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**DOI**
10.1080/13825585.2018.1451480
**Publication date**
2019
**Document Version**
Final published version
**Published in**
Aging, Neuropsychology, and Cognition
**License**
CC BY-NC-ND

Link to publication

**Citation for published version (APA):**
Lugtmeijer, S., de Haan, E. H. F., & Kessels, R. P. C. (2019). A Comparison of Visual Working Memory and Episodic Memory Performance in Younger and Older Adults. *Aging, Neuropsychology, and Cognition*, *26*(3), 387-406. https://doi.org/10.1080/13825585.2018.1451480

AGING, NEUROPSYCHOLOGY, AND COGNITION
2019, VOL. 26, NO. 3, 387–406
https://doi.org/10.1080/13825585.2018.1451480

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# A comparison of visual working memory and episodic memory performance in younger and older adults

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**ABSTRACT**

Working memory and episodic memory decline with age. However, as they are typically studied separately, it is largely unknown whether age-associated differences are similar. A task design was developed in which visual working memory and episodic memory performances were measured using the same stimuli, with both tasks involving context binding. A 2-back working memory task was followed by a surprise subsequent recognition memory task that assessed incidental encoding of object locations of the 2-back task. The study compared performance of younger ($N=30$; $M_{age}=23.5$, $SD_{age}=2.9$, range=20-29) and older adults ($N=29$; $M_{age}=72.1$, $SD_{age}=6.8$, range=62-90). Older adults performed worse than younger adults, without an interaction effect. In younger, but not in older adults, performance on the two tasks was related. We conclude that although age differences (Young>Older) are similar in the working memory and incidental associative memory tasks, the relationship between the two memory systems differs as a function of age group.

**ARTICLE HISTORY**
Received 6 July 2017
Accepted 5 March 2018

**KEYWORDS**
Aging; working memory; subsequent memory; episodic memory; binding

## Introduction

A decline in memory function is a common complaint of older adults. However, memory function is not a unitary construct, but consists of multiple memory systems that may be differentially affected by aging (Tulving, 1983; for a review, see Craik & Rose, 2012). For instance, procedural memory and semantic memory are relatively spared, whereas substantial decline has been demonstrated in working memory and episodic memory (Craik & Rose, 2012). To date, there is debate on how these systems are related and how their relation is affected by aging.

Several theories of memory and aging have been proposed (for a recent review, see Park & Festini, 2017). Two theoretical frameworks are of particular interest here, as they specifically address working memory and episodic memory. The first is the "associative deficit hypothesis" that states that older adults exhibit a disproportionate decrement in memory for bound, associative information, relative to memory for the associated items, and this is due to problems both with binding and retrieval (e.g., Chalfonte & Johnson, 1996; Naveh-Benjamin, 2000). An example of associative memory is context memory,

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which involves the binding of features to objects, such as spatial and temporal properties. Context information aids the retrieval of memories and has been found to be more impaired than item memory in older adults compared to younger adults (e.g., Chalfonte & Johnson, 1996; Kessels, Hobbel, & Postma, 2007; Naveh-Benjamin, 2000; Naveh-Benjamin, Guez, Kilb, & Reedy, 2004; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003; see meta-analyses by Spencer & Raz, 1995). Whereas age-related binding deficits are a robust finding in studies of long-term memory, research during the last decade has demonstrated that both item–context binding and item–item binding in working memory may be additionally affected in older adults (e.g., Chen & Naveh-Benjamin, 2012; Cowan, Naveh-Benjamin, Kilb, & Saults, 2006; Fandakova, Sander, Werkle-Bergner, & Shing, 2014; Peterson & Naveh-Benjamin, 2016; but see Read, Rogers, & Wilson, 2016) while within-item binding seems to be relatively spared by age (e.g., Parra, Abrahams, Logie, & Della Sala, 2009).

A second theory that might explain age-related differences in memory performance is the “irrelevant information deficit hypothesis” according to which older adults have relatively more difficulty in inhibiting irrelevant information and updating in the presence of distraction, resulting in inefficient encoding and impaired performance (for a review, see Hasher & Zacks, 1988; Healey, Campbell, & Hasher, 2008). While irrelevant information might hamper both working memory and episodic memory performance in older adults, some studies found that in situations where previously irrelevant information becomes relevant, older adults outperform younger adults (Healey et al., 2008). Studies discussed in the review by Healey et al. (2008) show that older adults can benefit more than younger adults from previously irrelevant verbal distractors in subsequent tasks, like a word fragment completion task or Remote Associates Test problems. Campbell, Hasher, and Thomas (2010) investigated associations between words and objects and reported hyper-binding in older adults, which means that older adults encode irrelevant co-occurrences and are able to use this in a subsequent task. Younger and older adults performed a 1-back task with line drawings of objects with irrelevant words superimposed. After a 10-min delay, 16 object–word pairs were presented in a study phase—half of the pairs were intact pairs from the 1-back task and the other half disrupted pairs. The study phase was directly followed by a testing phase in which the objects were shown and participants had to recall the corresponding words. Critical was the age-by-pair-type interaction with no differences between preserved and disrupted pairs in younger adults and an advantage for preserved pairs in older adults, showing that older adults, unlike younger adults, were able to use the associations incidentally learned during the 1-back task.

Inconclusive results from previous studies concerning the effects of aging on memory may be due to task differences. Working memory is a multifaceted system that comprises processes like encoding, maintenance, updating, temporal ordering, binding, attention, and inhibition. Therefore, it is unsurprising that different working memory tasks tap only partly overlapping components of working memory resulting in a weak correlation between tasks (Redick & Lindsey, 2013). Furthermore, the degree of age-related decline may also depend on task characteristics. That is, more complex working memory tasks being more sensitive to aging than less complex ones (Bopp & Verhaeghen, 2005). As is the case with working memory, episodic memory consists of different subprocesses, variation in encoding, and retrieval conditions influence age-associated differences (review by Tromp, Dufour, Lithfous, Pebayle, & Deprés, 2015). Furthermore, previous working and episodic memory tasks have often used different stimuli, all with their own specific characteristics (e.g., in terms of verbalizability, perceptual complexity, and sometimes even auditory versus visual presentation). Such task-specific properties may modify the relationships between the two memory systems, and stimulus-specific variability across studies makes comparison of working memory and episodic memory performance difficult.

A way to reduce task differences and assess the relationship between the subsystems is to use the same stimuli in a within-subjects design. To date, three studies investigated working memory and episodic memory by testing incidental encoding during the working memory task with a subsequent memory task (Bergmann, Rijpkema, Fernández, & Kessels, 2012; Van Geldorp et al., 2015; Werkle-Bergner, Freunberger, Sander, Lindenberger, & Klimesch, 2012). Two studies used a delayed match-to-sample working memory task during which participants needed to keep pairs, each consisting of both a house and a face stimulus, in mind and make a judgment. In an unexpected subsequent memory task, participants had to choose from two pairs of faces and houses, the pair they had seen before. Van Geldorp et al. (2015) compared the performance of younger and older adults and showed a similar effect of age on both tasks. A limitation of this study was the complexity of the stimuli used, which resulted in near chance-level performance on the subsequent memory task in older adults (Van Geldorp et al., 2015). A second consequence of using complex stimuli is the possibility that long-term memory was recruited during the working memory task due to an overload of working memory capacity (Jeneson & Squire, 2012), resulting in both tasks relying on the same memory subsystem. Bergmann et al. (2012) used the same paradigm in an event-related functional magnetic resonance imaging design with healthy students showing only partial overlap in the recruitment of brain regions for working and episodic memory. This suggests that the two systems may be differentially susceptible to the effects of age. A third study assessing working memory and episodic memory took relevant versus irrelevant information and age differences into consideration in new–old judgments of scenes (Werkle-Bergner et al., 2012). Each stimulus was preceded by a cue that indicated whether the stimulus needed to be remembered or not. Younger adults showed higher recognition on both tasks. On the subsequent episodic memory task, both groups performed at chance level for the stimuli cued as not-to-be remembered indicating successful inhibition of irrelevant information. No comparison was made between working memory and episodic memory performance. Thus, the question how working memory and episodic memory relate and if successful processing in working memory is required for successful long-term memory is still open to debate.

In order to shed some light on this unresolved issue in relation to age differences, we developed a task design to measure both working memory and long-term memory for the same visual stimuli in a within-subjects design taking into account findings and limitations from previous studies. As working memory measure, we used an *N*-back task in which participants have to respond when an item in a sequence of presentations matches the item *N* trials before (Kirchner, 1958). The *N*-back task we designed contained easy-to-name objects to avoid a floor effect on the subsequent memory task and contained no relevant associations apart from temporal order to reduce the chance of recruitment of long-term memory during the working memory task. The *N*-back task measures working memory as defined by Unsworth and Engle (2007), highlighting two essential working memory components: (1) cognitive control is needed to override automatic responses and (2) the maintenance and retrieval of novel information is required in the presence of distracting information where a discrimination process differentiates between relevant and irrelevant information (for a review, see Cowan, 2017). In the *N*-back task, only the item of the relevant lag needs to be compared to the current item in a continuous sequence, while control is needed to suppress responses to items of other lags and a discrimination process is needed to decide relevance of maintained items. This design allows for analyzing different types of errors. Errors on lure trials (i.e., trials with an object corresponding to a different but close lag to two) indicate responses based on familiarity rather than successful updating. Finally, the object component made the task suitable to test subsequent memory formation.

The *N*-back task was followed by an unexpected memory task, during which object–location associations incidentally encoded during the working memory task were tested. This subsequent recognition memory task relies on long-term memory, not only because of the longer retention interval but also because of the large number of items that need to be stored and the associations between object and location that are necessary for successful performance (Jeneson & Squire, 2012). The meta-analysis by Old and Naveh-Benjamin (2008) showed that intentional encoding instructions resulted in a larger age effect compared to incidental encoding instructions. However, we chose incidental encoding to minimize interference of long-term memory encoding during the working memory task, so that both tasks were non-dual tasks (Bergmann et al., 2012). Using the same stimuli and similar context binding in both tasks in a within-subjects design allows us to compare the working memory with the episodic memory performance and assess the relationship. The following research questions were addressed: (1) Do working memory and episodic memory performance show similar age differences when using the same stimuli? (2) How are working memory performance and episodic memory performance related in younger and older adults? and (3) Are there age-related differences in response patterns?

To answer the research questions, 30 younger and 30 older adults were tested on the working memory and episodic memory tasks. The results may have repercussions for several different theoretical accounts, but a particular set of hypotheses can be proposed based on the associative deficit hypothesis and the irrelevant information hypothesis. The associative deficit hypothesis predicts similar age-associated differences on the working memory and subsequent memory task as has been shown before in an item–item binding task (Chen & Naveh-Benjamin, 2012). Previous studies have shown that both object–temporal order and object–location binding are similarly sensitive to aging in long-term memory paradigms (Old & Naveh-Benjamin, 2008); furthermore, age-related binding deficits have been reported in working memory for object–location associations (Cowan et al., 2006; Peterson & Naveh-Benjamin, 2016). The correlation between performances on the two tasks is expected to be positive, indicating that both systems are related by a common mechanism. The irrelevant information deficit hypothesis predicts worse performance of older adults on the working memory task but a possible advantage on the subsequent memory task. Lack of inhibition of irrelevant objects from different lags than two might impair performance on the *N*-back task, while encoding of irrelevant location information during the working memory task in older adults might result in an advantage on the subsequent memory task. High performers on the *N*-back task are better at inhibition so it can be expected that they are the low performers on the subsequent memory task; therefore, a negative correlation is predicted. As aging has a stronger effect on recollection than on familiarity, older adults are expected to make more mistakes on lure trials in the working memory task. Correctly identified targets in the working memory task are expected to be processed better than missed targets and therefore more likely to be bound to the correct location in episodic memory in both younger and older adults. A signal-detection approach was used to analyze the data, which has been suggested for evaluating the binding deficit hypothesis (Cowan et al., 2006). Mixed results have been reported in the literature regarding the effects of age on response bias. For instance, a slightly more liberal response bias in older adults was found by Bender, Naveh-Benjamin, and Raz (2010), while others reported more a conservative response bias in older adults (e.g., Cowan et al., 2006; Read et al., 2016).

## Method

### Participants

Thirty older and 30 younger adults participated in the study between February and December 2016. Older adults were aged above 60 years and younger adults were aged between 20 and 30 years (in line with meta-analyses by Bopp & Verhaeghen, 2005; Koen & Yonelinas, 2014; Old & Naveh-Benjamin, 2008). Participants from both groups were matched on gender and level of education based on the Dutch educational system (range 1–7, low to highly educated; Verhage, 1964). Exclusion criteria were indication for cognitive impairment based on the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005) using a cutoff of 23 (Luis, Keegan, & Mullan, 2009), the diagnosis of a cognitive disorder or a psychiatric history. One older adult (age 69, male, education level 6) was excluded from analyses based on a MoCA score below the cutoff, resulting in a final sample of 29 older adults. Participants were recruited from social networks and received monetary compensation (EUR 10.00) for their participation. Informed consent was obtained from all participants according to the Declaration of Helsinki. The study was approved by the ethics committee of the faculty of social sciences of the Radboud University. Descriptive characteristics and neuropsychological test results are presented in Table 1.

### Neuropsychological measures

A brief battery of neuropsychological tests included the MoCA to assess general cognitive functioning, the Dutch version of the National Adult Reading Test to estimate IQ (Schmand, Lindeboom, & Van Harskamp, 1992), the Corsi Block-Tapping Task for visual working memory (Corsi, 1973; Kessels, van den Berg, Ruis, & Brands, 2008), and from the Doors and People Test, the Doors Test (part A and B) to test visual recognition (Baddeley, Emslie, & Nimmo-Smith, 1994). Older adults had a higher estimated IQ, whereas they performed worse than younger adults on standard clinical test measuring working memory and recognition (see Table 1), indicating an age-associated difference in memory performance.

**Table 1.** Descriptives, neuropsychological measures, and comparisons between two age-groups.

| | Older adults | Younger adults | Statistics | *p*-Value |
|---|---|---|---|---|
| Sex (m:f) | 13:16 | 14:16 | $\chi^2(1) = .020$ | .887 |
| Age (*M, SD*, range) | 72.1 (6.8, 62–90) | 23.5 (2.9, 20–29) | | |
| Education level[c] (*Mdn*, range) | 6 (3–7) | 6 (4–7) | $U = 398.0$ $z = -.600$ | .549 |
| MoCA (*M, SD*, range) | 26.9 (1.8, 24–29) | 27.7 (1.6, 24–30) | $t(57) = -1.92$ | .060 |
| NART IQ (*M, SD*) | 114.3 (10.3) | 96.7 (10.5) | $t(56)^{a} = 6.42$ | <.001 |
| Corsi forward[b] (*M, SD*) | 40.2 (14.4) | 57.9 (20.1) | $t(57) = -3.88$ | <.001 |
| Corsi backward[b] (*M, SD*) | 42.0 (14.7) | 62.6 (17.1) | $t(57) = -4.96$ | <.001 |
| Doors Test (A and B) (*M, SD*) | 17.5 (2.5) | 19.7(2.8) | $t(57) = -3.33$ | .002 |

*M*: mean, *SD*: standard deviation, *Mdn*: median; m: males; f: females; NART: National Adult Reading Test.
[a]One participant did not finish the NART.
[b]Product of the Block Span and the number of correctly repeated sequences.
[c]Education level was assessed using seven categories in accordance with the Dutch educational system (1 = less than primary school; 7 = academic degree).

## *Experimental tasks*

### *N*-back

During the *N*-back task, participants identify stimuli that are identical to a stimulus presented *N* trials before, in a sequence of serial presentations. Previous research showed consistent age effects on the 2-back task, in contrast to the 0-back and 1-back conditions (Daffner et al., 2011; Meissner, Keitel, Südmeyer, & Pollok, 2016). Studies comparing 1-back, 2-back, and 3-back conditions show an interaction between age and task load that is driven by a smaller or no difference in 1-back performance, and although performance on the 3-back condition is lower compared to the 2-back condition, the effect is to the same extent for younger and older adults (e.g., Heinzel et al., 2014; Mattay et al., 2006; Missonnier et al., 2011). We only included a 2-back version in our design, as it is hypothesized that if working memory capacity is exceeded, brain areas associated with long-term memory are recruited (Jeneson & Squire, 2012). Long-term memory involvement during the working memory task would result in overestimation of a potential correlation between visual working memory and incidental episodic memory.

The task was laptop-based and programmed using MATLAB_R2015a. Participants were seated at 50 cm from the screen. Stimuli were 50 easy-to-name objects selected from a database with colored pictures from the Snodgrass and Vanderwart's object set (Rossion & Pourtois, 2004). Equal numbers of objects from the following categories were used: toys, body parts, tools, furniture, instruments, transport, nature, fruits, insects, and clothing. The objects were presented in each of the four corners of the screen, in the center of the quadrant on a white background; the size of the objects was 325 × 325 mm. Presentation time was 500 ms followed by an interstimulus interval of 1,500 ms. A schematic overview of the task is represented in Figure 1. Participants responded to targets by pressing the left button of the mouse, whereas on nontarget trials they gave no response. In case of physical limitations, participants could also respond verbally. The task consisted of five blocks of 20 trials with four targets (20%) per block and a self-paced break between the blocks. Every object was presented twice within the same block and the second presentation was always in the same location as the first. The presentation order was pseudorandom: a random sequence of numbers was generated by MATLAB to determine the presentation sequence. After this

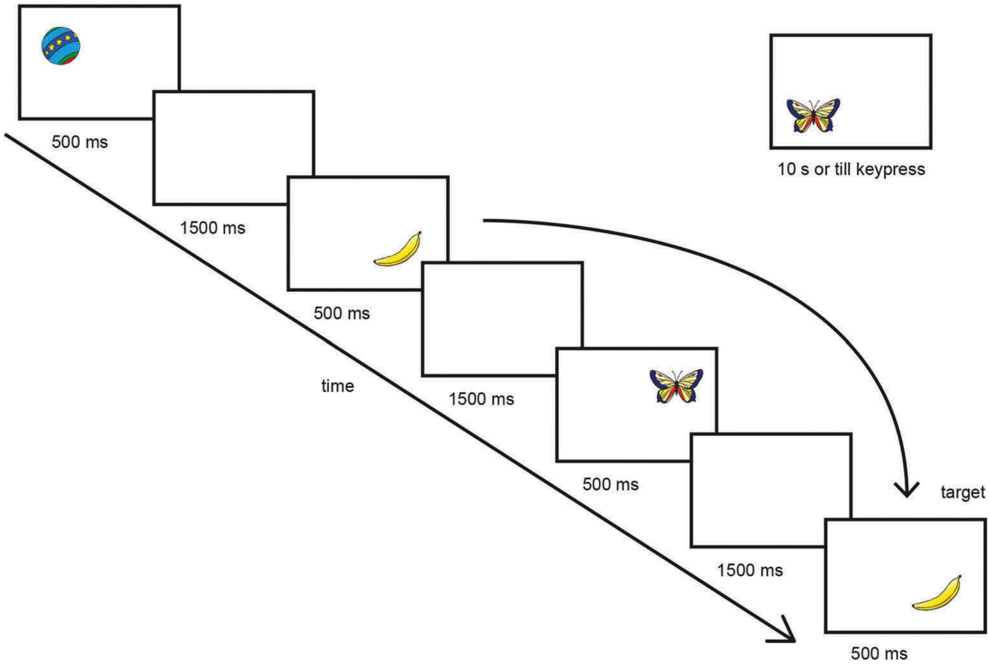


**Figure 1.** Schematic overview of four trials of the 2-back task. Upper right: single trial of the subsequent memory task, in this example the correct answer is "no" as the butterfly is now in the lower-left corner, while it was presented in the upper-right corner in the 2-back task. [To view this figure in color, please see the online version of this journal.]

procedure, the sequence was fixed to make sure that differences in performance between participants could not be due to differences in presentation order resulting in variation in amounts of lures or differences in similarity of successive objects. Instructions were given orally with support of paper-based examples; instructions were repeated on the laptop screen before starting the task. The instructions read as follows: "You will see a sequence of objects. Each object is presented in one of the four corners of the screen. Every object will appear twice. Please only respond when the object matches the one 2 trials earlier, so with one other item in between. The second appearance of an object is always on the same location as the first, irrespective from whether you have to give a response or not." Four types of responses were possible: hits, misses, false alarms, and correct rejections. How well participants could discriminate targets from nontargets was expressed as A-prime ($A'$), a measure suitable for tasks with high hit rate and low false alarm rates (Pollack & Norman, 1964).

### *Subsequent memory*

The 2-back task was directly followed by a surprise subsequent recognition memory test. Here, participants had to indicate whether the object was presented in the same corner of the screen now, as during the 2-back task. In order to reduce task differences, the subsequent memory task was designed as a context binding task as well, although this concerned object–location binding, whereas the *N*-back task is by definition a temporal order binding task. The stimuli were presented until the participant responded with a maximum of 10 s (see Figure 1). Participants responded to every stimulus indicating whether it was in the same location (left button) or a different location (right button). When they made no response during 10 s, the trial was noted down as a no response. All objects were presented only once in pseudorandom order. From the 20 targets of the 2-back task, half were presented in the same location as before, half in a new location. Of the previous nontargets, 10 were shown in the same location as before, and 20 in a new location. In total, there were 20 objects in the same location, of which half previous targets, and 30 objects in a new location, presented in one block of 10 trials and two blocks of 20 trials. Similar to the 2-back task, performance was calculated as $A'$.

### Procedure

Participants completed the experiment individually after providing informed consent. A brief interview on demographics was followed by the neuropsychological measures and the experimental tasks. Instructions were standardized and the order of the tasks was fixed: the MoCA, the Nederlandse Leestest voor Volwassenen, the Corsi Block-Tapping Task, the Doors, the 2-back task, and the subsequent memory task. The total duration varied between 50 and 60 min.

### Analyses

In line with previous studies on associative binding, we report $A'$ as main outcome measure (e.g., Chalfonte & Johnson, 1996; Naveh-Benjamin et al., 2003; Peterson & Naveh-Benjamin, 2016) and $B''_D$ for response bias (e.g., Bender et al., 2010). In *N*-back literature, the use of signal detection parameters $d'$ and $C$ is more common (Redick & Lindsey, 2013), but $A'$ has been reported as *N*-back measure in a patient study (Newsome et al., 2007). $A'$ is a nonparametric measure of sensitivity with scores typically ranging from 0.5, which is chance performance, to 1, which corresponds to perfect performance (Pollack & Norman, 1964; Stanislaw & Todorov, 1999). To express response bias, nonparametric measure $B''_D$ was used, because this measure of bias is sensitive in cases of lower recognition performance, as is the case in the subsequent episodic memory task (Donaldson, 1992). $B''_D$ ranges from −1 to +1 with values less than 0 indicating a bias toward responding with yes resulting in more hits/false alarms.

To answer the question whether working memory and episodic memory performance show similar age-associated differences, we first tested whether performance on both experimental tasks in each group separately was significantly above chance level with a one-sample *t*-test with test value 0.5. An interaction effect was tested with a 2 × 2 (Age [younger adults, older adults] × Task [2-back, subsequent memory]) repeated measures ANOVA. Effect sizes ($\eta_p^2$) were computed for each factor to describe the proportion of variance explained. Subsequent independent sample *t*-tests were used to investigate the effect of age-group on each of the tasks separately concerning both performances ($A'$) and response bias ($B''_D$).

To investigate how working memory performance and episodic memory performance relate in younger and older adults, Pearson correlations were calculated: overall, and for each of the two age-groups separately. By means of bootstrapping, a confidence interval for the correlation was determined as this method does not assume normally distributed data.

To investigate possible differences in response patterns in older and younger adults on the working memory task, hit rate and false alarm rate on the 2-back task were compared between the two age-groups using Mann–Whitney *U* tests, given the skewed distribution (i.e., a high number of hits and relatively few false alarms). To investigate the response patterns further, errors were identified at trial-level to test whether older adults were more sensitive to lures. Lures could be of two types, too close by (1-back, three trials) or too far back (4- or 5-back, eight trials). As the sequence was determined randomly, it is by coincidence that there were no 3-back lures. A third type of error that was analyzed concerns misses on targets preceded by another target (three trials). First, the accuracy on lures versus other nontargets, and on successive targets versus other targets was calculated for older adults and younger adults. This was calculated by the total number of errors on each type of trial divided by the total number of possible errors on that trial type. Mann–Whitney *U* tests were performed to test for differences between the groups. Second, the percentage of a specific type of false alarm or miss to the total number of false alarms or misses at individual level was calculated to correct for the total number of errors an individual made. This second analysis was performed to take into account that some individuals make large numbers of errors in general, while we were interested in susceptibility to specific errors.

Response patterns on the subsequent memory task were analyzed to gain insight into the transition from working memory to episodic memory in younger and older adults. We analyzed the accuracy on the subsequent memory task for the 20 items that were targets in the working memory task. Targets to which the participant responded correctly (hits) in the 2-back task were compared with targets that were missed. To illustrate, when a participant had 16 hits and 4 misses in the 2-back task, accuracy in the subsequent memory task on those 16 hit items was assessed by the percentage of correct responses (either "yes" when an item was in the correct location, or "no" when the item was in another location); this was then compared to the accuracy in the subsequent memory task for items that were missed in the 2-back task. Interaction between responses on the 2-back task and age-group was tested with a $2 \times 2$ (Age [younger adults, older adults] $\times$ Accuracy on the subsequent memory task for 2-back targets [2-back hits, misses]) repeated measures ANOVA.

Finally, performance on the experimental tasks is related to standard clinical tasks, namely the Corsi Block-Tapping Task, the Doors Test, and the MoCA, by calculating Pearson correlations. All tests are two-tailed unless specified differently. Bonferroni correction was applied to correct for multiple testing.

## Results

### *Do working memory and episodic memory performance show similar age differences when using the same stimuli?*

To rule out a ceiling effect on the 2-back task, a one sample *t*-test with test value 1 showed that both groups performed significantly different from the theoretically maximum score (older adults $A'$ = .92, $SD$ = .05; $t(28) = -8.60$, $p < .001$; younger adults $A'$ = .96, $SD$ = .03; $t(29) = -7.46$, $p < .001$). To control for chance-level performance on the subsequent memory task, a one sample $t$-test with test value 0.5 showed that both groups performed significantly above chance level (older adults $A'$ = .71, $SD$ = .11; $t(28) = 10.25$, $p < .001$; younger adults $A'$ = .76, $SD$ = .11; $t(29) = 13.04$, $p < .001$). There were two outliers performing more than 2 $SD$s below the group mean, both (age 75, male, education level 6; age 26, male, education level 6) performed at chance level on the subsequent memory task ($A'$ = .36, $B''_D = -.31$; $A'$ = .47, $B''_D = -.44$).

To analyze the performance of both groups on both tasks, a repeated measures ANOVA was performed, and the results are shown in Figure 2. There was no significant group by task interaction, $F(1, 57) = .09$, $p = .763$. The main effect of task was significant, with better performance on the 2-back task ($A'$ = .94, $SD$ = .05) than on the subsequent memory task ($A'$ = .74, $SD$ = .11), $F(1, 57) = 171.09$, $p < .001$, $\eta_p^2 = .75$, as was the main effect of group, where younger adults performed better than older adults, $F(1, 57) = 7.47$, $p = .008$, $\eta_p^2 = .116$.

There was no significant difference in response bias between older and younger adults on either of the tasks (2-back: older adults $B''_D$ = .49, $SD$ = .60; younger adults

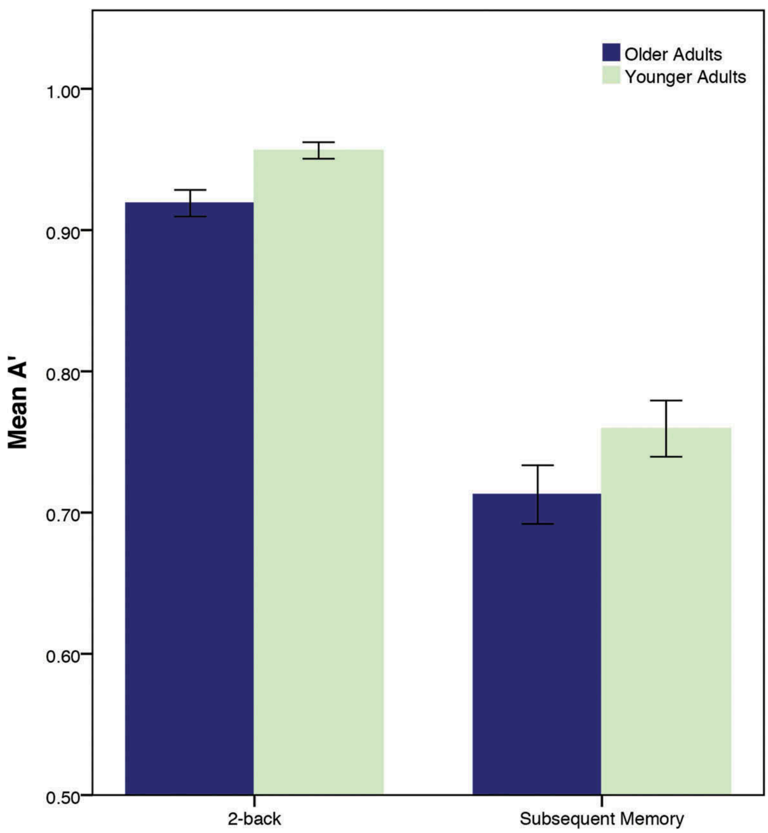


Figure 2. Mean performance expressed as $A'$ (±1 $SE$) for older adults and younger adults, on left the 2-back task and on the right the subsequent memory task.

$B''_D$ = .55; $SD$ = .53; $t(57) = -.44$, $p$ = .663; subsequent memory task: older adults $B''_D = -.03$, $SD$ = .36; younger adults $B''_D$ = .02; $SD$ = .40; $t(57) = -.47$, $p$ = .637). In the working memory task, there was a tendency toward not responding while there was no preference for answering *yes* or *no* in the subsequent memory task. Removing the two outliers did not result in different findings.

### *How are working memory performance and episodic memory performance related in younger and older adults?*

To investigate how working memory performance and episodic memory performance relate, Pearson's correlations were calculated. As the Pearson product–moment correlation is sensitive to outliers, the two participants with chance-level performance were excluded from the analyses. Overall, performance on the 2-back task was not significantly related to subsequent memory performance ($r$ = .174, $N$ = 57, $p$ = .196). In older adults, no significant correlation was found ($r = -.182$, $N$ = 28, $p$ = .355), while in younger adults 2-back and subsequent memory performance correlated significantly ($r$ = .504, $N$ = 29, $p$ = .005, Figure 3). Confidence intervals based on bootstrapping show that in older adults the interval included zero, while in younger adults both the lower and upper bound are positive. The intervals do not overlap (older adults: −.548 to .185; younger adults: .270–.745).

### *Are there age-related differences in response patterns?*

#### *2-Back task*

Comparing the total number of hits and false alarms between the two age-groups showed that older adults had a tendency toward fewer hits ($Mdn$ = 16 versus 18) and a nonsignificant difference in false alarms ($Mdn$ = 3 versus 1.5) on the 2-back task ($U$ = 283.0, $p$ = .020; $U$ = 308.0, $p$ = .051, respectively) after Bonferroni correction (adjusted $\alpha$ = .0125).

For further investigation of errors on the 2-back task, the effect of lures and successive targets was analyzed (Table 2). The only significant difference between older adults and younger adults was a lower accuracy on singular targets in older adults ($Mdn$ = 76.5% versus 88.2%), $U$ = 256.5, $p$ = .006. The difference between the two groups in accuracy on 5-back lure trials and other nontargets trials did not survive correction for multiple testing (adjusted $\alpha$ = .007). There was no significant effect of age on accuracy on successive targets, and 1-back, 4-back, and total lures.

Given that older adults made more errors on the whole, analysis of the percentage of specific errors related to the total number of errors for each individual showed that there was no significant difference in types of errors older adults made compared to younger adults (Table 3).

#### *Subsequent memory task*

The number of hits and false alarms on the subsequent memory task did not significantly differ between the two age-groups ($U$ = 375.5, $p$ = .364; $U$ = 338.5, $p$ = .141, respectively). The effect of correct working memory processing on transition from working memory to long-term memory was analyzed by comparing the

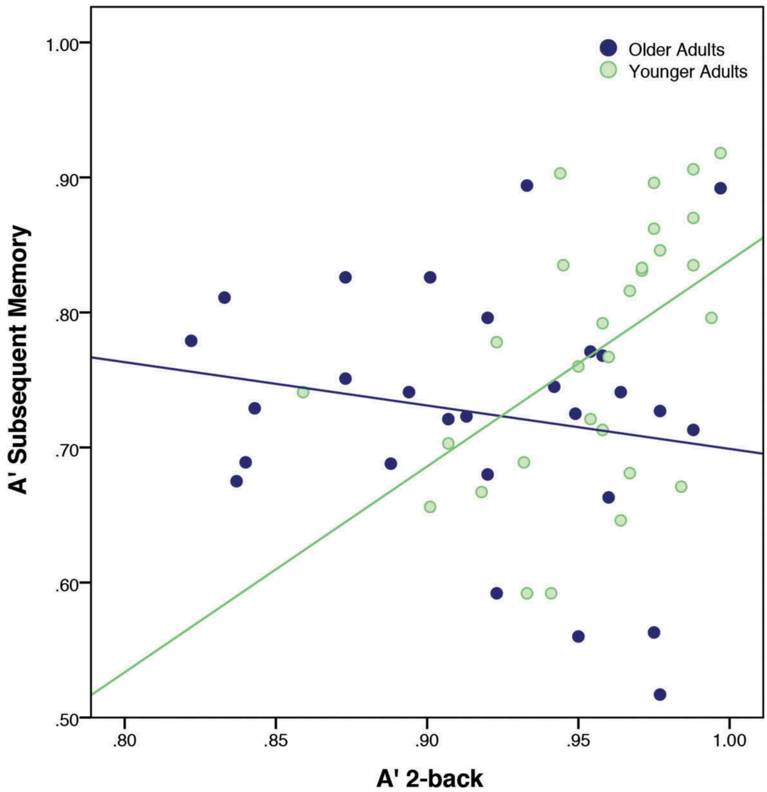


Figure 3. Correlation between performance on the 2-back task (*x*-axis) and the subsequent memory task (*y*-axis) with regression lines for older adults ($r = -.182$) and younger adults ($r = .504$).

Table 2. Median percentage of correct responses on different trial types for the total group, each age-group separately and a Mann–Whitney *U* test for differences between the age-groups.

| | | | | | Mann–Whitney *U* test | |
|---|---|---|---|---|---|---|
| | | Total | OA | YA | *U* | *p*-Value |
| Hits | Successive targets | 66.7 | 66.7 | 83.3 | 403.0 | .597 |
| | Singular targets | 88.2 | 76.5 | 88.2 | 256.5 | .006 |
| Correct rejections | 1-Back lures | 100.0[a] | 100.0 | 83.3 | 400.5 | .556 |
| | 4-Back lures | 100.0 | 50.0 | 100.0 | 400.5 | .554 |
| | 5-Back lures | 83.3 | 83.3 | 100.0 | 307.0 | .036 |
| | Total lures | 81.8 | 81.8 | 86.4 | 342.5 | .150 |
| | Other nontargets | 100.0 | 98.6 | 100.0 | 291.5 | .017 |

Adjusted α = .007 (.05/7). OA: older adults; YA: younger adults.
[a]An individual score of 100% indicates that all of the trials of that type were correctly responded to.

accuracy on the subsequent memory task for previous targets of the 2-back task that were correctly identified (hits) versus 2-back targets that were missed. A repeated measures ANOVA showed that there was no interaction between accuracy on the subsequent memory task for 2-back targets by group, $F(1, 52) = .01$, $p = .939$; no main effect of accuracy on the subsequent memory task for 2-back targets, $F(1, 52) = 3.20$, $p = .079$; or of group, $F(1, 52) = 2.52$, $p = .118$.

Table 3. Median percentage of specific errors corrected for the total number of errors at individual level, for the total group and each age-group separately. Differences between older and younger adults tested with a Mann–Whitney *U* test.

| | | | | | Mann–Whitney *U* test | |
|---|---|---|---|---|---|---|
| | | Total | OA | YA | *U* | *p*-Value |
| Misses | Successive targets | 12.7 | 10.0 | 25.0 | 302.5 | .261 |
| False alarms | 1-Back lures | 14.3 | 0.0 | 33.3 | 225.0 | .049 |
| | 4-Back lures | 7.7 | 7.7 | 5.6 | 323.0 | .984 |
| | 5-Back lures | 20.0 | 21.4 | 7.1 | 277.5 | .362 |
| | Total lures[a] | 75.0 | 66.7 | 100.0[b] | 231.0 | .063 |

Adjusted alpha = .01 (.05/5). OA: older adults; YA: younger adults.

[a]At the individual level, the percentages from the different lure types sums up to the total percentage of false alarms on lure trials.

[b]An individual score of 100% indicates that all of the false alarms made by that participant were on lure trials.

## Discussion

The present study investigated age-associated differences in visual working memory and episodic memory, and how performance relates in younger and unimpaired older adults using a task design in which working memory and subsequent recognition memory performance were measured using the same stimuli, with both tasks involving context binding. Most of the literature is based on studies investigating the effects of age differences on memory subsystems separately; assessment of working memory and episodic memory for the same stimuli within the same subjects allows investigation of the relationship between subsystems. The results show that the subsequent memory task was more difficult and older adults performed worse than younger adults but to similar extent on both tasks. Interestingly, performance on the working memory task and the subsequent memory task was related in younger but not in older adults. Analysis of errors shows that although older adults made more miss errors, they were not more susceptible to lures than younger adults in the object 2-back task. Correct identification of targets during the 2-back task had no influence on recognition of object–locations in the subsequent memory task.

In line with comparable studies by Van Geldorp et al. (2015) and Werkle-Bergner et al. (2012), our results showed that older adults performed worse than younger adults on both working memory and subsequent memory tasks with the same stimuli. We found a moderate-to-large effect size, and no interaction. However, some caution is warranted when drawing this conclusion. Although we aimed at designing the tasks to be similar, there are several differences that might have influenced the results. First, the working memory task required object–order binding while the subsequent memory task required object–location binding. The *N*-back task is by definition a temporal order binding task, as the object needs to be bound to a specific place in a continuous sequence. To reduce task differences, the subsequent memory task was designed as a context binding task as well. Temporal order–object binding was problematic for each object appearing twice during the 2-back task. Object–location binding was the most suitable alternative, although partly different neural correlates are associated with spatial and temporal order source memory (Ekstrom, Copara, Isham, Wang, & Yonelinas, 2011).

For two reasons we believe that the influence of these different types of context binding is limited. Previous studies have shown that temporal order–object and object–

location binding are highly comparable in the way they are affected by aging, a meta-analysis showed comparable effect sizes ($d$ = .99, $d$ = .94; Old & Naveh-Benjamin, 2008). Furthermore, in Van Geldorp et al. (2015), the same type of binding was used in the working memory and subsequent memory task, in both studies pairs of a house and a face needed to be remembered. Overall, their results are comparable to ours, no interaction was found.

The second difference between the two tasks used in the current study concerns the encoding instructions. The working memory task with intentional instructions was followed by an unexpected subsequent memory task. The meta-analysis by Old and Naveh-Benjamin (2008) showed that the effect of age was more pronounced under intentional instructions. However, a recent study indicates that at least part of the effect might not be explained by encoding instructions, but by differences in salience and complexity of stimuli used in different experiments (Bender, Naveh-Benjamin, Amann, & Raz, 2017). Bender et al. (2017) showed that older adults only showed a disproportionate deficit for face–name associations when the face stimuli were more complex, but not when standardized grayscale faces without visual context were used. As the same stimuli appeared in both of our tasks, they do not differ in salience. The difference in performance due to intentional and incidental instructions might be limited. Moreover, intentional instructions would have resulted in the working memory task becoming a dual task in which case working memory and long-term memory would be entwined and assessing the relationship between the two systems would be unreliable. However, we acknowledge that this limits our conclusions to incidental associative episodic memory. A third difference between the working memory and subsequent memory task is the timing. In the 2-back task, participants had to respond within 2 s, whereas in the subsequent memory task, participants had 10 s to answer. It is possible that the time constraint negatively influenced especially the performance of older adults on the working memory task, as a slowing-down of processing speed is a common hypothesis to explain age-related cognitive decline (Salthouse, 1996). However, this seems unlikely as a 2-s interstimulus interval is common in $N$-back tasks and generally no age-related differences are reported in 1-back conditions, indicating that 2 s is long enough processing time for older adults for these kinds of tasks.

Of further note is the issue of potential ceiling effects that may have influenced our results. While the 2-back performance for both groups is indeed high, the performance statistically differs from the theoretical maximum score, making a ceiling effect less likely (as there is room for improvement in both groups). Still, one could argue that because of this, the overall variance in subsequent memory performance is greater than in the working memory condition, potentially obscuring an additional decline in episodic memory performance in the older adults. However, the analysis of variance takes differences in variance across groups and measures into account. Based on this, we argue that our findings are reliable, but also stress the need for replication of our results in future studies.

Concerning theories on memory decline, our results are in line with the associative deficit hypotheses that predicted similar age differences in both memory systems. The irrelevant information hypothesis predicted, in this specific design, a possible advantage for older adults on the subsequent memory task, which we did not find. Previous studies (Campbell, Grady, Ng, & Hasher, 2012; Rowe, Valderrama, Hasher, & Lenartowicz, 2006) have shown that younger adults were able to ignore irrelevant information more effectively than older adults, resulting in better working memory performance but worse performance when the irrelevant items were subsequently tested, whereas older adults showed the reversed pattern. The main difference between previous studies and the current study is that the irrelevant information was tested separately from the target items (e.g., letters superimposed on line-drawings), while in the present task the object was in a specific location. This required binding of an object to a location while in previous designs no binding was required and only the distracters were tested subsequently. The only previous study that we are aware of that assessed this effect in the context of binding is Campbell et al. (2010). They found that older adults were able to encode the co-occurrence of the target and distractor stimuli from a previous task and use this information in a subsequent task. However, in their design, participants were not aware of the connection with the incidental learning task, so the effect was based on implicit memory, as opposed to explicit memory in our design. The current study shows that older adults do not show hyper-binding for irrelevant locations of objects in a way that they can explicitly use it for recognition memory. Future studies should further investigate under which circumstances older adults do benefit from irrelevant information.

The second issue we addressed was how working memory and episodic memory performance relate. An interesting finding is the significant correlation between working memory and episodic memory performance in younger, but not older adults. Given that there was no interaction between task and age-group, and that the correlation between the tasks was only significant in younger adults, we conclude that some of the older adults showed specific lower performance on the working memory task, while others showed more pronounced lower performance on the subsequent memory task, resulting in a main effect of age-group. However, it should be noted that the performance on both tasks was preserved in some older adults, two of whom even performing better than younger adults on both tasks. A possible interpretation, albeit a speculative one in the absence of neuroimaging data, is that while working memory and episodic memory are both affected by age, individual variability arises from the extent of atrophy of the underlying brain networks at an individual level, respectively, the frontoparietal network for working memory and the medial-temporal lobe for episodic memory (Maillet & Rajah, 2014; Rottschy et al., 2012). For instance, a longitudinal study showed that age-related brain shrinkage on average affected both these regions to a similar extent, but showed profound differences at an individual level (Raz et al., 2005). This may explain the lack of correlations between the performances on the two tasks in our study. Multiple factors may underlie individual variability in volume loss like physical activity, nutrition, hypertension, and genetics (Fjell & Walhovd, 2010).

Concerning the response patterns of older and younger adults, investigation of accuracy on the working memory task showed that, as expected, more errors were made on successive targets compared to singular targets and on lure trials compared to nonlure trials (Gray, Chabris, & Braver, 2003; Kane, Conway, Miura, & Colflesh, 2007). Differences in performance between the age-groups were driven by a lower hit rate in older adults. Interestingly, closer inspection revealed that older adults are not more susceptible to lures than younger adults in an object 2-back task. This finding is at odds with Schmiedek, Li, and Lindenberger (2009) who reported lower accuracy in older adults on 3- and 4-back lures. A possible explanation for this may be that our task did not include 3-back lures and that the type of stimuli differs from Schmiedek et al. (2009): black dots in a 3 × 3 grid versus common, easy-to-name objects. Common objects might provoke a stronger familiarity effect, as memory for objects is generally better than for locations (e.g., Kessels et al., 2007). A stronger effect of familiarity might explain that younger adults are also susceptible to lures.

In order to investigate whether successful episodic memory formation requires successful processing in working memory, we compared episodic memory performance on previous targets of the 2-back task comparing accuracy for objects that were correctly identified (hits) and objects that were missed during the working memory task. Neither a difference in accuracy was found nor an age-effect. In contrast to Werkle-Bergner et al. (2012), the current study suggests that correct working memory identification does not enhance episodic memory encoding. However, an alternative explanation is possible. Working memory tasks generally consist of three phases with different contributions to long-term memory formation: encoding, maintaining/updating, and testing (Bergmann, Kiemeneij, Fernández, & Kessels, 2013). Part of the maintaining phase is the transformation from perceptual representation to internal code, which is thought to be crucial for episodic memory formation (Bergmann et al., 2013). The maintaining phase is similar for all stimuli in our working memory task, which might explain why performance on the working memory task did not influence episodic memory recognition. In the task used by Werkle-Bergner et al. (2012), a cue was presented before stimulus presentation to indicate whether the item needed to be remembered or not, possibly resulting in differential encoding explaining the different findings.

In sum, previous studies have investigated the performance of younger and older adults on different working memory and episodic memory tasks, concluding that both systems show age-related impaired performance by older adults. By using the same stimuli and addressing working memory and episodic memory in one task design, we investigated the relation between working memory and episodic memory performance. We conclude that although mean age differences are similar on these visual working memory and incidental associative memory tasks, the relationship is different for younger and older adults. That is, working memory and episodic memory were correlated in younger but not in older adults. Longitudinal research is needed to investigate life-span changes in the relationship between working and episodic memory. As some neurodegenerative diseases are characterized by specific types of memory impairment, it is important to have a profile of functioning of memory subsystems for unimpaired older adults. The combining of the *N*-back task with a subsequent memory task is found to be a fruitful approach for investigation of the relation between visual working memory and episodic memory.

## Acknowledgments

We thank Mandy Jansen, Sanne van Doornik, and Roos Buijssen for assistance in recruiting and assessment of participants.

## Disclosure statement

No potential conflict of interest was reported by the authors.

## Funding

This study was supported by an ERC Advanced Grant (#339374) awarded to E. H. F. de Haan.

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