Context Matters: Memories of Prior Times

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DOI:
10.33612/diss.135934544

Publication date:
2020

Chapter 5
Timing with Aging Memory

This chapter is based on unpublished data collected in collaboration with Martin Riemer at the DZNE Magdeburg. The method and results sections are taken from Maaß, S. C., Wolbers, T., Van Rijn, H., & Riemer, R. (submitted).

Background

Bayesian optimization posits that behavior is best described by assuming that performance on a particular trial is driven by a combination of information collected during that trial itself (the likelihood) and information collected on previous trials (the prior). In the previous chapter, we presented evidence that Mild Cognitive Impairment patients, diagnosed with affected memory functioning, rely stronger on the prior than healthy controls. This paradoxical finding - as memory patients seem to rely more on memory - can be explained by assuming that memory affected individuals optimize their performance by relying less on the potentially brittle memory trace representing the current trial, but instead rely more on the more stable representation that is built up over multiple previous trials. The initial goal of that study was to compare clinically diagnosed memory patients with a control group of healthy participants. However, evaluation of the memory performance of the control group showed that a number of non-diagnosed participants also scored below the cut-off criteria for well-established clinical memory tests. We therefore categorized the healthy controls participant group into a $\text{controls}_{\text{failed}}$ and a $\text{controls}_{\text{pass}}$ group, and demonstrated that a similar behavioral difference could be observed between these groups as between the clinically affected and healthy control group. However, as this categorization was post-hoc, we intended to replicate this observation in another sample of healthy aged participants, that is, in participants who have not been diagnosed with and do not self-report any memory deficiencies.

Following the study reported in Chapter 4, Riemer collected data comparing the context effect (1) when elicited by more realistic versus more abstract stimuli, and (2) testing the observed context effects in different context regimes. For the former question, durations were either presented as the duration of an illuminated window in a street scene, or a color change of an abstract shape. For the latter question, a partially overlapping set of shorter or longer durations was either presented in isolation, or was presented in a mixed design in which each set was presented by means of a stimulus either on the left or the right side of the screen. As this work was initially set up as an independent research line instead of a direct replication, it deviates slightly from the experimental protocol used in Chapter 4. Most notably, this study did not contain an independent measure of clock variability (i.e., the 1-second task, see Chapters 3 and 4). However, the data collected do allow for evaluation of the conclusions of Chapter 4 that memory functioning determines the reliance on the prior, also in healthy aged participants.

Methods

Participants and Measures of Memory Functioning

Forty participants (all above 65 years old) were recruited from the local community in Magdeburg, Germany, by means of public advertisements in local newspapers. All participants were invited to the DZNE building at the University Hospital Magdeburg, and tested individually. Cognitive functioning, focusing on memory skills, was assessed with a delayed word recall task (identical to the word list recall task of the CERAD test battery, but with the default ten words replaced by words matching in complexity; Fillenbaum et al., 2008; Morris et al., 1989), and the Montreal Cognitive Assessment survey (MoCA, alternative version three; Nasreddine et al., 2005). Word recall scores ranged from 3 to 10, with a mean of 6.6 correct responses. However, to account for differences associated with education, age, and sex, word recall scores will be expressed as a distance to the standard score for education, age, and sex. Scores on this distance measure ranged from -2.4 to 5.95, with a mean of 1.7 (8 participants below the cutoff). Based on an education-corrected MoCA cut-off criterion of 26 (Nasreddine et al., 2005), participants were assigned to a group with few or no cognitive deficits (11 females, 12 males; mean age 69.6 years, ranging from 65 to 75, MoCA score > 25) and a group that just failed this threshold (9 females, 8 males; mean age 69.5 years, ranging from 65 to 80, mean MoCA score 23.0, ranging from 17 to 25, SD=2.1).

One participant completed only half of the experiment and was removed from further analyses. Participants received monetary compensation and gave written informed consent to the experimental protocol that was approved by the DZNE ethics committee.

Task and Stimuli

Participants were seated in front of a computer monitor and saw a visual scene depicting the front of a house (Figure 1a) or an abstract frame on grey background (Figure 1b). In each trial, either the left or the right window (or left or right panel of the frame) was illuminated for a specific duration, and then turned dark again. Participants were asked to register the duration of the illumination. After an inter-stimulus interval of one second, an orange frame appeared around the visual scene / grey background to indicate that participants could initiate the reproduction by pressing the spacebar for the just perceived duration. The experiment consisted of two parts (see Table 1), repeated twice, once using the realistic scene and once using the abstract stimuli, the order of which was counterbalanced over participants. In the first part, participants were either first presented durations sampled from a short context (1066, 1600, and 2400 ms), followed by durations sampled from a long context (2400, 3600 and 5400 ms), or vice versa. The short and long contexts were associated to either the left or the right stimulus. Both context order and association to a stimulus side were counterbalanced over participants. In the second part, presented durations were randomly sampled from both contexts, yet each context was still associated with the same stimulus side. The first part will be referred to as the *separate* context blocks, whereas the second part will be referred to as the *mixed* context block. Note that both contexts contain a standard duration of 2400 ms on which the analyses will focus. In the separate context blocks, each duration was presented 5 times for a total of 15 trials. In the mixed context block, the 2400 ms duration was presented 2 x 5 times, whereas the other durations were presented 5 times, matching the number of presentations in the separate context blocks. Durations were presented in pseudo-random order as, to ensure a sufficiently established context, the standard duration was not presented before the 5th or 9th trial in the separate / mixed blocks respectively.

Before the start of the experiment proper, participants performed practice trials that included performance-based feedback provided by the experimenter, until the task was deemed to be sufficiently understood. No feedback was provided during experimental trials. Participants were instructed to refrain from chronometric counting.

Table 1. Experimental Design. Note that context regime (separate/mixed), stimulus type (abstract/realistic) and location (left or right) was counterbalanced across participants.

	Part 1 (context regime *separate*)		Part 2 (context regime *mixed*)
Stimulus type *realistic*	Short 1066, 1600, 2400 ms	Long 2400, 3600, 5400 ms	Mixed left/right 1066, 1600, 2400 ms/2400, 3600, 5400 ms
Stimulus type *abstract*	Short 1066, 1600, 2400 ms	Long 2400, 3600, 5400 ms	Mixed left/right 1066, 1600, 2400 ms/2400, 3600, 5400 ms

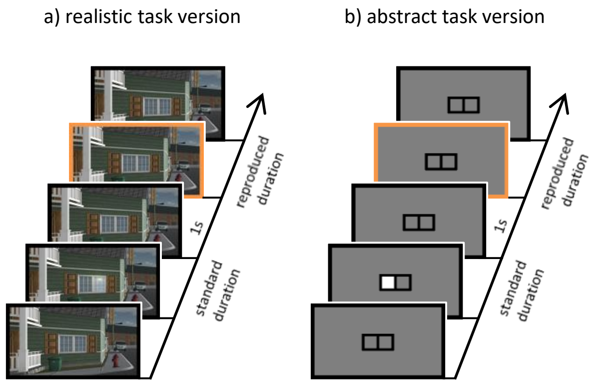

Figure 1. Outline of the experimental task. In each trial, participants reproduced the duration of (a) a lit window in the realistic version, and (b) a white square in the abstract version.

Statistical Analysis

Data and analysis scripts can be found at https://osf.io/4bpag/. All analyses focussed on the standard duration of 2400 ms. Responses shorter than 0.5 s and longer than 10 s were excluded from analysis (0.5 % of the data). To test whether the reproduction of the standard duration was influenced by context, we fitted a linear mixed model (LMM) using the *lme4* package (Bates et al., 2015) and the *lmerTest* package (Kuznetsova et al., 2017) (using Satterthwaite's degrees of freedom method) in R (R Core Team, 2016), with the reproduced duration (expressed in seconds) as dependent variable. We included fixed factors for *context* (short vs. long, coded as -.5 and .5), *context regime* (blocked vs. mixed, -.5 and .5) and *stimulus type* (abstract vs. realistic, -.5 and .5) and all first and second order interactions, and, based on our earlier work (Maaß et al., 2019a), we included an interaction between *context* and the score on the word recall task (*RecallTask*). Instead of coding word recall score as a binary variable as is common procedure, we utilized the higher precision that can be obtained by entering a numerical deviation from a cut-off score that is corrected for age, sex, and education. The cut-off criteria were identical to the original version of this task in the CERAD test battery (Morris et al., 1989). The deviation from the corrected cut-off score was entered into the model as a continuous variable. In addition, a random intercept for subjects was added.

Moreover, we ran two additional models which focused on the explanatory power of the MoCA test. For these models we removed the RecallTask-based interaction, but included either an interaction between *context* and binary

MoCA (score lower than 26 vs. higher than 25, coded as .5 and -.5 respectively, so that *MoCA* expressed the effect of scoring lower than the cut-off) or *context* and the *MoCA* memory subscore (median split on only the scores of the memory components of the *MoCA*, i.e., delayed recall, orientation and forward digit span; see Lam et al., 2013).

Results

As expected, the base model contained a significant intercept (β = 2.22, SE = 0.06, df = 37.00, t = 38.41, p< .001) and a significant overall effect of *context* (β = 0.07, SE = 0.03, df = 1508.01, t = 2.52, p = .012), indicating that context indeed influences the reproduced duration for the standard duration. The interaction between *RecallTask* and *context* indicates that the recall task score modulates the context effect (β = -0.03, SE = 0.01 df = 1508.00, t = -2.54, p = .011): For each additional point on the recall task, the context effect is 30 ms smaller, supporting the hypothesis that the context effect is smaller for participants with better memory performance (Figure 2).

The main effects of *stimulus type* and *context regime* indicate that realistic stimuli (β = 0.14, SE = 0.03, df = 1508.02, t = 5.42, p< .001) and mixed blocks (β = 0.05, SE = 0.03, df = 1508.01, t = 2.01, p = .044) increase the overall reproduced duration (i.e., independent of context). More importantly, where *context regime* did not modulate the context effect (*context regime* x *context:* β = -0.05, SE = 0.05, df = 1508.02, t = -0.89, p = .376), *stimulus type* did (*stimulus type* x *context:* β = 0.11, SE = 0.05, df = 1508.01, t = 2.04, p = .045), indicating that when realistic stimuli are presented, the difference between the two contexts is 110 ms larger than when abstract stimuli are presented. Neither the interaction between *context regime* x *stimulus type*, nor the three-way interaction between *context regime x stimulus type x context* reached significance (*t*s < 0.89, *p*s > 0.291). Model comparisons between this model and the models including higher order interactions indicated that the more complex models were not warranted (χ^2s < 0.187, df = 1, ps > 0.66).

The MoCA-based model contained a significant intercept (β = 2.25, SE = 0.06, df = 37.00, t = 37.99, p < .001). Interestingly, there is no overall effect of *context* (β = 0.04, SE = 0.03, df = 1508.01, t = 1.58, p = .114), yet the interaction between *MoCA* and *context* indicates that MoCA status modulates the context effect (β = 0.16, SE = 0.05, df = 1508.01, t = 2.99, p = .003), with participants failing the MoCA threshold showing a larger context effect. Specifically, participants failing the MoCA threshold showed a 160 ms larger reproduction difference between short and long contexts than participants passing the MoCA threshold (Figure 3). The other main and interaction effects were qualitatively similar to those of the *RecallTask* model reported above.

The model including the MoCA memory subscore (the summation of the memory components of the MoCA) contained a significant intercept (β = 2.21, SE = 0.06, df = 37.00, t = 35.56, $p < .001$) and a significant main effect of *context* (β = 0.09, SE = 0.03, df = 1508.00, t = 3.37, $p < .001$). Again, an interaction with *context* indicates that the MoCA memory score modulates the context effect (β = 0.16, SE = 0.05, df = 1508.00, t = 2.98, p = .003). The other main and interaction effects were qualitatively similar to those of the *RecallTask* model reported above.

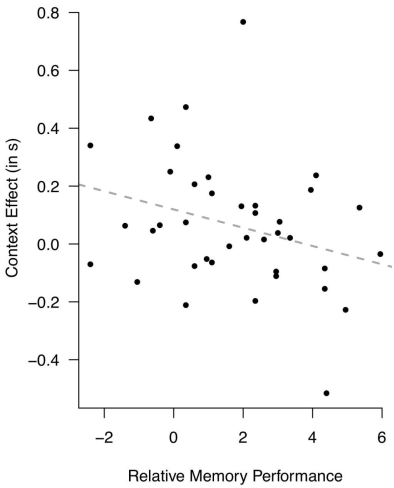

Figure 2: Context effects (defined as the difference between reproductions of the medium standard duration in the long and the short context) as a function of memory performance (defined as the recall task cut-off distance score), plotted per participant. The dashed line depicts the regression line.

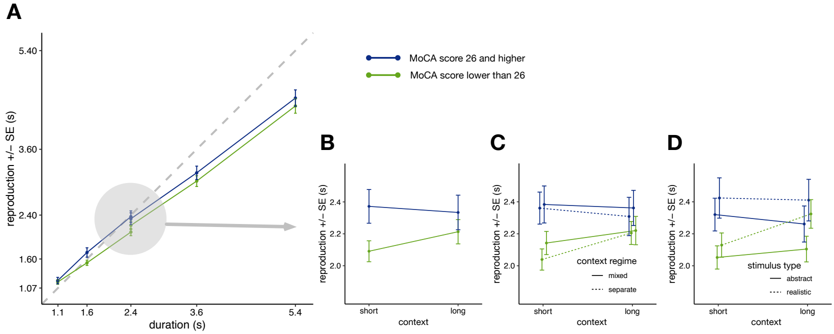

Figure 3. Effect of MoCA score on context effects. A: Average interval reproductions as a function of MoCA scores. **B:** Reproductions of the medium standard duration (i.e., 2400 ms) as a function of MoCA scores. **C:** Reproductions of the medium standard duration as a function of MoCA scores and context regime (i.e., whether contexts were presented in separate blocks, or mixed). **D:** Reproductions of the medium standard duration as a function of MoCA scores and stimulus type (realistic vs. abstract). Error bars represent standard errors of the mean with the within-participants Cousineau-Morey correction applied.

Conclusion

The reproduction of durations is highly influenced by the temporal context in which the physical interval is presented. In a time reproduction task, an interval of 2.4 seconds triggers a longer reproduction when it is presented within a set of longer intervals than when it is presented together with shorter intervals (Maaß et al., 2019b; Petzschner et al., 2015). Although the physical duration is the same, the context shapes either how the duration is perceived, or how the duration is reproduced.

In the present study, we tested the influence of temporal contexts on duration reproduction in older adults and assessed whether the participant's memory score influenced their temporal performance. On the basis of our previous study (Maaß et al., 2019a), we reasoned that cognitive decline, especially regarding memory functions, coincides with a pronounced susceptibility to contextual information. The analyses reported in this Chapter serve as a replication of the post-hoc finding reported by Maaß et al. (2019a) that memory functioning also influences performance for participants that are not diagnosed for memory deficiencies. The results support the notion that individuals with lower memory scores exhibit stronger context effects than individuals that score higher. Additionally, it demonstrates the generalizability of the observed effect as (1) it was also observed in a more naturalistic task setting, (2) remained present when the two earlier presented contexts were mixed in a final block, and (3) the durations in this experiment were about twice as long (but still in the second range) as the durations used in Maaß et al. (2019a). Moreover, the results were independent of the method by which memory or more general cognitive functioning was assessed, as this pattern of results was observed both when memory functioning was assessed by a delayed word recall task modelled after the CERAD test battery (Morris et al., 1989), and when using the scores on the Montreal Cognitive Assessment (MoCA; (Nasreddine et al., 2005) to predict the influence of the temporal context.

When comparing the relative effect sizes of the context effect ($\beta = 0.07$) and the effect of the deviance score on the recall task ($\beta = -0.03$), also depicted in Figure 2, it quickly becomes apparent that participants with higher memory performance scores demonstrate negligible context effects. Even though context effects are observed in practically all studies, earlier work by Cicchini et al. (2012) has demonstrated that expert percussionists do not show context effects. Our work suggests that in addition to professional rhythm instruction musicians, individuals with excellent memory skills might also reproduce durations without being influenced by context.