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Distraction by unintentional recognition:

Neurocognitive mechanisms and effects of aging

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Running head: Aging and distraction by unintentional recognition

Author note: The data in this article have been presented as posters or talks at several conferences, but they have not been previously disseminated online or in written form. The individual-level behavioral data and ERP mean amplitude data have been uploaded to the Open Science Framework, which can be accessed at <https://osf.io/vzs5p/>

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Abstract

Sometimes, we intentionally evaluate stimuli to assess if we recognise them, whereas other times, stimuli automatically elicit recognition despite our efforts to ignore them. If multiple stimuli are encountered in the same environment, intentional recognition judgements can be biased by unintentional recognition of to-be-ignored stimuli. Aging is associated with increased distractibility and impaired intentional retrieval processes, which can make older adults more susceptible to distraction-induced recognition biases. We measured recognition memory performance, ERPs and EEG oscillations in old (60-74) and young (18-24) adults to investigate how aging affects unintentional and intentional memory processes, and how these processes interact over time to produce distraction-induced recognition biases. Older participants had poorer intentional recognition memory, but the biasing effect of unintentional distractor recognition was similar across age groups. ERP effects related to intentional and unintentional recognition that were strongly expressed in the younger group were reduced or absent in the older group. Furthermore, the older group showed qualitatively different ERP activity during intentional recognition compared to the younger group. However, similar patterns of theta and alpha oscillations were found in both age groups, who showed theta power increases for both intentional and unintentional recognition, whereas alpha power was enhanced for intentional recognition but reduced for unintentional recognition. Overall, the findings show that unintentional and intentional recognition involve multiple dissociable memory processes that have different time-courses and functional characteristics, and are differentially affected by aging. Whereas aging has strong effects on the neurocognitive mechanisms underlying intentional recognition memory, unintentional recognition mechanisms are less affected.

Keywords: Aging; recognition; cognitive control; ERPs; EEG oscillations

Introduction

We often recognize familiar items automatically and unintentionally rather than through a conscious elaborate search in long-term memory. We can for example recognize a familiar person in the supermarket even if we are preoccupied with trying to remember the next item on our shopping list. Unintentional retrieval is important for everyday functioning and is as frequent as intentional retrieval (Rubin & Berntsen, 2009), yet most cognitive neuroscience research on memory have focused on intentional retrieval. Interestingly, unintentional recognition of distracting information can bias intentional recognition of a target stimulus (Ste-Marie & Jacoby, 1993). Furthermore, such biases are more prevalent in older adults (Anderson, Jacoby, Thomas, & Balota, 2011; Gutchess, et al., 2007), suggesting that unintentional retrieval in response to distractions may contribute to memory problems in older age. Recent research has begun to delineate the neurocognitive mechanisms that give rise to distraction-induced recognition biases in young adults (Bergström, Williams, Bhula, & Sharma, 2016). However, less is known regarding how these neurocognitive processes are modulated by healthy aging, and how they contribute to the increased distraction-induced recognition biases sometimes observed in older age, as investigated here.

Healthy aging is associated with impaired cognitive control functions (West, 1996), and as a consequence, older adults often show a reduced ability to selectively attend to task-relevant stimuli while ignoring distractions (Amer, Campbell & Hasher, 2016; Biss, Ngo, Hasher, Campbell, & Rowe, 2013; De Fockert, Ramchurn, van Velzen, Bergström, & Bunce, 2009; Lustig & Jantz, 2015; Powell, Strunk, James, Polyn & Duarte, 2018). Episodic memory also deteriorates with healthy aging (Nyberg, Lövdén, Riklund, Lindenberger, & Bäckman, 2012), which appears to be partially related to a reduced ability to engage cognitive control during retrieval (Morcom, 2016). Cognitive control is required in many episodic memory retrieval situations, such as when people need to judge whether they recognise a stimulus,

while ignoring other stimuli in the same environment that may or may not be familiar (Gutchess et al., 2007; Wais & Gazzaley, 2014). In their “Memory Stroop” paradigm, Anderson et al. (2011) found that participants’ intentional recognition of target words was biased by concurrently displayed old or new distractor images that they were asked to ignore. That is, participants were more likely to respond that a target word was old if the distractor image was also old than if the distractor was new, suggesting that they misattributed unintentional recognition of distractors to the targets. Furthermore, this effect was more prevalent in older adults when compared to a young adult group, suggesting that older people are particularly biased by unintentional recognition of distracting information in their environment.

The dual-process model of episodic recognition proposes that recognition is supported by two independent processes: familiarity and recollection (Mandler, 1980; Yonelinas & Jacoby, 2012). Familiarity is a relatively rapid and *unintentional* process that gives rise to a feeling that a stimulus has been previously encountered without retrieval of any accompanying context. In contrast, recollection is a slower, typically more *intentional* process, which involves the retrieval of contextual details from a previous event. In support of this model, researchers have found dissociable Event-Related Potential (ERP) correlates of the two processes (reviewed in Rugg & Curran, 2007). Familiarity is expressed as an early mid-frontal ERP positivity around 300-500ms post-stimulus onset for old compared with new stimuli (the “FN400 old/new effect”; but see Paller, Voss & Boehm, 2007), whereas recollection is correlated with a greater left parietal ERP positivity between 500-800ms for old compared to new items (the “left parietal old/new effect”). The dual process model predicts that unintentional recognition of distractors should primarily involve familiarity rather than recollection, because the former is a more automatic process than the latter. Consistent with this prediction, we (Bergström et al., 2016) recently found a link between a

large FN400 old/new ERP effect for unintentional distractor recognition and behavioural recognition biases in the “Memory Stroop” paradigm (Anderson et al., 2011). The left parietal old/new ERP effect was only associated with intentional target recognition, consistent with previous suggestions that this effect is a correlate of recollection and is under voluntary control (Bergström, Velmans, De Fockert, & Richardson-Klavehn, 2007; Mecklinger, Parra, & Waldhauser, 2009).

Although many studies have attempted to delineate how aging affects retrieval-related ERP effects, the available evidence is sometimes contradictory (reviewed in Friedman, 2013). Whereas some studies have found comparable FN400 old/new effects across young and old participants (e.g. Friedman, De Chastelaine, Nessler, & Malcolm, 2010; James, Strunk, Arndt & Duarte, 2016; Wegesin, Friedman, Varughese, & Stern, 2002), others have found reduced ERP correlates of familiarity in older age groups (e.g. Duarte, Ranganath, Trujillo, & Knight, 2006; Wang, de Chastelaine, Minton, & Rugg, 2012). Regarding recollection, older adults often show reduced left parietal old/new ERP effects (Ally, Simons, McKeever, Peers, & Budson, 2008; Friedman et al., 2010; Wang et al., 2012) or sometimes even reversed effects, with more negative parietal ERPs for old than new items (Li, Morcom, & Rugg, 2004). Thus, whereas age differences in the ERP correlate of familiarity are rather inconsistent, there is typically a more consistent reduction (or even reversal) of the ERP correlate of recollection in older compared to younger adults (but see Duarte et al., 2006; James et al., 2016), in line with theoretical suggestions that aging primarily affects intentional processes that contribute to recollection, and has smaller effects on automatic familiarity (Koen & Yonelinas, 2016; see also Fraundorf, Hourihan, Peters & Benjamin, 2019).

In addition to the positive old/new differences described above, episodic retrieval attempts also often elicit a later sustained posterior negativity (the “LPN”) for old compared to new items (Johansson & Mecklinger, 2003), that often overlaps with parietal old/new

effects, and continues and peaks afterwards. The LPN appears to reflect late stage memory processes such as monitoring in situations of response conflict or additional retrieval search when task-relevant memories are not readily available (Mecklinger, Rosburg & Johansson, 2016). In the Memory Stroop paradigm, Bergström et al. (2016) found an LPN effect for previously seen distractors that was interpreted as related to monitoring of unintentionally retrieved information. Late, sustained old/new negativities resembling the LPN are often seen in older adults during episodic retrieval (e.g. Duarte, et al., 2006; Dulas & Duarte, 2013; James, et al., 2016; Friedman, 2013), but these tend to have a different topography than the LPN in young participants and are therefore thought to reflect different cognitive processes (Mecklinger et al., 2016), such as additional brain processes that are engaged to compensate for reduced memory performance (see Cabeza et al., 2018; Cabeza, Anderson, Locantore, & McIntosh, 2002; Craik & Rose, 2012; Morcom & Johnson, 2015). LPN-like negativities can make it difficult to estimate aging-related reductions of positive old/new ERP effects, since these may sometimes overlap with and “cancel out” at the scalp (Dulas & Duarte, 2013; Li et al., 2004). Thus, even if familiarity and recollection processes are spared in aging, they may not always be detected with standard ERP methods.

As a complementary technique to ERPs, the raw EEG can be decomposed using time-frequency transforms to measure EEG oscillations at different frequencies, and these methods may be particularly useful for studying how memory changes with ageing. Measures of “induced” oscillations that are not strictly phase-locked to an event (Tallon-Baudry & Bertrand, 1999) are less sensitive to the enhanced temporal variability (“jitter”) of EEG peaks that occurs with aging (e.g. Tran et al., 2016), which can reduce ERP component amplitudes (Saville et al., 2011). Furthermore, decomposing the EEG data into non-overlapping frequency bands may also facilitate dissociating different neurocognitive processes that may be difficult to distinguish with ERPs due to component overlap. Research has shown that

event-related synchronization (power increases) and desynchronization (power decreases) of oscillations in different frequency bands relate to memory processes (Hanslmayr, Staresina, & Bowman, 2016; Hanslmayr & Staudigl, 2014; Hsieh & Ranganath, 2014; Nyhus & Curran, 2010). Familiarity has been associated with increased power in the gamma band (~30-100 Hz, Gruber, Tsivilis, Giabbiconi, & Müller, 2008). However, other evidence links theta (4-8 Hz) synchronisation with familiarity (Klimesch, Doppelmayr, Yonelinas, et al., 2001) so it is unclear whether familiarity is associated with a specific oscillatory frequency. In contrast, many studies have found that recollection correlates with increased synchronised theta activity in younger adults, that often has a left parietal distribution and thus may be related to (but separable from) the left parietal old/new ERP effect (Gruber et al., 2008; Guderian & Düzel, 2005; Jacobs, Hwang, Curran, & Kahana, 2006; Klimesch, Doppelmayr, Schwaiger et al., 2000). In addition, alpha (8-12 Hz) and beta (12-30 Hz) desynchronisation also correlates with successful memory retrieval (Hanslmayr, Staudigl, & Fellner, 2012). There is less research on aging and retrieval-related EEG oscillations, however a recent study (Strunk et al., 2017) found similar theta power increases associated with source recollection in young and old groups, and interpreted this to indicate that similar amounts of information were recollected by both groups. Thus, there is some evidence that older and younger adults can show similar retrieval-related EEG oscillation effects, even though their ERP effects are often markedly different.

We investigated behavioural, ERP and EEG oscillation measures of distractor-induced recognition biases in our adapted version (Bergström et al., 2016) of the Memory Stroop paradigm (Anderson et al., 2011) within older (aged 60-74) and younger (aged 18-24) groups. In this adapted version, both young and older adults completed the Memory Stroop recognition test with a simultaneous Working Memory (WM) load task, which has been shown to increase distractor processing in previous research (De Fockert, Rees, Frith, &

Lavie, 2001). We aimed to replicate the behavioural finding that older adults were more susceptible to distraction-induced recognition biases than younger adults (Anderson et al., 2011), which would be manifest as a larger bias for recognition decisions to targets based on whether a simultaneously presented distractor was old or new. We also examined how the ERP old/new effects for intentional target recognition and unintentional distractor recognition were affected by ageing. Because previous research has suggested that recollection is impaired in older age (e.g. Koen & Yonelinas, 2016), we expected the older group to show a reduction in the recollection-related left parietal old/new ERP positivity previously found for intentional target recognition in younger adults (Bergström et al., 2016). Given the evidence that familiarity is less likely to be impaired than recollection in older age (Koen & Yonelinas, 2016), we predicted that the FN400 old/new effects should be more similar across age groups, and might even be enhanced for distractor recognition in the older adults due to their increased difficulty at selectively attending to target information, which could lead to increased unintentional recognition of distractors in this group (*cf.* De Fockert et al., 2009). We also expected that the older group may show additional changes to late negative ERP components in line with the literature (Friedman, 2013).

Finally, we also undertook a time-frequency decomposition of the EEG signals to investigate how oscillations in different frequency bands relate to intentional versus unintentional recognition memory, and to explore whether these oscillatory effects differed between older and younger adults. This analysis followed the most relevant previous study (Strunk et al., 2017), by investigating age differences in retrieval-related oscillatory power in theta, alpha and beta bands. We expected to find increased theta power (Gruber et al., 2008) and a decrease in alpha and beta power (Hanslmayr et al., 2012) as a function of intentional target recognition for the younger group, with similar but perhaps weaker effects in the older group due to impaired recollection. Alternatively, if some aging-related changes in retrieval-

related ERP effects are due to jitter of evoked responses and/or component overlap, then oscillation effects may be rather similar across age groups, despite ERP differences. Due to a lack of prior research, we had no firm predictions for how EEG oscillations would covary with unintentional distractor recognition. Instead, we simply aimed to explore the role of recognition intentionality and aging on oscillatory memory retrieval effects.

Method

Participants

All participants were native English speakers, right handed, neurologically healthy, had normal or corrected to normal vision, and took part either due to course requirements (24 in the younger group, first reported as Experiment 1 in Bergström et al., 2016, $M_{\text{age}} = 21$; range = 18-24; 8 males, 16 females) or as unpaid volunteers from the local community (24 in the older group, $M_{\text{age}} = 66$; range = 60-74; 11 males, 13 females). The older group were all socially active and scored higher than 26/30 on the MMSE (Folstein, Folstein, & McHugh, 1975). The older group was generally highly educated (mean number of years in full-time education: 16.5, range 12-22), and the younger group were all current university students. All participants provided informed consent prior to taking part and the study was approved by the Research Ethics Committee of the University of Kent.

Materials

Experimental stimuli were comprised of 272 words and 272 colour photographs, of which 16 of each type were used for practice. The words were 4-8 characters long with 1-2 syllables, and were all taken from the ANEW database (Bradley & Lang, 1999) with valence ratings ranging from 3.8 and 7.6 (on a 9 point scale). The majority of photographs came from the IAPS database (valence ratings between 1.51 and 6.62 on a 9-point scale; Lang, Bradley, & Cuthbert, 2008) with the remainder from the GAPED database (valence ratings

between 1.35 and 45.7 on a 100-point scale; Dan-Glauser & Scherer, 2011). Half of the photographs were rated neutral and half negative valence, however as valence had no impact on ERPs or behavioural recognition biases in our previous study (Bergström et al., 2016), nor had different effects on behaviour in the young and old groups in the current study, all EEG analyses were conducted with this factor collapsed in order to achieve sufficient measurement reliability. The assignment of stimuli to experimental conditions was fully counterbalanced across participants.

Experimental design and procedure

The paradigm was nearly identical to Experiment 1 in Bergström et al. (2016), and involved multiple study-test blocks where in each block, participants first studied pictures and words, and then undertook a recognition memory test for the words while ignoring simultaneously presented pictures. All tasks were implemented in E-Prime (Psychology Software Tools, Pittsburgh, PA); participants' responses were given using the buttons 1-4 on a keyboard, and response hand was counterbalanced across participants. The only change from Bergström et al. (2016) was that older adults were only required to complete eight out of the ten study-test blocks that had been completed by the young group in order to avoid fatigue. We then extracted data from the first eight blocks in the young group to use as a matched comparison.

Participants first practiced all phases of the task before moving on to the main experiment. In each study phase, 16 words and 16 pictures were presented randomly intermixed, and participant rated the 'pleasantness' of each stimuli on a 4-point scale to ensure deep encoding. Each trial commenced with a 500ms fixation cross which was followed by the stimulus for 3000ms. Next, participants completed the main recognition test where on each trial, a background 'distractor' picture was overlaid with a 'target' word, presented simultaneously for 3000ms and preceded by a 500ms fixation cross. Each test phase contained four conditions: old word and old picture (eight trials), old word and new

picture (eight trials), new word and old picture (eight trials), and new word and new picture (eight trials), presented in random order. Participants were instructed to consider only the target word and to: press ‘1’ if they recognised that the word had been presented previously in the study phase (‘old) or ‘2’ if they judged it to be a new word (i.e. not previously presented) and also to reply as quickly as possible, whilst maintaining accuracy.

Since previous research has shown that the effect of incongruent distractors is increased when participants’ attention is divided (Anderson et al., 2011; Ste-Marie & Jacoby, 1993), all participants were required to maintain a random sequence of four digits (drawn between 1-4) in working memory (De Fockert, et al., 2001) during the Memory Stroop test. This WM task was presented interleaved with the recognition test, so that every 4-6 trials participants were first tested on a number string they were currently rehearsing, and were then given a new number string to maintain for the next 4-6 trials (see Bergström et al., 2016, for details) To ensure compliance, participants were given immediate feedback on their WM task accuracy and were instructed that both the recognition and WM task were equally important.

After each main recognition test, participants were given a very brief “distractor recognition test” where two previously seen pictures (shown in the study phase) were presented intermixed with two new pictures (not previously shown in the experiment), and participants were required to make old/new recognition decisions. This task was included to encourage participants to attend to both pictures and words in the study phases (since both item types would be “tested”) but performance on this test was not measured. Participants were given short breaks at the end of each study-test block.

EEG recording and pre-processing

EEG was recorded at 500Hz with a 0.05-70Hz bandwidth from 64 scalp electrodes using an actiCAP system (Brain Products GmbH, Germany). Electrode locations were positioned in accordance with the extended 10-20 system with FCz as the acquisition reference. The electrooculogram (EOG) was recorded from below the left eye (vertical EOG) and from the right outer canthus (horizontal EOG), and impedances were reduced below 25 KOhms (required threshold for these types of active electrodes).

Offline EEG processing was conducted with EEGLAB (Delorme & Makeig, 2004). The EEG was re-referenced to the average of mastoids and segmented into 3500ms epochs (including a 500 ms prestimulus period), timelocked to the onset of the word–picture pair in the target recognition test. Concatenated epochs were submitted to independent component analysis using Runica from the EEGLAB toolbox, with default extended-mode training parameters (Delorme & Makeig, 2004). Independent components reflecting eye movements and other sources of noise were identified by visual inspection of component scalp topographies, time courses, and activation spectra and were discarded from the data by back-projecting all but these components to the data space. Corrected data were subsequently lowpass filtered digitally at 30 Hz (two-way least-squares finite impulse response filter). Any trials that still contained visible artifacts after filtering were removed, as were trials where participants failed to respond within the allocated time. Only a very small percentage of trials (5% in the young group and 7% in the old group) were deleted in total. Because the young group had more EEG trials than the old group (due to completing 10 blocks rather than eight), we randomly paired each young participant with an old participant and matched the trials across each condition by deleting trials from the end of the young participants' data. This matching process ensured identical EEG trial numbers per condition across the two groups, which were as follows: old word old picture (mean trial numbers = 59, range 44-63),

old word new picture (mean trial numbers = 59, range 46-64), new word old picture (mean trial numbers = 58, range 41-64), and new word new picture (mean trial numbers = 58, range 46-64). As in our previous research (Bergström et al., 2016), EEG conditions included both accurate and inaccurate responses in order to be maximally sensitive to neural activity associated with unintentional recognition, which cannot be directly measured and has the effect of biasing intentional recognition judgements to be either more or less accurate depending on target-distractor congruency. Thus excluding incorrect responses is inappropriate because it could lead to systematic exclusion of trials where unintentional recognition was occurring, which would confound EEG comparisons between the conditions.

Next, the pre-processed EEG data were further analysed in two ways. First, ERPs were created by averaging together the raw EEG across epochs for each condition and participant separately. Second, the raw single-trial EEG data was also submitted to time-frequency (TF) decomposition with Morlet wavelets to extract event-related spectral perturbations (ERSP; Makeig, Debener, Onton & Delorme, 2004), which captured both evoked (strictly time-locked) and induced (less time-locked) oscillations. In order to ensure that the prestimulus period was sufficiently long for reliably estimating the baseline power of lower frequencies, we mirrored each 500ms pre-stimulus segment and concatenated it to the beginning of each epoch (see e.g. Vogelsang, et al., 2018), thus resulting in a 1000ms prestimulus period. To avoid edge effects, data points at the start and at the end of each epoch were removed resulting in epoch durations being truncated down to -582ms to +2580ms. The ERSP was next estimated in relation to the average power during a baseline period between -582ms to -375ms pre-stimulus. This baseline period thus fell before the time point where post-stimulus activity might “bleed” into the pre-stimulus period due to the low temporal resolution of the lower frequency wavelets, thus ensuring that the baseline was not biased by stimulus-elicited activity (*cf.* Vogelsang et al., 2018). ERSP was estimated for theta (4-7Hz

inclusive), alpha (8-11Hz inclusive) and beta (12-30Hz inclusive) frequency bands, with wavelets centred at 1Hz intervals and the number of wavelet cycles increasing slightly from lower frequencies to higher (in order to optimise the trade-off between temporal versus frequency resolution), ranging from 3 cycles at 4Hz to 11.25 cycles at 30Hz. However, since there were no significant old/new effects in the beta band, only theta and alpha results are presented.

EEG statistical analysis

For ERPs, we initially conducted targeted analyses focusing only on the time-windows and electrode locations where the ERP correlates of familiarity and recollection are typically expressed. Thus, following Bergström et al. (2016) and a large body of literature (e.g. Rugg & Curran, 2007), we extracted mean ERP amplitudes from the mid-frontal Fz electrode between 300-500ms to measure the FN400 old/new effect and from the left parietal P3 electrode between 500-800ms to measure the left parietal old/new effect, and analysed these with univariate GLM methods, with the factors Group (old vs. young), Target Word memory status (old vs. new) and Distractor Picture memory status (old vs. new). These analyses focused on the Target and Distractor old/new effects and whether those effects interacted with each other or with age group, but we do not report or interpret main effects of age group on ERPs since such effects could be due to non-specific aging factors (such as structural brain changes, changes in scalp/skull quality, etc.) that can affect ERP morphology without being related to episodic retrieval processes, which was the focus of our investigation. We did not include the LPN old/new effect in this targeted ERP analysis since the timing and spatial distribution of this effect has varied between studies and age groups (Mecklinger, et al., 2016).

Analysing EEG data only from specific time windows at a few, specific electrode sites may overlook effects occurring at other time points and scalp locations, which could be

problematic when comparing age groups given the evidence that EEG effects can have different timing and topography in older adults (e.g. Friedman, 2013). Furthermore, there is not much literature on to the location and timing of memory-related oscillation effects in older adults. To provide a comprehensive and data-driven account, non-rotated Task Partial Least Square (Task-PLS) analyses (McIntosh & Lobaugh, 2004; Krishnan, Williams, McIntosh, & Abdi, 2011) of the whole spatiotemporal data were therefore conducted both on the ERPs and on the derived oscillation data. Task PLS is a multivariate technique that analyses the cross-block covariance between a matrix of the spatiotemporal EEG data and orthogonal contrast vectors representing differences between experimental conditions. In nonrotated PLS (e.g. Bergström, et al., 2016; McIntosh & Lobaugh, 2004), the sums of squares of the cross-block covariance between each contrast vector and the spatiotemporal data matrix is used to measure how strongly a particular contrast is expressed in the EEG data. Because the analysis is conducted on the cross-block covariance matrix between the spatiotemporal EEG data and the set of specified contrasts, the contrasts together account for 100% of the total cross-block covariance. Therefore, the percent accounted for by an individual contrast is dependent on both how much it covaries with the data and also on what other contrasts are entered into the analysis (the total of all contrasts sum to 100%). Random permutation testing is used to assess whether each contrast is accounting for a *significant* amount of covariance, thus allowing a direct assessment of the hypothesized experimental effects. Correction for multiple comparisons is not required, because the PLS only tests the same number of contrasts as degrees of freedom in the design. The PLS analysis outputs electrode saliences that identify the electrodes that most strongly covary at a particular point in time with the experimental effect expressed in the contrast vector. The standard errors of the electrode saliences are estimated through bootstrap resampling. The ratio of the electrode salience to the bootstrapped standard error gives a standardized measure of reliability that is

approximately equivalent to a z score, whereby values above 1.96 and below -1.96 are reliably different from zero with a 95% confidence interval, values above 2.58 and below -2.58 are reliably different from zero with a 99% confidence interval, and values above 3.29 and below -3.29 are reliably different from zero with a 99.9% confidence interval, etcetera (McIntosh & Lobaugh, 2004).

In the current analysis, nonrotated task-PLS was used to test the full factorial design with contrasts coding for the main effects of group (old vs. young), word memory status (old vs. new) and picture memory status (old vs. new) as well as their interaction terms, on three separate datasets: 1) the ERP data from all scalp channels between 0-1500ms (as in Bergström et al., 2016); 2) the average theta band power from all scalp channels between -375 ms to 1500ms; and 3) the average alpha band power from all scalp channels between -375 ms to 1500ms. As in the GLM analysis of ERPs, only PLS effects involving the Target or Distractor memory status factors (either as main effects or interactions), are reported and interpreted since main effects of Age group on ERPs or oscillations are not meaningful in this study. This longer time window for power was chosen since a wavelet with 3 cycles at 4Hz extends -375 ms into the pre-stimulus period when centred at stimulus onset, and thus the pre-stimulus period from -375 -0ms could potentially be influenced by post-stimulus brain responses. The covariance of the experimental contrasts with the spatiotemporal data was tested for significance using 3000 permutations, and the reliability of the electrode saliences was tested using 500 bootstraps (see McIntosh and Lobaugh, 2004, for a full description of PLS). MATLAB code to perform PLS is available at www.rotman-baycrest.on.ca/pls/.

Results

Individual behavioural data and ERP mean amplitudes from the targeted analysis are available on the Open Source Framework (see <https://osf.io/vzs5p/>).

Behaviour

Both groups were highly accurate on the WM task and did not differ significantly in performance (Younger adults $M = 0.84$, $SD = 0.10$; Older adults: $M = 0.79$, $SD = 0.11$; $t(46)=1.55$, $p=.13$, Cohen's $d=.48$; calculated here and in all subsequent between and within groups comparisons as the difference in mean divided by the pooled standard deviation, uncorrected for the correlation when comparing within-subjects conditions to avoid inflating effect size estimates; Dunlap, Cortina, Vaslow, & Burke, 1996). One participant in each group scored lower than two standard deviations below the mean (WM accuracy = 0.57 and 0.55 respectively for the younger and older group) however excluding these participants did not affect the Memory Stroop results, so all participants were included in all analyses.

Table 1 shows proportion accurate responses for all conditions (i.e. “hits” if the target word is old, “correct rejections” if the target word is new) and responses times (for all trials, regardless of accuracy) on the target recognition task for both groups.

Table 1. Mean proportion accurate responses and reaction times (ms) of target recognition decisions in both groups.

Condition	Younger adults		Older adults	
	Mean (SD) Accuracy	Mean (SD) RT	Mean (SD) Accuracy	Mean (SD) RT
Old Word Old Picture	.94(.07)	1220(206)	.86(.12)	1454(244)
Old Word New Picture	.90(.08)	1174(191)	.83(.12)	1419(218)
New Word Old Picture	.90(.11)	1291(201)	.89(.08)	1496(193)
New Word New Picture	.93(.07)	1253(222)	.91(.08)	1456(220)

A 2x2x2 mixed ANOVA was carried out on the accuracy data (within subjects factors: Target Word old/new status and Distractor Picture old/new status; between subjects factor: Age). This revealed a main effect of Age, with lower accuracy in the old than the young group ($F(1,46)=4.66, p=.04, \eta_p^2=.092$). There was also a trend for an interaction between Age and Target Word old/new status ($F(1,46)=3.56, p=.066, \eta_p^2=.072$), which was driven by lower overall hit rates for older adults compared to younger adults ($t(37.5)=2.65, p=.01, d=0.76$), but no significant difference between groups in correct rejection rates for new words ($t(46)=1.55, p=.13, d=0.17$).

Importantly, replicating the Memory Stroop effect (Anderson et al., 2011), there was also a significant effect on accuracy based on the congruency of the Target and Distractor memory status, with reduced accuracy for incongruent (old word & new picture or new word and old picture) compared to congruent conditions (old/old or new/new; Interaction between Target Word old/new status and Distractor Picture old/new status: $F(1,47)=14.97, p<.001, \eta_p^2=.242$). Unexpectedly, there was however no effect of Age on this congruency effect (Three-way interaction: $F(1,46)=0.15, p=.70, \eta_p^2=.003$) and no other significant effects (Target Word: $F(1,46)=2.35, p=.132, \eta_p^2=.049$; Distractor Picture: $F(1,46)=0.923, p=.342, \eta_p^2=.020$; Distractor Picture x Age: $F(1,46)=0.004, p=.949, \eta_p^2<.0001$), indicating that older adults were not more biased by unintentional recognition than younger adults. To follow up on the significant Target Word x Distractor Picture congruency interaction, paired samples *t*-tests were performed to compare accuracy for old vs. new distractors separately, collapsed across age groups. As expected, accuracy for old targets was higher with old than new distractors ($t(47)=3.38, p=.001, d=0.31$) whereas accuracy for new targets was higher with new than old distractors ($t(47)=2.61, p=.012, d=0.25$).

A 2x2x2 mixed ANOVA of the same design was similarly carried out RTs. This showed only significant main effects for Age, Word memory status and Picture memory

status. Overall, older adults were significantly slower than younger adults ($F(1,46)=15.5$, $p<.001$, $\eta_p^2=.252$). Responses for Old Words were overall significantly faster than responses for New Words ($F(1,46)=5.82$, $p=.02$, $\eta_p^2=.112$). Trials with Old distractor pictures elicited significantly slower responses than trials with New distractor pictures ($F(1,46)=19.66$, $p<.001$, $\eta_p^2=.299$). As found previously (Bergström et al., 2016), there were no significant interactions between any of the factors, including no congruency bias (Target Word x Age: $F(1,46)=0.802$, $p=.375$, $\eta_p^2=.017$; Distractor Picture x Age: $F(1,46)=0.001$, $p=.979$, $\eta_p^2<.001$; Target Word x Distractor Picture: $F(1,46)=0.044$, $p=.835$, $\eta_p^2=.001$; Target Word x Distractor Picture x Age: $F(1,46)=0.524$, $p=.473$, $\eta_p^2<.011$).

In sum, the behavioural analysis showed an overall congruency bias for target recognition accuracy with greater accuracy for trials where the old/new status of target words and distractor pictures were the same, which is consistent with previous findings (Anderson et al., 2011; Bergström et al., 2016). There was however no significant difference in this congruency bias between the old and young groups, contrary to predictions (Anderson et al., 2011). Neither group showed a congruency bias for reaction times (consistent with Bergström et al., 2016), but there was evidence of both lower accuracy and generally slower responses in the old group. Thus, whereas the older group showed impaired performance in terms of target recognition accuracy and speed, the influence of unintentional distractor recognition was very similar across age.

ERPs

Grand-average ERPs for the mid frontal (Fz) and the left parietal (P3) sites are shown in Figure 1, together with scalp topography plots showing old/new differences for target words and distractor pictures.

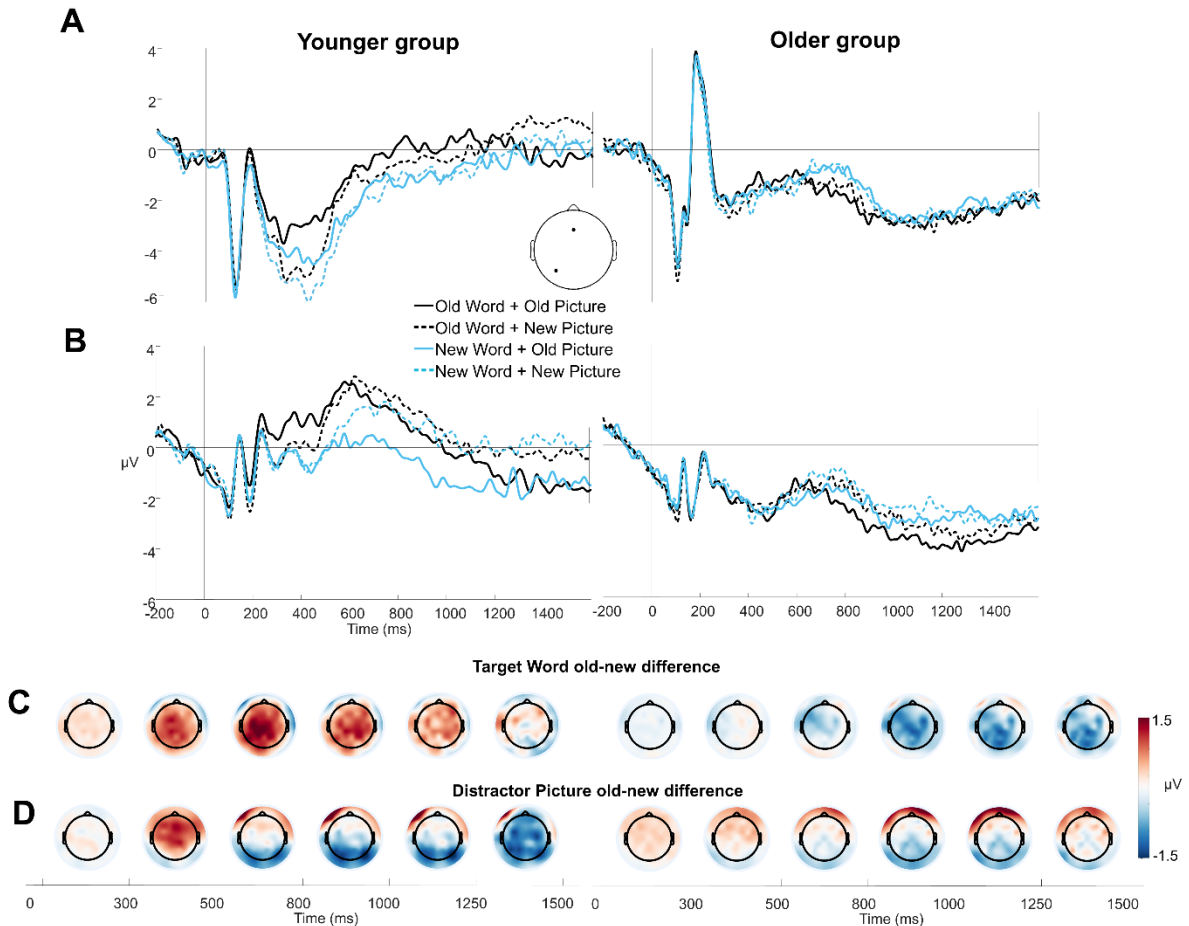


Figure 1. Grand-average ERPs and scalp topographies of old/new effects for targets and distractors in both groups. ERPs from mid-frontal (Fz; **A, top row**) and left parietal (P3; **B, bottom row**) sites in Young adults (left panel) and Old adults (right panel). Scalp topographies of the mean amplitude old minus new difference for Words irrespective of Picture memory status (**C, top row**) and the old minus new difference for Pictures irrespective of Word memory status (**D, bottom row**) in Young adults (left panel) and Old adults (right panel). Scalp maps show the mean amplitude differences between the time-points on the scale below. In Young adults, targets elicited both typical early (300-500ms) and late (500-800ms) positive ERP old/new effects, whereas distractors only elicited the early ERP old/new effect, which was followed by an old/new negativity across posterior sites. These effects were weaker in the Older group, who instead showed a centro-parietal negativity for old compared to new targets.

Targeted ERP analysis

FN400 old/new effects

First, we investigated the prediction that the familiarity-related FN400 old/new effect would be present for both intentional target recognition and unintentional distractor recognition in

both age groups. We conducted a 2x2x2 mixed ANOVA on mean ERP amplitudes at Fz between 300-500ms with the same factors as the behavioural analysis (Target Word Old/New status; Distractor Picture Old/New status; Age group). This analysis revealed significant FN400 modulations dependent on whether both Target Words ($F(1,46)=6.83, p=.012, \eta_p^2=.129$) and Distractor Pictures ($F(1,46)=43.91, p<.001, \eta_p^2=.488$) had been previously seen, however there was a highly significant interaction for Distractor Picture old/new status with Age ($F(1,46)=14.56, p<.001, \eta_p^2=.24$) and a trend toward an interaction between Target Word old/new status and Age (Target Word x Age: $F(1,46)=4.03, p=.051, \eta_p^2=.081$). No other interactions were significant (Target Word x Distractor Picture: $F(1,46)=0.970, p=.330, \eta_p^2=.021$; Target Word x Distractor Picture x Age: $F(1,46)=0.189, p=.666, \eta_p^2=.004$). Follow up paired t-tests within each group revealed that for Target Words, positive FN400 ERPs for Old compared to New Words were only evident in the younger group ($t(23)=2.64, p=.014, d=0.19$) with no FN400 differences between Old and New Target Words in the older group ($t(23)=0.624, p=.539, d=0.04$). However, the old Distractor Pictures elicited significantly more positive FN400s than new Distractor Pictures in both younger ($t(23)=6.68, p<.001, d=0.28$) and older participants, albeit the difference was smaller in the latter group ($t(23)=2.25, p=.034, d=0.13$). Thus, while a familiarity-related FN400 was present both for unintentional and intentional recognition in the young group, these effects were either reduced or absent in the older group.

Parietal old/new effects

Next we investigated the prediction that the left parietal old/new effect would only be present for intentional recognition, and that it would be reduced in the older compared to younger group. For the left parietal site (P3), mean ERP amplitudes between 500-800ms were submitted to another 2x2x2 mixed measures ANOVA (same factors as in previous analyses). The results revealed significant Old/New main effects for Target Words ($F(1,46)=11.34,$

$p=.002$, $\eta_p^2=.198$) and also an interaction between Age and Target Word Old/New status ($F(1,46)=12.21$, $p=.001$, $\eta_p^2=.21$), which was caused by the typical parietal Old/New difference for target Words being present only in the young group ($t(23)=4.29$, $p<.001$, $d=0.28$) with no difference in the older group ($t(23)=0.106$, $p=.917$, $d<0.01$).

In line with Bergström et al. (2016) there was also a main effect of Distractor Picture ($F(1,46)=7.10$, $p=.011$, $\eta_p^2=.134$) that was in the opposite direction to typical old/new effects, but this effect did not significantly interact with Age ($F(1,46)=0.632$, $p=.431$, $\eta_p^2=.014$). That is, old Distractor Pictures elicited more *negative* parietal ERPs in this time-window than new Distractor Pictures in both young and old adults (see Fig. 1), consistent with the previously described LPN effect for old compared to new distractor pictures. There was no other significant effects (Word x Picture ($F(1,46)=2.56$, $p=.117$, $\eta_p^2=.053$; Word x Picture x Age ($F(1,46)=0.279$, $p=.60$, $\eta_p^2=.006$)).¹

Whole-head PLS analysis of ERPs

Next, we conducted a data-driven non-rotated Task PLS analysis of the ERP data from all scalp channels and across the whole 0-1500ms time-window, in order to investigate ERP effects that may have been missed by the targeted focal analysis. This analysis used the same full factorial model as previous analyses (Factors: Target Word old/new status; Distractor Picture old/new status; Age group), and revealed significant main effects of Target Word Old/New status ($p=.045$, accounting for 2% of the cross-block covariance) and Distractor Picture Old/New status ($p=.003$, 4%) as well as a highly significant interaction between Target Word status and Age group ($p<.001$, 5%), but the other effects were not significant

¹ In an additional analysis, we split the older group into two equally sized sub-groups based on their overall recognition accuracy collapsed across all conditions. The purpose of this analysis was to understand whether the small old/new ERP differences in the older group were simply due to their on-average poorer target recognition memory, or due to other factors. However, even within the highest performing sub-group (which was matched in recognition accuracy to the young group) the FN400 and left parietal old/new effects were substantially reduced, suggesting that the ERP changes with age were not simply linked to lower performance.

(all p s $\geq .098$). To follow up on the significant interaction, subsequent non-rotated PLS analyses with the Word and Picture factors within each group showed significant old/new main effects for Target Words within both old and young groups (Word Old/New status in Young group: $p=.003$ (44%); Old group: $p=.007$ (57%)). For Distractor Pictures however, the old/new main effect was only significant for the young group (Distractor Picture Old/New status in Young group: $p=.005$ (37%); Old group: $p=.096$ (29%)). There was no interaction between these factors in either group (Young group: $p=.138$ (18%); Old group: $p=.704$ (14%)).

Figure 2 shows the spatiotemporal reliability of the old/new contrasts within each group, as assessed with bootstrap resampling. This figure illustrates that the Target Word x Age interaction in the full factorial PLS analysis was caused by *opposite* going old/new ERP differences for Target Words in the young compared to old group. That is, while the young group showed sustained ERP positivities for Old compared to New Word Targets, the old group showed sustained ERP negativities with a later onset. Both groups showed a similar pattern of ERPs for Old compared to New distractor Pictures (as indicated by a lack of an interaction between Distractor Picture Old/New status x Age group), with an early fronto-central positivity (FN400 old/new effect) followed by a later posterior negativity (LPN old/new effect), although these effects were somewhat weaker in the older group (but not significantly so).

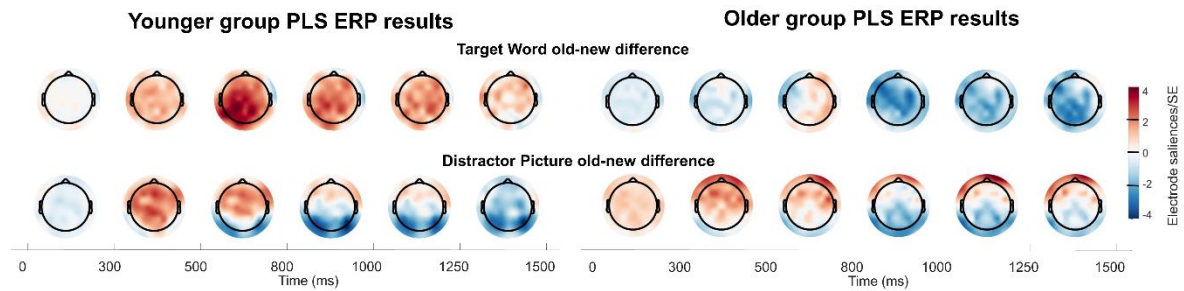


Figure 2. Scalp topographies of the ratio of electrode saliences to their bootstrapped standard error for old/new contrasts in the whole-head PLS analysis on ERPs. These plots show the direction and reliability of old/new effects for Target Words (top) and Distractor Pictures (bottom) separately for younger (left) and older (right) groups. Positive bootstrap ratio values (red) indicate scalp locations and time-points that show more positive ERP amplitudes for Old than New items, whereas negative values (blue) indicate scalp locations and time-points that show more negative ERP amplitudes for Old than New items. The bootstrap ratios are approximately equivalent to z scores; values > 1.96 or < -1.95 indicate scalp locations and time points that show reliable effects with a 95% confidence interval, values > 2.58 or < -2.58 indicate reliability with a 99% confidence interval, and values > 3.29 or < -3.29 indicate reliability with a 99.9% confidence interval, etc. Scalp maps show the mean bootstrap ratios between the time-points on the scale below.

Taken together, the data driven whole head PLS analysis shows a consistent pattern of results with the targeted ANOVA analyses, while also revealing late sustained slow-drifts related to both unintentional and intentional recognition. Unintentional recognition was associated with an FN400 and an LPN in both age groups but this pattern was non-significant in the older group, whereas intentional recognition was related to a left parietal old/new effect in the young group and a sustained centro-posterior negativity in the old group.

Time-frequency analysis

Figure 3 shows the estimated ERSP old/new differences at an example electrode at the left parietal scalp (P3), as well as line plots that illustrate how mean alpha and theta activity differed for the four conditions within each age group. Figure 4 shows the scalp topographies of the old-new differences in the alpha and theta band for the young and old groups separately. Note that there were no significant effects in the beta band, hence those results are not presented. As can be seen in these figures, the older and younger groups showed quite

similar oscillatory old/new effects in these frequency bands, in that both groups showed enhanced alpha and theta power for old compared to new words, whereas old pictures elicited enhanced theta power but reduced alpha power.

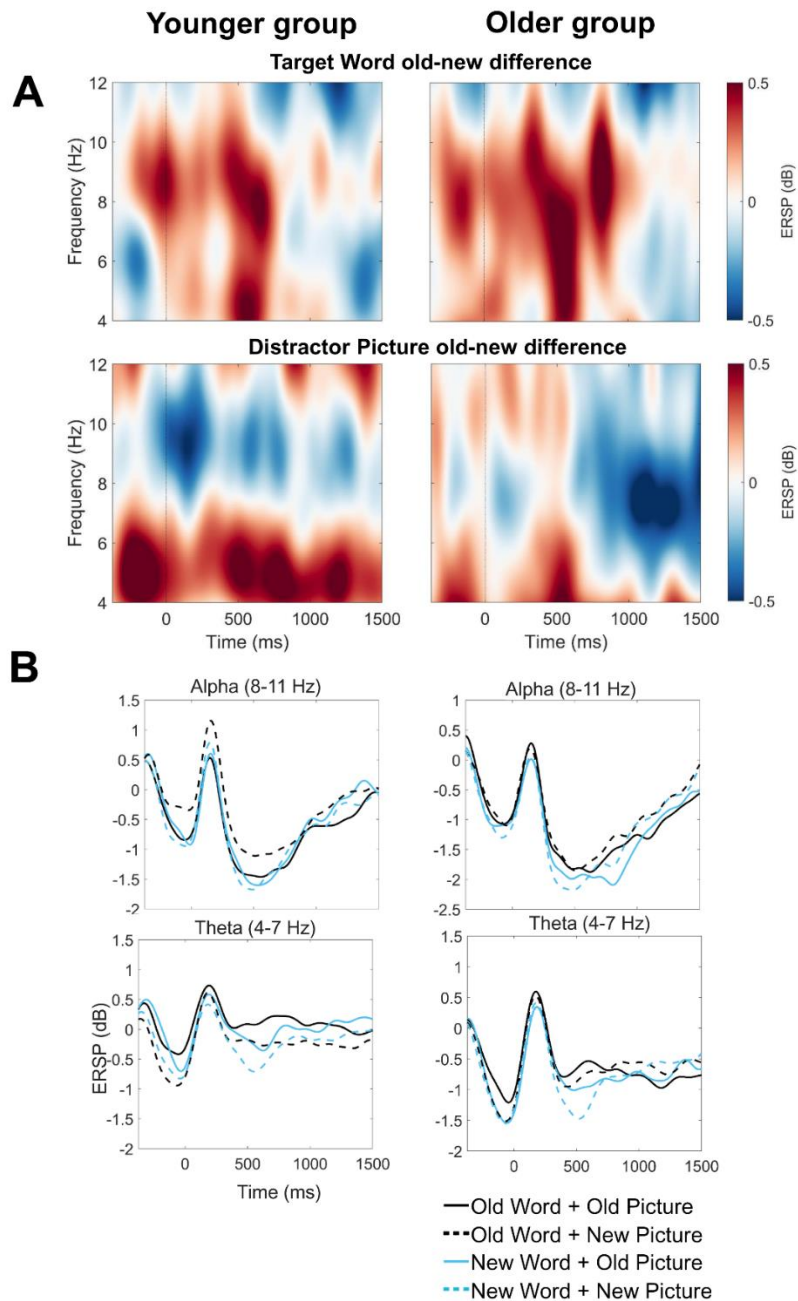


Figure 3. Time-frequency and line plots illustrating oscillatory old/new effects at the left parietal electrode (P3). **A**, ERSP old-new main effects for Target Words irrespective of Distractor Picture memory status (top) and for Distractor Pictures irrespective of Target Word memory status (bottom) for the younger (left) and older (right) groups. **B**, Mean alpha (8-11 Hz, top) and theta (4-7 Hz, bottom) ERSP for the four conditions at the left-parietal electrode for younger (left) and older (right) groups.

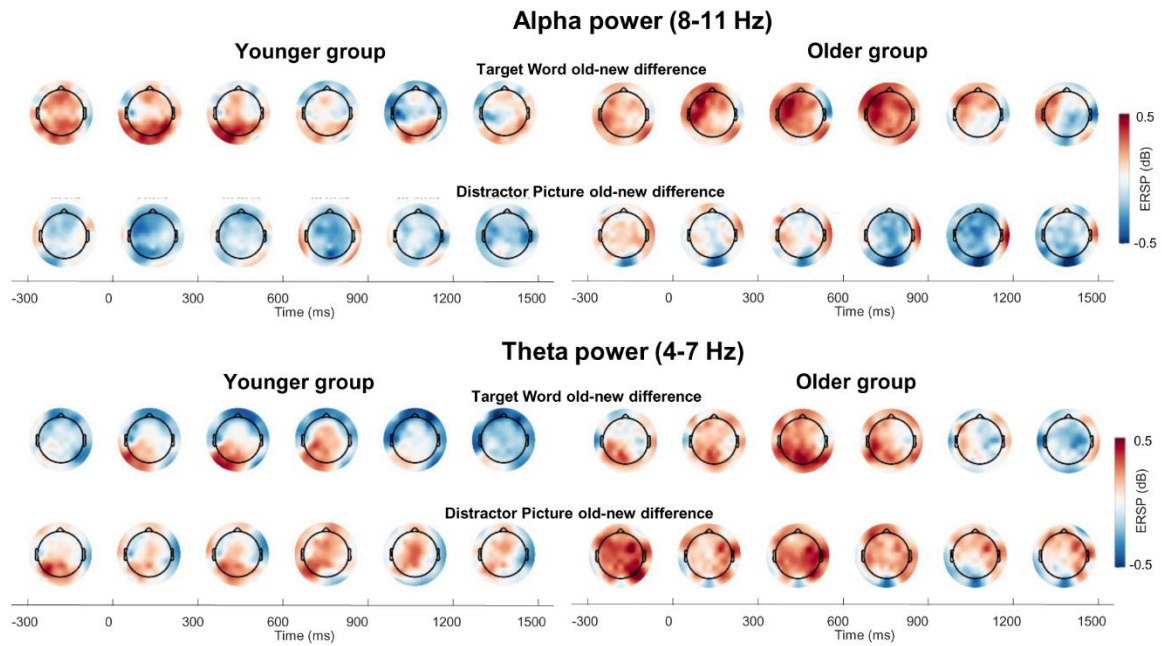


Figure 4. Scalp topographies of mean ERSP Target Word and Distractor Picture old-new differences in the alpha (top) and theta (bottom) frequency bands, for the younger (left) and older (right) groups. Scalp maps show the mean ERSP differences between the time-points on the scale below.

Whole-head PLS analysis of theta and alpha oscillations

Non-rotated Task PLS analyses of the ERSP data were conducted on all scalp channels and over a time window of -374ms to 1500ms, separately for the theta and alpha bands. We again tested the full factorial model including all three factors and their interaction terms (Factors: Target Word old/new status, Distractor Picture old/new status, Age group). These analyses revealed significant or near-significant main effects of Target Word old/new and Distractor Picture old/new status, but no interactions between Age and the other factors (Table 2). Thus, both old and young groups showed relatively similar oscillatory old-new differences in alpha and theta bands.

Table 2. Results (p-values) of the whole-head PLS analysis of ERSP in the theta and alpha frequency bands. Percentage of cross-block covariance accounted for is shown in parentheses. Significant and near significant results are highlighted in bold.

	Target Word	Distractor Picture	Target Word x Distractor Picture	Target Word x Age	Distractor Picture x Age	Target Word x Distractor Picture x Age
Theta	.058 (4%)	.046 (5%)	.849 (2%)	.266 (3%)	.296 (3%)	.826 (2%)
Alpha	.018 (7%)	.064 (5%)	.417 (3%)	.133 (5%)	.528 (3%)	.694 (3%)

Figure 5 illustrates the spatiotemporal reliability of the theta and alpha ERSP old/new effects for target Words and distractor Images, across both age groups, as assessed with bootstrap resampling. These show that there was a widespread and sustained increase in theta power for old Target Words and old Distractor Pictures, compared to new Words and Pictures. Both groups also showed broad and sustained increases in alpha power when recognising old compared to new Target Words, but reduced alpha power for old compared to new Distractor Pictures.

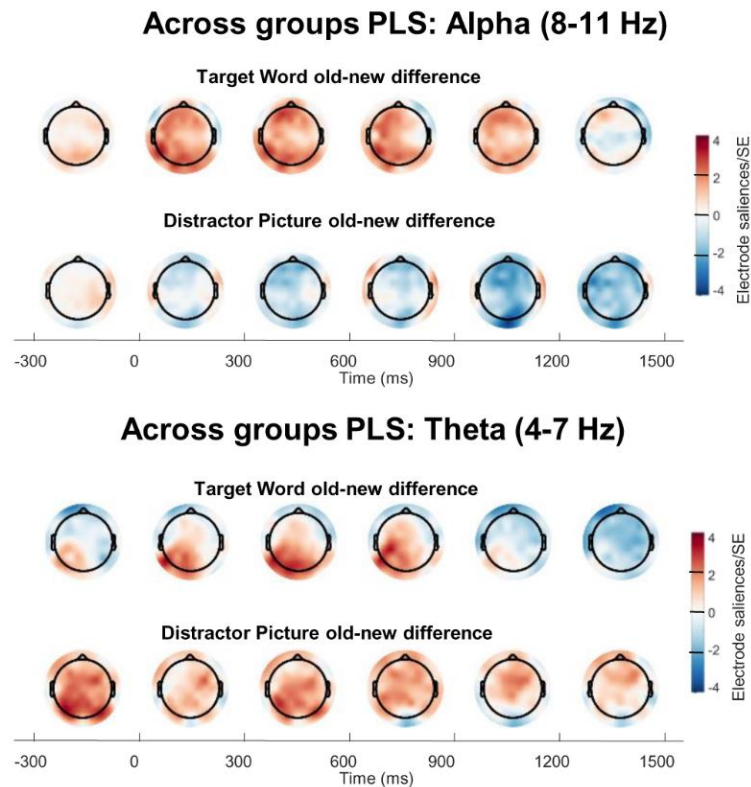


Figure 5. Scalp topographies of electrode saliences to bootstrapped standard error ratios for old/new effects in the whole-head PLS analysis of ERSP in the alpha (top) and theta (bottom) bands. These plots show the reliability of old/new effects for Target Words and Distractor Pictures in alpha and theta bands separately, but across both age groups. Positive bootstrap ratio values (red) indicate scalp locations and time-points that show greater power for Old than New items, whereas negative values (blue) indicate scalp locations and time-points that show lower power for Old than New items. The bootstrap ratios are approximately equivalent to z scores; values > 1.96 or < -1.95 indicate scalp locations and time points that show reliable effects with a 95% confidence interval, values > 2.58 or < -2.58 indicate reliability with a 99% confidence interval, and values > 3.29 or < -3.29 indicate reliability with a 99.9% confidence interval, etc. Scalp maps show the mean bootstrap ratios between the time-points on the scale below.

In sum, the ERP and time-frequency ERSP analyses revealed very different results. In the ERP analysis, old/new ERP differences for intentional recognition of Target Words and unintentional recognition of Distractor Pictures that were strongly expressed in the younger group were either very reduced or reversed in the older group. In the ERSP analysis however, old/new differences in alpha and theta power were similar across age groups. Theta power

effects were also similar between intentional and unintentional recognition whereas alpha power differed across Targets versus Distractors, with increased power for intentional Target Word recognition and reduced power for unintentional Distractor Picture recognition.

Discussion

We investigated the neurocognitive mechanisms that underlie the biasing effects of unintentional recognition of distractors on intentional recognition judgements, and how these mechanisms may differ across younger and older adults (Anderson et al., 2011; Bergström et al., 2016). The results revealed equivalent behavioural recognition biases in young and old groups but markedly different ERP effects, indicating that old and young adults may be engaging different neural mechanisms during recognition. In contrast, alpha and theta oscillations were not significantly different across age groups, suggestive of similarities in neurocognitive processing. Thus, the results revealed a complex pattern of similarities and differences between age groups across different behavioural and EEG measures.

The behavioural findings showed that both older and younger adults were susceptible to biases during a target recognition task due to unintentional recognition of distractors. Although older adults had significantly poorer memory for targets, they were similarly biased by unintentional recognition. That is, for both old and young groups, target recognition decisions were more accurate when the distractor image was of the same episodic status (“old” or “new”) as the target word than when it was of incongruent status, with no group difference in this pattern. This behavioural result thus suggests that unintentional and intentional recognition processes are differentially affected by aging, which converges with neural evidence (Bergström et al., 2016) that dissociable neurocognitive processes underlie

intentional and unintentional recognition. It is also consistent with theoretical proposals that intentional memory processes are more affected by aging than unintentional forms of memory (Koen & Yonelinas, 2016; Morcom, 2016).

Nevertheless, the lack of an age difference is unexpected given prior evidence that older adults are more distracted by task-irrelevant information in other types of paradigms (Amer, et al., 2016; Biss, et al., 2013; De Fockert, et al., 2009; Wais & Gazzaley, 2014). Anderson et al. (2011) found that young adults only showed a distraction-induced recognition bias when their attention was divided with a secondary task, but not without a secondary task. In their study, older adults showed a bias even without a secondary task, but were not tested with a secondary task. Our design was different, since both age groups completed a WM task that has been found to increase distractor processing in other paradigms (De Fockert et al., 2001). We therefore predicted that recognition biases might be even larger in the older group in our study, but this prediction was not confirmed. There was also no neural evidence of increased distractor recognition in the older than younger group. The FN400 effect for old distractors that is associated with unintentional recognition (Bergström, et al., 2016) was in fact smaller in the old group than in the young group. Old and young groups showed more similar effects for unintentional recognition in the oscillatory than ERP domain, but there was no significant increase in distractor old/new effects in the older compared to younger group in either theta or alpha bands. Thus, there was no evidence in the current study that older adults experienced increased distractor recognition.

One possibility is therefore that the lack of an age difference in bias from unintentional recognition arose because cognitive control was in fact spared in our older group, consistent with evidence that aging-related cognitive control impairments are variable in the literature (Verhaegen, 2011; see also Lustig & Jantz, 2015). Our old participant group

were highly educated and socially active, and these lifestyle factors are associated with preserved cognitive functions in older age (Chan et al., 2018; Nyberg & Pudas, 2019; Nyberg, et al., 2012). Furthermore, the mean age of our older group (66 years) was also 10 years younger than the mean age of the older group in Anderson et al. (2011), so perhaps our older group had relatively spared cognitive control for that reason. However, the mean age of our old group was similar to an older group (68 years) in another study that found aging-related increases in false alarms to new objects due to unintentional context recognition (Gutchess, et al., 2007), suggesting that other possible reasons may underlie the lack of an age difference in recognition biases in our study.

Although we based our design on Anderson et al.'s Memory Stroop task, we also introduced several major novel design elements. For example, we used a different secondary task than they did, and compared older and younger groups when both groups were completing the secondary WM task. In contrast, Anderson et al. found enhanced biases in old participants when compared to a young group without a secondary task in either group. It is possible that the effects of aging and WM load are not additive in affecting performance, such that our WM task may have made the young adults more distractible but had less effect on the older groups' distractibility. Another key difference between our design and Anderson et al.'s studies is that we used negative and neutral colour photographs as distractor pictures, whereas they used line drawings of objects. Our photograph distractors are likely to have been more salient than line drawings, which could have reduced age differences in bias, perhaps especially since younger adults sometimes show stronger attentional biases towards negative information than older adults (Murphy & Isaacowitz, 2008). Future research should investigate the effects of variations in WM load and distractor salience on unintentional recognition biases across age groups.

Alternatively, our older participants may have had impaired cognitive control, but resulting effects on behaviour could have been counteracted by poorer memory for the distractors due to impaired episodic encoding and/or retrieval processes (Friedman, 2013). The amount of recognition bias produced by distractors is not a direct measure of how much participants are attending to or processing the distractors, because the bias is dependent on whether those distractors also elicit unintentional recognition. Older adults may have attended more to the distractors and may have been more biased on the occasions that they did recognise the pictures, but they may have had poorer memory for the distractors than the young group, producing similar levels of behavioural bias across groups. Although memory for distractor pictures was not assessed directly, older adults were less likely to recognise the target words than younger adults, suggesting that they may have also had poorer memory for the distractors. The lack of evidence for enhanced recognition biases in older age may hence be due to a combination of reduced memory for distractors and reduced cognitive control (*cf.* Anderson & Levy, 2007). Although speculative, this account is consistent with the weaker FN400 ERP effect for distractor recognition in the older group.

Because the ERP effects in the young group have been extensively discussed elsewhere (Bergström, et al., 2016), we focus our discussion here on how these effects were modulated by aging. The amplitudes of the FN400 and left parietal ERP correlates of familiarity and recollection (Rugg & Curran, 2007), that we previously associated with unintentional and intentional recognition respectively (Bergström, et al., 2016), were either very reduced or absent in the older group. This strong group difference in the ERP correlates of recognition contrasts with the relatively modest group difference in behavioural memory accuracy. The PLS analysis showed that old/new differences for unintentional distractor recognition were similar in polarity, timing and spatial distribution for young and older groups (although tended to be weaker within the older group). In contrast, old/new ERP

effects for intentional target recognition were qualitatively different across groups. Whilst the younger group exhibited the commonly found positive old/new differences for targets, the older group showed an effect in the *opposite* direction with a sustained, late negativity for old targets that was widely distributed and peaked over central electrode sites. Thus, positive ERP old/new effects for intentional target recognition in the older group might have been attenuated by this temporally overlapping negative component. Similar late centroparietal negativities during retrieval in older adults have been widely described in the literature (Duarte et al., 2006, Dulas & Duarte, 2013; James et al., 2016; Friedman, 2013; Li et al., 2004; Mecklinger et al., 2016), but their functional significance is unclear. Our novel finding that this effect was only found for intentional but not unintentional recognition suggests it reflects a strategic process that older adults engage voluntarily during intentional retrieval, perhaps to compensate for reduced memory performance (Cabeza et al., 2002; Cabeza et al., 2018; Craik & Rose, 2012; but see Morcom & Johnson, 2015).

In contrast to the strong ERP differences across age groups, theta (4-7 Hz) and alpha (8-11 Hz) oscillations showed similar old/new effects for both target and distractor recognition across young and older participants. Both groups exhibited greater left parietal theta power for old compared to new items, in line with previous findings in young (e.g. Gruber et al., 2008; Guderian & Düzel, 2005; Hanslmayr et al., 2016; Hsieh & Ranganath, 2014; Nyhus & Curran, 2010) and older adults (Strunk et al., 2017). Interestingly, significant positive old/new differences in theta power were found for both intentional target recognition and unintentional distractor recognition. This finding contrasts with research that has linked theta increases specifically with recollection (Gruber et al., 2008), but is consistent with evidence that familiarity is also associated with theta power increases (Klimesch, et al., 2001). Since recollection is considered a relatively intentional process (e.g. Yonelinas & Jacoby, 2012) and has been associated with the left parietal old/new ERP effect (Rugg &

Curran, 2007) that was only associated with intentional target recognition in the current study, these results support the view that theta power and the left parietal ERP old/new effect are dissociable (Chen & Caplan, 2016; Jacobs et al., 2006; Klimesch et al., 2000), and also indicate that theta power is not simply a marker of recollection. Instead, theta oscillations may index a more general/core retrieval process that is common to both familiarity and recollection and that is insensitive to retrieval intentionality. This core memory-related brain process appears less affected by ageing than the processes reflected in FN400 and left parietal ERPs.

We also found old/new effects in alpha power for targets and distractors, and again these effects were similar across the two age groups. Alpha power reductions have been interpreted as reflecting reactivation of perceptual and conceptual memory details in neocortical regions during retrieval (Hanslmayr et al., 2012; 2016). Interestingly, our results showed a reversal in old/new differences in alpha power between target words and distractor pictures. For both age groups, alpha power was enhanced for old compared to new target words, contrary to the theory that alpha desynchronization indexes successful retrieval (Hanslmayr et al., 2016), but old distractor pictures were associated with reduced alpha power compared to new distractor pictures, consistent with the theory. It is unclear however whether this alpha difference between targets and distractors is related to differences in the intentionality of retrieval, or alternatively due to the different stimuli material (words for targets and images for distractors). This issue can be addressed in future research by varying the material types that are used for targets vs. distractors in the Memory Stroop paradigm (*cf.* Anderson et al., 2011; Bergström et al., 2016) to investigate whether unintentional vs. intentional recognition of different materials elicit alpha desynchronization or synchronization.

Future research should also investigate whether there are differences in peak frequencies of oscillatory correlates of unintentional and intentional recognition across age groups. There is accumulating evidence that the peak frequencies of EEG oscillations slow down with aging, so that younger adults tend to have a faster alpha peak (around 10Hz) than older adults (around 8-9 Hz), which can produce age differences in alpha effects if the EEG is analysed with fixed frequency bands (see e.g. Scally, Burke, Bunce & Delvenne, 2018). Our analysis followed previous research that used fixed frequency bands to investigate potential age differences in episodic retrieval-related oscillations (e.g. Strunk et al., 2017) and also did not show any such age differences, but it is possible that age differences would have emerged if we had been able to adjust the analysis for individual frequency peaks. However, detecting individual alpha peaks would have required recordings of EEG during rest with eyes closed, which we did not incorporate in our design.

In sum, previous research had shown that older adults are more susceptible to distraction-induced recognition biases than younger adults (Anderson et al., 2011) and that intentional and unintentional recognition involved dissociable memory processes as evidenced by ERPs (Bergström et al., 2016). Here, we found that the biasing effects of distractor recognition were similar across older and younger adults, despite a reduction in target recognition accuracy in the older group. Thus, aging had different effects on behavioural markers of target versus distractor recognition, supporting the view that intentional and unintentional recognition processes are dissociable, and more generally that intentional memory processes are particularly affected by aging (Morcom, 2016). The ERP effects associated with distractor and target recognition were markedly different across age groups, whereas theta and alpha EEG oscillations showed broadly similar patterns in the two groups. These findings illustrate how different EEG analysis methods might lead researchers to draw different conclusions about age differences in memory; the ERPs indicate strong

differences in retrieval processing between older and younger participants, whereas the EEG oscillations highlight similarities between the age groups. Thus, these methods provide complementary and sometimes conflicting sources of information about the neurocognitive mechanisms that underlie episodic memory. Taken together, the results indicate that older adults engage similar unintentional recognition processes as young adults, whereas their intentional recognition processes are different. In everyday life, we often need to recognise one stimulus while surrounded by distracting stimuli that range in familiarity. Distraction effects on recognition may thus be a prevalent source of real life memory biases in both young and older adults.

References

- Ally, B. A., Simons, J. S., McKeever, J. D., Peers, P. V., & Budson, A. E. (2008). Parietal contributions to recollection: Electrophysiological evidence from aging and patients with parietal lesions. *Neuropsychologia*, *46*(7), 1800–1812.
<https://doi.org/10.1016/j.neuropsychologia.2008.02.026>
- Amer, T., Campbell, K. L., & Hasher, L. (2016). Cognitive control as a double-edged sword. *Trends in Cognitive Sciences*, *20*, 905-915. <https://doi.org/10.1016/j.tics.2016.10.002>
- Anderson, B. A., Jacoby, L. L., Thomas, R. C., & Balota, D. A. (2011). The effects of age and divided attention on spontaneous recognition. *Memory & Cognition*, *39*(4), 725–735. <https://doi.org/10.3758/s13421-010-0046-z>
- Anderson, M. C., & Levy, B. J. (2007). Theoretical issues in inhibition: Insights from research on human memory. In D. S. Gorfein & C.M. MacLeod (Eds.), *Inhibition in cognition* (pp. 81–102). Washington, DC: American Psychological Association.
<https://doi.org/10.1037/11587-005>
- Bergström, Z., Velmans, M., de Fockert, J., & Richardson-Klavehn, A. (2007). ERP evidence for successful voluntary avoidance of conscious recollection. *Brain Research*, *1151*, 119-133. <https://doi.org/10.1016/j.brainres.2007.03.014>
- Bergström, Z., Williams, D., Bhula, M., & Sharma, D. (2016). Unintentional and intentional recognition rely on dissociable neurocognitive mechanisms. *Journal Of Cognitive Neuroscience*, *28*, 1838-1848. https://doi.org/10.1162/jocn_a_01010
- Biss, R. K., Ngo, K. W. J., Hasher, L., Campbell, K. L., & Rowe, G. (2013). Distraction Can Reduce Age-Related Forgetting. *Psychological Science*, *24*(4), 448–455.
<https://doi.org/10.1177/0956797612457386>

- Bradley, M. M., & Lang, P. J. (1999). Affective norms for English words (ANEW): Stimuli, instruction manual and affective ratings. Technical report C-1, Gainesville, FL. The Center for Research in Psychophysiology, University of Florida.
<https://doi.org/10.1109/MIC.2008.114>
- Cabeza, R., Anderson, N. D., Locantore, J. K., & McIntosh, A. R. (2002). Aging gracefully: Compensatory brain activity in high-performing older adults. *NeuroImage*, *17*(3), 1394–1402. <https://doi.org/10.1006/nimg.2002.1280>
- Cabeza, R., Albert, M., Belleville, S., Craik, F.I.M., Duarte, A., Grady, C.L., Lindenberger, U., Nyberg, L., Park, D.C., Reuter-Lorenz, P.A., Rugg, M.D., Steffener, J., & Rajah, M.N. (2018). Maintenance, reserve, and compensation: the cognitive neuroscience of healthy aging. *Nature Reviews Neuroscience*, *19*, 701-710.
<https://doi.org/10.1038/s41583-018-0068-2>
- Chan, D., Shafto, M., Kievit, R., Matthews, F., Spink, M., Valenzuela, M., & Henson, R. N. (2018). Lifestyle activities in mid-life contribute to cognitive reserve in late-life, independent of education, occupation, and late-life activities. *Neurobiology of Aging*, *70*, 180–183. <https://doi.org/10.1016/j.neurobiolaging.2018.06.012>
- Chen, Y., & Caplan, J. (2016). Rhythmic Activity and Individual Variability in Recognition Memory: Theta Oscillations Correlate with Performance whereas Alpha Oscillations Correlate with ERPs. *Journal of Cognitive Neuroscience*, *29*, 183-202.
https://doi.org/10.1162/jocn_a_01033
- Craik, F. I. M., & Rose, N. S. (2012). Memory encoding and aging: A neurocognitive perspective. *Neuroscience and Biobehavioral Reviews*, *36*(7), 1729–1739.
<https://doi.org/10.1016/j.neubiorev.2011.11.007>

- Dan-Glauser, E. S., & Scherer, K. R. (2011). The Geneva affective picture database (GAPED): a new 730-picture database focusing on valence and normative significance. *Behavior Research Methods*, *43*(2), 468–477. <https://doi.org/10.3758/s13428-011-0064-1>
- De Fockert, J. W., Ramchurn, A., van Velzen, J., Bergström, Z. M., & Bunce, D. (2009). Behavioral and ERP evidence of greater distractor processing in old age. *Brain Research*, *1282*, 67–73. <https://doi.org/10.1016/j.brainres.2009.05.060>
- De Fockert, J. W., Rees, G., Frith, C. D., & Lavie, N. (2001). The Role of Working Memory in Visual Selective Attention. *Science*, *291*(5509), 1803–1806. <https://doi.org/10.1126/science.1056496>
- Delorme, A. and Makeig, S. (2004) EEGLAB: An Open Source Toolbox for Analysis of Single-Trial EEG Dynamics Including Independent Component Analysis. *Journal of Neuroscience Methods*, *134*, 9-21. <https://doi.org/10.1016/j.jneumeth.2003.10.009>
- Duarte, A., Ranganath, C., Trujillo, C., & Knight, R. T. (2006). Intact Recollection Memory in High-performing Older Adults: ERP and Behavioral Evidence. *Journal of Cognitive Neuroscience*, *18*(1), 33–47. <https://doi.org/10.1162/089892906775249988>
- Dulas, M. R., & Duarte, A. (2013). The influence of directed attention at encoding on source memory retrieval in the young and old: An ERP study. *Brain Research*, *1500*, 55-71. <https://doi.org/10.1016/j.brainres.2013.01.018>
- Dunlap, W. P., Cortina, J. M., Vaslow, J. B., & Burke, M. J. (1996). Meta-analysis of experiments with matched groups or repeated measures designs. *Psychological Methods*, *1*, 170–177. <http://dx.doi.org/10.1037/1082-989X.1.2.170>
- Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). “Mini-mental state”. A practical

- method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, 12(3), 189–198. [https://doi.org/10.1016/0022-3956\(75\)90026-6](https://doi.org/10.1016/0022-3956(75)90026-6)
- Fraundorf, S.H., Hourihan, K.L., Peters, R.A., & Benjamin, A.S. (2019). Aging and recognition memory: A meta-analysis. *Psychological bulletin*, 145, 339-371. <http://dx.doi.org/10.1037/bul0000185>
- Friedman, D. (2013). The Cognitive Aging of Episodic Memory: A View Based on the Event-Related Brain Potential. *Frontiers in Behavioral Neuroscience*, 7(August), 1–15. <https://doi.org/10.3389/fnbeh.2013.00111>
- Friedman, D., de Chastelaine, M., Nessler, D., & Malcolm, B. (2010). Changes in Familiarity and Recollection across the Lifespan: An ERP Perspective, *Brain Research*, 1310, 124–141. <https://doi.org/10.1016/j.brainres.2009.11.016>.
- Gruber, T., Tsvivilis, D., Giabbiconi, C.-M., & Müller, M. M. (2008). Induced electroencephalogram oscillations during source memory: familiarity is reflected in the gamma band, recollection in the theta band. *Journal of Cognitive Neuroscience*, 20(6), 1043–1053. <https://doi.org/10.1162/jocn.2008.20068>
- Guderian, S., & Düzel, E. (2005). Induced theta oscillations mediate large-scale synchrony with mediotemporal areas during recollection in humans. *Hippocampus*, 15(7), 901-912. <https://doi.org/10.1002/hipo.20125>
- Gutchess, A.H., Hebrank, A., Sutton, B.P., Leshikar, E., Chee, M.W., Tan, J.C., Goh, J.O., & Park, D.C. (2007). Contextual interference in recognition memory with age. *NeuroImage*, 35, 1338-1347. <https://doi.org/10.1016/j.neuroimage.2007.01.043>
- Hanslmayr, S., Staresina, B. P., & Bowman, H. (2016). Oscillations and Episodic Memory: Addressing the Synchronization/Desynchronization Conundrum. *Trends in*

Neurosciences, 39(1), 16–25. <https://doi.org/10.1016/j.tins.2015.11.004>

Hanslmayr, S., & Staudigl, T. (2014). How brain oscillations form memories - A processing based perspective on oscillatory subsequent memory effects. *NeuroImage*, 85, 648–655. <https://doi.org/10.1016/j.neuroimage.2013.05.121>

Hanslmayr, S., Staudigl, T., & Fellner, M.-C. (2012). Oscillatory power decreases and long-term memory: the information via desynchronization hypothesis. *Frontiers in Human Neuroscience*, 6(April), 1–12. <https://doi.org/10.3389/fnhum.2012.00074>

Hsieh, L. T., & Ranganath, C. (2014). Frontal midline theta oscillations during working memory maintenance and episodic encoding and retrieval. *NeuroImage*, 85, 721-729. <https://doi.org/10.1016/j.neuroimage.2013.08.003>

Jacobs, J., Hwang, G., Curran, T., & Kahana, M. J. (2006). EEG oscillations and recognition memory: Theta correlates of memory retrieval and decision making. *NeuroImage*, 32(2), 978–987. <https://doi.org/10.1016/j.neuroimage.2006.02.018>

James, T., Strunk, J., Arndt, J., & Duarte, A. (2016). Age-related deficits in selective attention during encoding increase demands on episodic reconstruction during context retrieval: An ERP study. *Neuropsychologia*, 86, 66–79. <https://doi.org/10.1016/j.neuropsychologia.2016.04.009>

Johansson, M., & Mecklinger, A., (2003). The late posterior negativity in ERP studies of episodic memory: action monitoring and retrieval of attribute conjunctions. *Biological Psychology*, 64, 91–117. [https://doi.org/10.1016/S0301-0511\(03\)00104-2](https://doi.org/10.1016/S0301-0511(03)00104-2)

Klimesch, W., Doppelmayr, M., Schwaiger, J., Winkler, T., & Gruber, W. (2000). Theta oscillations and the ERP old/new effect: Independent phenomena? *Clinical Neurophysiology*, 111(5), 781-793. [https://doi.org/10.1016/S1388-2457\(00\)00254-6](https://doi.org/10.1016/S1388-2457(00)00254-6)

- Klimesch, W., Doppelmayr, M., Yonelinas, A. P., Kroll, N. E. A., Lazzara, M., Röhms, D., & Gruber, W. (2001). Theta synchronization during episodic retrieval: Neural correlates of conscious awareness. *Cognitive Brain Research*, *12*(1), 33–38.
[https://doi.org/10.1016/S0926-6410\(01\)00024-6](https://doi.org/10.1016/S0926-6410(01)00024-6)
- Koen, J. D., & Yonelinas, A. P. (2016). Recollection, not familiarity, decreases in healthy ageing : Converging evidence from four estimation methods. *Memory*, *24*, 37–41.
<https://doi.org/10.1080/09658211.2014.985590>
- Krishnan, A., Williams, L. J., McIntosh, A. R., & Abdi, H. (2011). Partial Least Squares (PLS) methods for neuroimaging: A tutorial and review. *NeuroImage*, *56*(2), 455–475.
<https://doi.org/10.1016/j.neuroimage.2010.07.034>
- Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (2008). *International affective picture system (IAPS): Affective ratings of pictures and instruction manual*. Gainesville, FL: University of Florida, The Center for Research in Psychophysiology.
- Li, J., Morcom, A. M., & Rugg, M. D. (2004). The effects of age on the neural correlates of successful episodic retrieval: An ERP study. *Cognitive, Affective and Behavioral Neuroscience*, *4*(3), 279–293. <https://doi.org/10.3758/CABN.4.3.279>
- Lustig, C., & Jantz, T. (2015). Questions of age differences in interference control: When and how, not if? *Brain Research*, *1612*, 59-69.
<https://doi.org/10.1016/j.brainres.2014.10.024>
- McIntosh, A.R., & Lobaugh, N.J. (2004). Partial least squares analysis of neuroimaging data: applications and advances. *NeuroImage*, *23*, s250-s263.
<https://doi.org/10.1016/j.neuroimage.2004.07.020>
- Makeig, S., Debener, S., Onton, J., & Delorme, A. (2004). Mining event-related brain

- dynamics. *Trends in Cognitive Sciences*, 8, 204-210.
<https://doi.org/10.1016/j.tics.2004.03.008>
- Mandler, G. (1980). Recognizing: The judgment of previous occurrence. *Psychological Review*, 87(3), 252–271. <https://doi.org/10.1037/0033-295X.87.3.252>
- Mecklinger, A., Parra, M., & Waldhauser, G. T. (2009). ERP correlates of intentional forgetting. *Brain Research*, 1255, 132-47. <https://doi.org/10.1016/j.brainres.2008.11.073>
- Mecklinger, A., Rosburg, T., & Johansson, M. (2016). Reconstructing the past: The late posterior negativity (LPN) in episodic memory studies. *Neuroscience and Biobehavioral Reviews*, 68, 621–638. <https://doi.org/10.1016/j.neubiorev.2016.06.024>
- Morcom, A. M. (2016). Mind Over Memory. *Current Directions in Psychological Science*, 25(3), 143–150. <https://doi.org/10.1177/0963721416645536>
- Morcom, A. M., & Johnson, W. (2015). Neural Reorganization and Compensation in Aging. *Journal of Cognitive Neuroscience*, 27(7), 1275–1285.
https://doi.org/10.1162/jocn_a_00783
- Murphy, N. A., & Isaacowitz, D. M. (2008). Preferences for emotional information in older and younger adults: A meta-analysis of memory and attention tasks. *Psychology and Aging*, 23(2), 263-286. <http://dx.doi.org/10.1037/0882-7974.23.2.263>
- Nyberg, L., Lövdén, M., Riklund, K., Lindenberger, U., & Bäckman, L. (2012). Memory aging and brain maintenance. *Trends in Cognitive Sciences*, 16(5), 292–305.
<https://doi.org/10.1016/j.tics.2012.04.005>
- Nyberg, L., & Pudas, S. (2019). Successful Memory Aging. *Annual Review of Psychology*, 70, 219–243. <https://doi.org/10.1146/annurev-psych-010418>

- Nyhus, E., & Curran, T. (2010). Functional role of gamma and theta oscillations in episodic memory. *Neuroscience and biobehavioral reviews*, *34*(7), 1023–1035.
<https://doi.org/10.1016/j.neubiorev.2009.12.014>
- Paller, K. A., Voss, J. L., & Boehm, S. G. (2007). Validating neural correlates of familiarity. *Trends in Cognitive Sciences*, *11*(6), 243–250.
<https://doi.org/10.1016/j.tics.2007.04.002>
- Powell, P.S., Strunk, J., James, T., Polyn, S.M., & Duarte, A. (2018). Decoding selective attention to context memory: An aging study. *NeuroImage*, *181*, 95-107.
<https://doi.org/10.1016/j.neuroimage.2018.06.085>
- Rubin, D. C., & Berntsen, D. (2009). The frequency of voluntary and involuntary autobiographical memories across the life span. *Memory & Cognition*, *37*(5), 679–688.
<https://doi.org/10.3758/37.5.679>
- Rugg, M. D., & Curran, T. (2007). Event-related potentials and recognition memory. *Trends in Cognitive Sciences*, *11*(6), 251–257. <https://doi.org/10.1016/j.tics.2007.04.004>
- Saville, C. W. N., Dean, R. O., Daley, D., Intriligator, J., Boehm, S., Feige, B., & Klein, C. (2011). Electrocortical correlates of intra-subject variability in reaction times: Average and single-trial analyses. *Biological Psychology*, *87*(1), 74–83.
<https://doi.org/10.1016/j.biopsycho.2011.02.005>
- Scally, B., Burke, M.R., Bunce, D.M., & Delvenne, J. (2018). Resting-state EEG power and connectivity are associated with alpha peak frequency slowing in healthy aging. *Neurobiology of Aging*, *71*, 149-155.
<https://doi.org/10.1016/j.neurobiolaging.2018.07.004>
- Ste-Marie, D. M., & Jacoby, L. L. (1993). Spontaneous versus directed recognition: The

- relativity of automaticity. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 19(4), 777–788. <https://doi.org/10.1037/0278-7393.19.4.777>
- Strunk, J., James, T., Arndt, J., & Duarte, A. (2017). Age-related changes in neural oscillations supporting context memory retrieval. *Cortex*, 91, 40–55. <https://doi.org/10.1016/j.cortex.2017.01.020>
- Tallon-Baudry, C., & Bertrand, O. (1999). Oscillatory gamma activity in humans and its role in object representation. *Trends in Cognitive Sciences*, 3(4), 151-162. [https://doi.org/10.1016/S1364-6613\(99\)01299-1](https://doi.org/10.1016/S1364-6613(99)01299-1)
- Tran, T.T., Hoffner, N.C., LaHue, S.C., Tseng, L., & Voytek, B. (2016). Alpha phase dynamics predict age-related visual working memory decline. *NeuroImage*, 143, 196-203. <https://doi.org/10.1016/j.neuroimage.2016.08.052>
- Verhaeghen, P., (2011). Aging and executive control: reports of a demise greatly exaggerated. *Current Directions in Psychological Science*, 20(3), 174-180. <https://doi.org/10.1177/0963721411408772>
- Vogelsang, D. A., Gruber, M., Bergström, Z. M., Ranganath, C., & Simons, J. S. (2018). Alpha Oscillations During Incidental Encoding Predict Subsequent Memory For New “Foil” Information. *Journal of Cognitive Neuroscience*, 30, 667-679. https://doi.org/10.1162/jocn_a_01234
- Wais, P. E., & Gazzaley, A. (2014). Distractibility during retrieval of long-term memory: Domain-general interference, neural networks and increased susceptibility in normal aging. *Frontiers in Psychology*, 5. <https://doi.org/10.3389/fpsyg.2014.00280>
- Wang, T. H., de Chastelaine, M., Minton, B., & Rugg, M. D. (2012). Effects of Age on the Neural Correlates of Familiarity as Indexed by ERPs. *Journal of Cognitive*

Neuroscience, 24(5), 1055–1068. https://doi.org/10.1162/jocn_a_00129

Wegesin, D. J., Friedman, D., Varughese, N., & Stern, Y. (2002). Age-related changes in source memory retrieval: an ERP replication and extension. *Cognitive Brain Research*, 13(3), 323–338. [https://doi.org/10.1016/S0926-6410\(01\)00126-4](https://doi.org/10.1016/S0926-6410(01)00126-4)

West, R. (1996). An application of prefrontal cortex function theory to cognitive aging. *Psychological Bulletin*, 120(2), 272–292. <https://doi.org/10.1037/0033-2909.120.2.272>

Yonelinas, A. P., & Jacoby, L. L. (2012). The process-dissociation approach two decades later: Convergence, boundary conditions, and new directions. *Memory and Cognition*, 40(5), 663–680. <https://doi.org/10.3758/s13421-012-0205-5>