The loss of residual visual memories over the passage of time

Tom Mercer and Paul Duffy

Institute of Psychology, University of Wolverhampton, Wolverhampton, UK

Running head: Loss of residual visual memories.

Corresponding author: Tom Mercer, Institute of Psychology, Mary Seacole (MH) Building, Faculty of Education, Health and Wellbeing, Nursery Street, University of Wolverhampton, Wolverhampton, WV1 1AD. Email: t.mercer2@wlv.ac.uk. Tel: +44(0)1902 321368.

Acknowledgements: We are indebted to Amy Plumb for her assistance with the final stages of participant recruitment and data collection. We are also grateful to Dr Simon Farrell and two anonymous reviewers for comments on an earlier version of this manuscript. Stimulus images were provided courtesy of Michael J. Tarr, Center for the Neural Basis of Cognition, Carnegie Mellon University, http://www.tarrlab.org/.

ABSTRACT

There has been extensive discussion of the causes of short-term forgetting. Some accounts suggest that time plays an important role in the loss of representations, whereas other models reject this notion and explain all forgetting through interference processes. The present experiment used the recent-probes task to investigate whether residual visual information is lost over the passage of time. On each trial, three unusual target objects were displayed and followed by a probe stimulus. The task was to determine whether the probe matched any of the targets and the next trial commenced after an inter-trial interval lasting 300 ms, 3.3 s or 8.3 s. Of critical interest were recent negative (RN) trials, on which the probe matched a target from the *previous* trial. These were contrasted against non-recent negative (NRN) trials, in which the probe had not been seen in the recent past. RN trials damaged performance and slowed reaction times in comparison to NRN trials, highlighting interference. However, this interfering effect diminished as the inter-trial interval was lengthened, suggesting that residual visual information is lost as time passes. This finding is difficult to reconcile with interference-based models and suggests that time plays some role in forgetting.

Keywords: Visual memory, forgetting, time, short-term memory, recent-probes task.

The loss of residual visual memories over the passage of time

Short-term memory (STM) is responsible for maintaining small amounts of information over brief periods of time, but it has a limited lifetime and may be lost within a few seconds (see Jonides et al., 2008, for a review). There has been intense speculation concerning how the passage of time affects STM, and specifically whether time plays a causal role in the loss of short-term representations (e.g. Altmann & Schunn, 2012; Lewandowsky, Oberauer, & Brown, 2009; Oberauer & Lewandowsky, 2013; Portrat, Barrouillet, & Camos, 2008). Some theorists have proposed that STM decays over the passage of time unless actively maintained (e.g. Barrouillet, De Paepe, & Langerock, 2012), whereas others have argued that *all* information loss is a result of interference (e.g. Lewandowsky et al., 2009).

Evidence supporting this interference-based view was reported by Berman, Jonides, and Lewis (2009), who used the recent-probes task to explore time-based forgetting in verbal STM. On each trial four target words were presented and succeeded by a single probe word after a short interval. Participants had to judge whether the probe matched any of the four targets and the next trial began after a variable inter-trial interval (ITI). On positive trials the probe did match one of the targets, but of more interest were trials in which the probe word matched a target from the *previous* trial. This is termed a recent negative (RN) trial and Berman et al. were able to compare response times following a RN probe with trials on which the probe was novel and had not occurred recently (non-recent negative or NRN trials). Response times are slowed on RN trials, primarily because stimuli from the previous trial remain active within memory and produce proactive interference. As such, it takes longer to reject RN probes in comparison to NRN probes. Yet if memories are really lost as time passes, response times on RN trials should *decrease* as the ITI is lengthened, since memory for events in the past will be degraded and produce less interference. The recent-probes procedure therefore offers a useful tool for exploring the role of time in the loss of STM. It also has the added advantage of alleviating concerns about memory maintenance strategies, which is one of the most problematic issues affecting forgetting research (Lewandowsky, Geiger, Morrell, & Oberauer, 2010). Specifically, there is no reason for participants to actively rehearse or refresh stimuli from a previously completed trial – indeed, such a strategy would be counterproductive.

In six experiments, Berman et al. (2009) reported that response times on RN trials did not change, even at very long ITIs. Conversely, the introduction of a single intervening trial abolished the influence of RN probes, demonstrating the power of interference. Berman et al.'s findings offer convincing support for interference-based explanations, but pose a problem for any theory of forgetting incorporating a temporal component. Yet it would be premature to exclude any role for time since Berman et al. uncovered a small but reliable effect of the ITI when they combined data across all of their experiments. More recently, Campoy (2012) found clearer evidence of time-based forgetting in verbal STM using the recent-probes procedure. He argued that RN probes may be subjected to a rapid decay process, and by reducing the length of the ITIs used in this paradigm Campoy uncovered a decline in response times on RN trials, possibly indicating fast-acting decay.

Additionally, both Berman et al. (2009) and Campoy (2012) used verbal materials as stimuli, but nonverbal STM may be more susceptible to the passage of time (e.g. McKeown & Mercer, 2012; Mercer & McKeown, 2014; Ricker & Cowan, 2010). However, only one previous study has used the recent-probes task to examine nonverbal STM and, surprisingly, there was no evidence for forgetting as the ITI was lengthened. McKeown, Holt, Delvenne, Smith, and Griffiths (2014) adapted the recent-probes task by replacing words with abstract and meaningless visual objects that were difficult to verbalise. McKeown et al. also varied the retention interval separating the targets from the probe. In Experiment 1 they reported the classic disadvantage on RN trials (response times were slower and performance poorer in comparison to NRN trials), but there was no effect of the ITI and no interaction between the retention interval and ITI. In Experiment 2 McKeown et al. altered the design to see whether there was any evidence for Campoy's (2012) fast-acting decay. Again participants were slower to respond on RN trials, in comparison with NRN trials, but this effect was not influenced by ITI. There was also no significant interaction, suggesting that residual visual memories are not subjected to time-based forgetting over the short-term.

The null effect of the ITI is difficult to reconcile with theories that propose a role for time in STM loss, but the recent-probes paradigm has yielded contradictory results and the influence of time may be relatively subtle, as shown by Berman et al.'s (2009) discovery of time-based forgetting with their aggregated data set. The present experiment aimed to re-examine the loss of residual visual STM over the passage of time by creating a scenario in which forgetting would be valuable. The recent-probes task was adopted and, similar to McKeown et al. (2014), abstract and unfamiliar objects were used as the stimulus set. However, the present experiment employed complex objects of a uniform colour, whereas McKeown et al. used somewhat simpler objects that differed in colour. These more complex images may be harder to retain in STM and more susceptible to forgetting (Eng, Chen, & Jiang, 2005). Furthermore, the present experiment employed only nine objects as stimuli, which contrasts with both Berman et al. (2009), who typically used a large number of words (440 in Experiment 1), and McKeown et al., who used 260 visual objects. This is an important consideration since a small stimulus set creates heightened proactive interference and an increased likelihood of confusing items across trials. Time-based forgetting may be more evident within this situation as the removal of residual STM would usefully alleviate the powerful influence of proactive interference (see Altmann & Gray, 2002). Interestingly, Campoy (2012) – who did report forgetting within the recent-probes task – only included 10 digits within the stimulus set. In contexts of high proactive interference, losing residual STMs over the passage of time would have a clear adaptive role and would prevent participants from retrieving the wrong information.

Overall, the present experiment aimed to determine whether time plays any role in the loss of residual visual STM, or whether a purely interference-based account of forgetting offers the best explanation. Three ITIs were used (300 ms, 3.3 s and 8.3 s) and there was an equal mixture of RN and NRN trials. Accuracy on NRN trials was expected to exceed RN trials, and response times were predicted to be faster, but if representations from the past are steadily lost over time, RN trials would show smaller interfering effects at longer ITIs. Conversely, an interference-based view would expect RN trials to interfere with responding regardless of the ITI.

METHOD

Participants

Twenty-nine individuals (18 female) aged between 18 and 45 (*M* = 22.07, *SD* = 5.05) completed the experiment. Participants were recruited from the University of Wolverhampton and were predominantly undergraduate students. All individuals reported normal or corrected-to-normal vision.

Materials

Abstract and novel visual stimuli known as Fribbles were used in the discrimination task (stimulus images courtesy of Michael J. Tarr, Center for the Neural Basis of Cognition, Carnegie Mellon University, http://www.tarrlab.org/). Fribbles are complex objects that consist of a body and four different appendages – a head, legs, tail 1 and tail 2 (Barry, Griffith, De Rossi, & Hermans, 2014). There are 12 different species of Fribble, each with 81 exemplars, arranged into three different families (A, B, and C). Each Fribble family possesses four different species or categories (numbered 1, 2, 3 and 4), and there are systematic differences between Fribbles of the same species. For the present experiment, nine blue Fribbles were selected from the Tarrlab database (see Figure 1). These represented exemplars from each of the different species and families; hence they were perceptually distinct. The combination of Fribbles on each trial was always unique. A pure tone warning signal (4.8 kHz) was generated using Audacity (version 2.0.3) and presented via speakers at approximately 65 dB. The experiment was run on a PC using SuperLab software (version 4.5). All stimuli were displayed on a HannsG HP191 19" monitor. Participants were seated approximately 60 cm from the screen and made their response on a keyboard.

"Figure 1 about here"

Design and Procedure

The experiment employed a 2x3 within-subjects design with trial type and ITI as independent variables. Task performance and response times were recorded. Each trial began with a warning tone (300 ms) and a fixation cross (100 ms) that was presented 200 ms after the onset of the tone. This was followed by the three target stimuli that remained on screen for 2 s. The targets were followed by a blank retention interval lasting 400 ms after which a single probe stimulus was displayed. Participants were asked to press the "M" key if they believed the probe matched any of the three targets, or the "Z" key if it was not a match. The probe remained on screen until participants responded or until 2 s had elapsed. After this, the next trial began following an ITI of 300 ms, 3.3 s or 8.3 s. This created total decay intervals lasting approximately 3, 6 and 11 s, respectively. On RN trials, the current probe matched one of the targets from the previous trial (but never the probe). On NRN trials the probe stimulus had not been seen for at least two previous trials, whereas on positive trials the probe matched one of the current target stimuli.

Sixty-four trials were created for each ITI condition, including 16 RN, 16 NRN and 32 positive. Following Berman et al. (2009), there were 192 experimental trials in total. In addition, 18 practice trials were completed at the beginning of the study. During practice, participants were given feedback on their response time and performance, so that they learnt to respond within 2 s. Participants were then asked to complete the experimental trials. These trials were arranged into six blocks, each of which contained 32 trials. The order of trials within a block was fixed (to allow control over the occurrence of RN and NRN trials), but the order of the blocks was randomised for each participant. Breaks were offered between each block to alleviate fatigue effects. The experiment lasted approximately 50 minutes.

RESULTS

Preliminary analysis

Trials on which participants failed to respond (or where an invalid button was pressed) were excluded from the analysis. However, this represented only 1.94 % of trials, in total. Positive trials were not incorporated into the analysis since they are theoretically uninformative (Berman et al., 2009; Campoy, 2012; McKeown et al., 2014).

Performance

Figure 2 shows task performance on RN and NRN trials according to the three ITIs. Accuracy on NRN trials showed a slight decline as the ITI was lengthened, whereas performance on RN trials progressively improved at longer ITIs. At 8.3 s, accuracy on RN and NRN trials was very similar. To assess these trends, a 2 (Trial type: RN vs. NRN) x 3 (ITI: 300 ms vs. 3.3 s vs. 8.3 s) within-subjects ANOVA was carried out. This revealed a significant main effect of trial type, $F(1, 28) = 18.09$, $MSE = .009$, $p < .001$, $\eta_p^2 = .393$, which was due to worse performance on RN trials ($M = .83$) in comparison with NRN trials ($M = .89$). There was no main effect of ITI, $F(2, 56) = 2.34$, $MSE = .006$, $\eta_p^2 = .077$, but there was a significant trial type x ITI interaction, $F(2, 56) = 5.63$, $MSE = .007$, $p = .006$, $\eta_p^2 = .167$. A subsequent simple effects analysis, corrected for multiple comparisons using the Holm-Šidàk procedure, confirmed that performance on RN and NRN trials at the 8.3 s ITI was not significantly different ($p = .765$), but task accuracy on NRN trials exceeded RN trials at 3.3 s ($p = .048$) and 300 ms ($p < .001$).

"Figure 2 about here"

Response times

Mean response times on RN and NRN trials can be seen in Figure 3. These data only include trials with correct responses, although an analysis of the full data set did not change the overall trends. A 2x3 within-subjects ANOVA found a significant main effect of trial type, $F(1, 28) = 8.59$, $MSE = 5498.84$, $p = .007$, $\eta_p^2 = .235$, with response times on RN trials ($M = 934.27$) being slower than those on NRN trials ($M = 901.33$). There was no main effect of ITI, $F(2, 56) = .15$, $MSE = 7400.65$, $\eta_p^2 = .005$, but the interaction was significant, $F(2, 56) = 6.17$, $MSE = 4618.67$, $p = .004$, $\eta_p^2 = .181$. A simple effects analysis, again corrected using the Holm-Šidàk procedure, showed that RN and NRN response times for the 8.3 and 3.3 s ITIs were not significantly different ($p = .876$ and $p = .403$, respectively), whereas at 300 ms participants were significantly slower to respond on RN trials than on NRN trials ($p < .001$).

"Figure 3 about here"

DISCUSSION

The present study found that residual visual STMs are forgotten over the passage of time. RN trials damaged discriminatory ability and slowed response times in comparison to NRN trials, but this effect became less evident as time passed. For the performance data, RN trials led to significantly worse performance at the 300 ms and 3.3 s ITIs (task accuracy was lower than NRN trials by an average of 11 % and 7 %, respectively). Yet by 8.3 s, performance on RN and NRN trials was not reliably different (indeed, mean accuracy differed by less than 1 %). The representation from the previous trial stopped producing interference at the longest ITI. For the response time data, RN trials stopped (significantly) slowing responding by the 3.3 s ITI. There was a slight discrepancy here, with performance (but not response times) being hindered on RN trials at the 3.3 s ITI. Yet the results from both measures were consistent with the loss of residual visual information over time.

Importantly, these findings appear incompatible with purely interference-based explanations and indicate that time plays some role in STM loss. These results also conflict with Berman et al. (2009), who found that verbal information is not lost as the ITI is extended. Whilst differences in stimuli (words vs. Fribbles) could explain the disagreement between the present findings and Berman et al., these data broadly support Campoy (2012) and show that lengthening the ITI reduces proactive interference effects. The present data were also incompatible with the results of McKeown et al. (2014), who found that passively maintained visual representations are not lost over time. This might have been due to the size of the stimulus set - McKeown et al. used a very large number of stimuli, whereas the present study employed a smaller number of images. The Fribbles utilised in this experiment were of a uniform colour and, although different from one another, they shared the same basic structure (a body with four appendages). McKeown et al.'s stimuli consisted of a variety of textures, shapes and colours, so the overall novelty of stimuli was much higher. Whilst both the present experiment and McKeown et al. introduced proactive interference on RN trials, overall proactive interference was heightened in the present experiment as a result of exposing participants to the same stimulus set throughout the procedure. In this context, the need to forget events on the previous trial might be more critical and the loss of residual representations serves an adaptive purpose. Time-based forgetting of representations therefore has a functional role (Altmann & Gray, 2002) and this was manifested in the declining impact of RN probes.

Such time-based forgetting could be due to temporal decay. According to this view, the absolute amount of time that has passed is important, since visual STMs that are not being actively maintained slowly decline over time. The present findings are consistent with this account and the recent-probes task has been forwarded as an effective tool for measuring decay in the absence of continuous maintenance (Berman et al., 2009; Campoy, 2012; McKeown et al., 2014). Nonetheless, the time-based forgetting found in the present experiment is also explicable by temporal distinctiveness models, which emphasise the role of relative time (e.g. Brown, Neath, & Chater, 2007). The recent-probes task creates situations of temporal crowding or isolation by varying the ITI. As the ITI is lengthened, events on the current trial are temporally separated from those on the previous trial, and this would make the items in memory more distinct and less likely to be confused.

The decay and distinctiveness explanations offer different interpretations of the present data, but both include a temporal dimension. These theories therefore appear to provide a better account of the present findings than models relying solely on interference. However, neither decay or distinctiveness accounts can explain the full range of data emerging from the recent-probes task. The present findings show that residual information is lost over time when proactive interference is high. But in situations featuring increased stimulus novelty and lower trial-to-trial similarity (e.g. McKeown et al., 2014), residual visual memories may persist. Information held within visual STM may be removed from STM according to the level of proactive interference. This possibility is in need of further testing but, if true, models of short-term forgetting would benefit from considering the broader context in which memories are formed and maintained.

In conclusion, the present study found that visual memories were steadily lost over the passage of time in a situation that minimised active maintenance. This finding is difficult to reconcile with purely interference-based models of forgetting and suggests that time does play some role in the life and death of residual visual representations.

Main text: 2,983 words.

REFERENCES

Altmann, E. M., & Gray, W. D. (2002). Forgetting to remember: The functional relationship of decay and interference. *Psychological Science*, *13*, 27-33. doi:10.1111/1467-9280.00405

Altmann, E. M., & Schunn, C. D. (2012). Decay versus interference: A new look at an old interaction. *Psychological Science*, *23*, 1435-1437. doi:10.1177/0956797612446027

Barrouillet, P., De Paepe, A., & Langerock, N. (2012). Time causes forgetting from working memory. *Psychonomic Bulletin & Review*, *19*, 87-92. doi:10.3758/s13423-011-0192-8

Barry, T. J., Griffith, J. W., De Rossi, S., & Hermans, D. (2014). Meet the Fribbles: Novel stimuli for use within behavioural research. *Frontiers in Psychology*, *5*, 103. doi:10.3389/fpsyg.2014.00103

Berman, M. G., Jonides, J., & Lewis, R. L. (2009). In search of decay in verbal short-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *35*, 317-333. doi:10.1037/a0014873

Brown, G. D. A., Neath, I., & Chater, N. (2007). A temporal ratio model of memory. *Psychological Review*, *114*, 539-576. doi:10.1037/0033-295X.114.3.539

Campoy, G. (2012). Evidence for decay in verbal short-term memory: A commentary on Berman, Jonides, and Lewis (2009). *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *38*, 1129-1136. doi:10.1037/a0026934

Eng, H. Y., Chen, D., & Jiang, Y. (2005). Visual working memory for simple and complex stimuli. *Psychonomic Bulletin & Review*, *12*, 1127-1133. doi:10.3758/BF03206454

Jonides, J., Lewis, R. L., Nee, D. E., Lustig, C. A., Berman, M. G., & Moore, K. S. (2008). The mind and brain of short-term memory. *Annual Review of Psychology*, *59*, 193-224. doi:10.1146/annurev.psych.59.103006.093615

Lewandowsky, S., Geiger, S. M., Morrell, D. B., & Oberauer, K. (2010). Turning simple span into complex span: Time for decay or interference from distractors? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *36*, 958-978. doi:10.1037/a0019764

Lewandowsky, S., Oberauer, K., & Brown, G. D. A. (2009). No temporal decay in verbal short-term memory. *Trends in Cognitive Sciences*, *13*, 120-126. doi:10.1016/j.tics.2008.12.003

McKeown, D., Holt, J., Delvenne, J-F., Smith, A., & Griffiths, B. (2014). Active versus passive maintenance of visual nonverbal memory. *Psychonomic Bulletin & Review*, *21*, 1041-1047. doi:10.3758/s13423-013-0574-1

McKeown, D., & Mercer, T. (2012). Short-term forgetting without interference. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *38*, 1057-1068. doi:10.1037/a0027749

Mercer, T., & McKeown, D. (2014). Decay uncovered in nonverbal short-term memory. *Psychonomic Bulletin & Review*, *21*, 128-135. doi:10.3758/s13423-013-0472-6

Oberauer, K., & Lewandowsky, S. (2013). Evidence against decay in verbal working memory. *Journal of Experimental Psychology: General*, *142*, 380-411. doi:10.1037/a0029588

Portrat, S., Barrouillet, P., & Camos, V. (2008). Time-related decay or interference-based forgetting in working memory? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*, 1561-1564. doi:10.1037/a0013356

Ricker, T. J., & Cowan, N. (2010). Loss of visual working memory within seconds: The combined use of refreshable and non-refreshable features. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *36*, 1355-1368. doi:10.1037/a0020356

FIGURE CAPTIONS

Figure 1. Example Fribble stimuli. Three Fribbles were selected from the “FA” family, three from the “FB” family and three from the “FC” family. Image 1 shows an example “FA” Fribble, image 2 shows an example “FB” Fribble and image 3 shows an example “FC” Fribble.

Figure 2. Mean proportion correct data according to trial type and ITI duration. Error bars show 95 % confidence intervals, corrected for the within-subjects design.

Figure 3. Mean response time data according to trial type and ITI duration (for correct responses only). Error bars show 95 % confidence intervals, corrected for the within-subjects design.

Figure 1.

Figure 2.

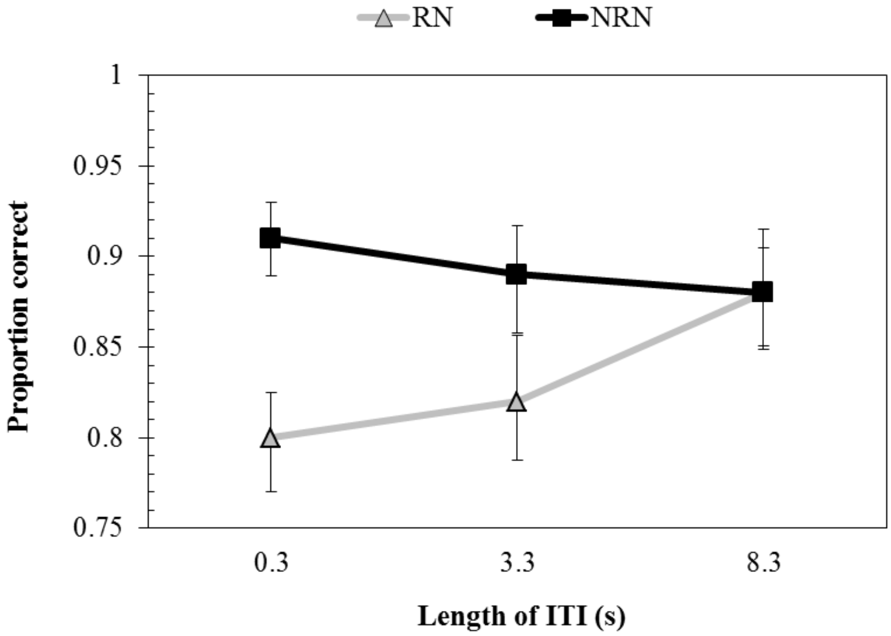
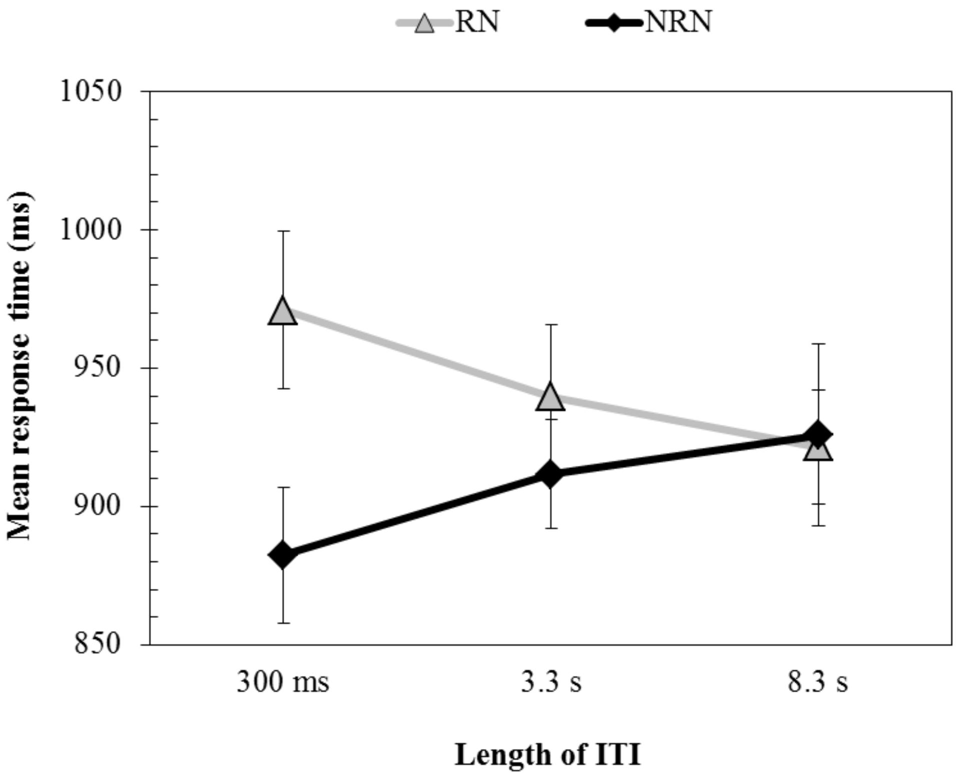

RN
NRN
1
0.95
0.9
0.85
0.8
0.75
Proportion correct
0.3
3.3
8.3
Length of ITI (s)

Figure 3.


RN
NRN
1050
1000
950
900
850
Mean response time (ms)
300 ms
3.3 s
8.3 s
Length of ITI