (SSS) was higher in the evening than in the morning ($F_{(1,38)} = 12.18$, $p = .001$, $\eta_p^2 = 0.243$). The analysis of mood using the multidimensional mood questionnaire (MDBF) revealed no significant effects of Session, Context or their interactions for positive mood and calmness (all $F \leq 2.40$, $p \geq .130$). For the tiredness dimension there was a significant increase in the evening session (Session: $F_{(1,38)} = 22.36$, $p \leq .001$, $\eta_p^2 = 0.370$). There was no significant difference in verbal fluency used as measure of long-term memory retrieval ability in the evening session (version “hobby”: $t(38) = 1.44$, $p = .157$, $d = 0.46$; version “letter”: $t(38) = -0.04$, $p = .972$, $d = -0.01$).

Table 2

M(SD) for the control measures in experiment 1.

	same context		different context	
<i>PVT</i>				
Lapses morning	2.15	(5.94)	1.11	(1.20)
Mean 1/rt morning	3.16	(0.24)	3.12	(0.24)
Lapses evening	0.55	(0.94)	0.42	(0.51)
Mean 1/rt evening	3.23	(0.18)	3.16	(0.32)
<i>SSS</i>				
Morning	2.45	(0.60)	2.35	(0.49)
Evening	2.95	(1.19)	3.10	(1.02)
<i>MDBF</i>				
Good-bad mood morning	17.80	(2.33)	18.35	(1.18)
Calm-nervous morning	17.05	(2.46)	17.30	(1.84)
Awake-tired morning	15.80	(2.59)	16.60	(2.14)
Good-bad mood evening	17.60	(2.80)	17.60	(2.33)
Calm-nervous evening	16.65	(2.50)	17.30	(2.25)
Awake-tired evening	14.15	(4.13)	13.40	(2.52)
<i>WFT</i>				
Hobbies	17.0	(4.29)	19.0	(4.90)
Word starting with P	17.6	(5.15)	17.6	(3.53)

For experiment 2, descriptive data for the control measures can be found in Table 3. In the psychomotor vigilance task participants showed significantly faster reaction speed in the same context condition ($F_{(1,37)} = 4.19$, $p = .048$), but there was no effect of Session or a Context x Session interaction, nor was there an effect of Context and/or session on the number of lapses (all $F \leq 1.37$, $p \geq .250$). Subjective sleepiness showed no effects of Session, Context or their interactions (all $p \geq .094$). The analysis of mood showed that there were no significant effects of Session, Context or their interactions for positive mood and calmness (all $F \leq 2.99$, $p \geq .092$). There was, however, evidence for significantly higher tiredness in the evening session ($F_{(1,38)} = 11.91$, $p = .001$). We did not find any significant differences in long-term memory retrieval performance comparing the contexts as measured by the word fluency task (version “hobby”: $t(38) = 0.00$, $p > .999$, $d = 0.00$, version “letter”: $t(38) = 0.73$, $p = .467$, $d = 0.23$). For the letter counting task, which participants completed while being exposed to the other context in the morning, they counted more letters across runs (continuous counting: $F_{(1.95, 74.01)} = 26.91$, $p < .001$, $\eta_p^2 = 0.415$; single counting: $F_{(1.8, 68.44)} = 470.54$, $p < .001$, $\eta_p^2 = 0.925$), but there was neither an effect of Context nor a Context x Run interaction (all $F \leq 1.61$, $p \geq .210$).

Table 3*M(SD) for the control measures in experiment 2.*

		same context		different context	
<i>PVT</i>					
	Lapses morning	1.37	(1.16)	1.15	(1.14)
	Mean 1/rt morning	3.30	(0.37)	3.12	(0.23)
	Lapses evening	1.00	(0.94)	1.34	(1.34)
	Mean 1/rt evening	3.32	(0.28)	3.17	(0.29)
<i>SSS</i>					
	Morning	2.25	(1.12)	2.65	(0.93)
	Evening	2.65	(1.09)	2.95	(1.10)
<i>MDBF</i>					
	Good-bad mood morning	17.20	(2.53)	18.35	(1.14)
	Calm-nervous morning	16.90	(2.29)	17.55	(1.50)
	Awake-tired morning	15.60	(2.74)	15.30	(2.39)
	Good-bad mood evening	17.60	(2.78)	17.95	(1.96)
	Calm-nervous evening	16.60	(1.79)	16.90	(2.10)
	Awake-tired evening	13.65	(2.81)	13.60	(2.80)
<i>WFT</i>					
	Hobbies	17.20	(3.40)	17.20	(4.16)
	Word starting with P	16.00	(4.72)	17.0	(4.31)
<i>Letter counting</i>					
	Single letters run 1	756	(6.33)	752	(3.78)
	Single letters run 2	759	(6.21)	758	(5.96)
	Single letters run 3	780	(3.93)	779	(6.57)
	Continuous run 1	1110	(235)	1049	(69.9)
	Continuous run 2	1204	(199)	1132	(89.2)
	Continuous run 3	1192	(230)	1138	(89.6)

4. Discussion

We investigated the effect of context on learning in two experiments. In the first, participants learned word pairs in the morning and then learned a new set of word pairs in either the same or a different context in the evening. In a second experiment, participants were additionally exposed to the other context after learning in the morning. In experiment 1, participants learned more new word-pairs in the same context than in the other context during the evening session, as was expected as evidence for a context-dependent learning enhancement. Compared to the morning learning session, participants also enhanced their learning performance in the same context during the first run of the evening learning session. Unexpectedly, new learning performance during the evening session in the other context was decreased significantly. Experiment 2 did not confirm these results: Rather the familiarization with the other context using a task without learning elements, wiped out the differential effects found for the two context conditions in experiment 1. This means learning performance in the evening learning session of experiment 2 did not differ significantly from learning performance in the evening learning session of the same context group of experiment 1. However, learning performance during the first run of the evening learning session in the other context group of experiment 1 was significantly lower than performance of that group in experiment 2.

Contrary to our results, other studies found a change of context rather than a similar context to be beneficial for new learning (Pastötter et al., 2008; Smith, 1982). However, in Pastötter et al., (2008), both retrieval sessions took place after the context change, which might have caused interference because the first list still had to be kept in memory across the context change. Crucially, the learning episodes in the two aforementioned studies were conducted immediately after each other, creating an overlap in their temporal context. Temporal landmarks can be used during retrieval to separate information learned in different contexts (Smith, 1982), which could explain why we found the opposite pattern with our learning episodes being separated by 12 h. In fact, Smith (1982) finds that increased intervals between learning sessions can improve new learning performance, and argues that context effects on memory might not generalise across different time intervals. Likewise, Cox & Fell (2020), who

placed their two learning sessions 24 h apart, found that new learning benefits from matching contexts. Against this backdrop, our data raises the possible explanation that the degree of contextual overlap determines whether a change in context is beneficial for new learning. Context overlap might influence memory performance in the form of an inverted U-shape, where new learning in a very similar context is impaired due to too many overlapping “landmarks” (e.g., both spatial and temporal), new learning in a context with moderate differences is enhanced (e.g. only a temporal difference), and new learning in a very dissimilar context is impaired (e.g. temporospatial differences). In very different contexts, the complete lack of shared “landmarks” could lead to a failure to retrieve metacognitive strategies about the task. Adding to the complexity of this question, research on memory reconsolidation suggests that when reminders of the first learning context are presented before learning a second list, memory for list 1 is disturbed by list 2, but critically, the reminders did not affect performance for list 2 (Hupbach et al., 2007). While reconsolidation processes by definition do not affect new learning, it is tempting to speculate that in this study, the reminder cues of the first context compensated any negative effects the context change may otherwise have had on new learning.

Not only external contextual factors, but also internal contextual factors such as mood can affect memory performance (Bower et al., 1978; Robinson & Rollings, 2010). However, evaluating all of our control measures (vigilance, mood, sleepiness, letter counting and word fluency), the only difference that emerged between the two context conditions was the difference in vigilance in experiment 2. This difference was already evident in the morning, which means that it likely reflects a difference in trait rather than state. In addition, the reduced vigilance would have led to reduced learning in the other context group, which is not what we found. The classical context-dependence of memory can be at least partially cognitively controlled by the mental reinstatement of a context (Smith, 1979). In this scenario, the learner has to merely imagine the original encoding context to benefit the recall performance. However, such reinstatement should have equally occurred in experiment 1 and 2 and additionally cannot explain why performance in the other context dropped compared to the

morning learning session. Alternatively, the benefit of new learning in a familiar context may be due to the facilitated access to meta-cognitive learning processes, cued by contextual features. More familiar cues are better at triggering memory retrieval (Robin & Moscovitch, 2014), which is an elegant explanation why familiarization with the other context in our second experiment abolished the differences between the same and other context condition. However, we did not collect information about meta-cognitive strategies that our participants might have used, which limits the conclusions that can be drawn about such processes.

The hippocampus is critically involved in processing of the contextual information that a learning situation occurs in (Anagnostaras et al., 2001; Ekstrom & Ranganath, 2018; Maren, 2001; Myers & Gluck, 1994; Rugg et al., 2012) and at the same time serves as hub to bind the different aspects of declarative memories like temporal and spatial attributes together to create associations (Battaglia et al., 2011). This dual involvement of the hippocampus in task and context processing may have led to the pattern of effects observed in experiment 1. An interesting perspective is added when considering cholinergic models of hippocampal function (Easton et al., 2012; Hasselmo et al., 1996; Meeter et al., 2004). Behaviourally relevant stimuli, e.g. because they are novel or arousing, trigger the release of acetylcholine in the frontal cortex and the hippocampus, while familiar stimuli fail to elicit a cholinergic response (Acquas et al., 1996). Higher levels of cholinergic activity, following exposure to novel contextual cues, may bias the hippocampus toward forming distinctive memories by prioritizing encoding over retrieval (Douchamps et al., 2013). Whereas lower cholinergic levels occurring in familiar contexts (Giovannini et al., 2001), may bias the hippocampus toward memory reactivation aiding pattern completion processes (Duncan et al., 2012). This competition of pattern separation and pattern completion processes likely only played an important role in the evening learning phase, where participants were already familiar with the task. One can speculate that the unfamiliar other context in the evening learning session of experiment 1 may have driven cholinergic activity that by promoting pattern separation would prevent access to neuronal processing steps relevant for task execution that were associated to the familiar morning context. In the morning, when the context was also unfamiliar, but no pattern

separation processes were initiated because the task was entirely novel as well, this access would not have been blocked, leading to the performance measured in the morning session. This explanation goes beyond novelty binding of attention resources since it assumes that access to processing resources is gated by context. This intriguing possibility should be systematically examined in further experiments.

A potential limitation of our study comes from the short interval between switching the contexts in the morning session of experiment 2. It is conceivable that participants did not encode the two contexts as distinct episodes but rather linked them in memory, so that the context formed a larger meta-context. In experiment 1, we tried to separate the context also in time, but this was not possible for experiment 2 in the same way. In future experiments it would be helpful to familiarize the participants with the contexts with at least one day in between these sessions and without any learning occurring initially. This would allow applying the same paradigm as in experiment 1 with both contexts being familiar.

In conclusion, while experiment 1 seemingly provided evidence that the classical context dependence of memory extends to new learning this assumption was falsified by experiment 2. It seems that it is sufficient to be familiar with a context to be able to learn new information without detriment and that learning a task in that precise context is unnecessary for this benefit. However, the reduction in new learning from morning to evening in the other context group of experiment 1 leaves the question, which processes are interfering with new learning in unfamiliar contexts, if the learning procedure is familiar.

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6. Transparency and Openness

During the review process, all data and analysis code can be accessed privately by the reviewers. Upon publication, all data and analysis code will be made publicly available at the PsychArchives of the Leibniz Institute of Psychology (ZPID) and will be accessible at a persistent DOI. This study's design and its analysis were not pre-registered.

7. Author Contributions

MAA, GBF and JB developed the study concept and study design. Data collection was performed by MAA, SB and GN. MAA and JT performed the data analysis and interpretation under the supervision of GBF. MAA drafted the manuscript, and JT, GBF and JB provided critical revisions. All authors approved the final version of the manuscript for submission.

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