Characterising neural signatures of successful aging: Electrophysiological correlates of preserved episodic memory in older age

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ABSTRACT

While aging is associated with a gradual decline in memory, substantial preservation of function is observed in certain individuals and dissecting this heterogeneity is paramount to understanding successful aging. A cohort of elderly individuals were classified according to their level of memory preservation and administered a test of episodic memory in which participants were cued to learn or simply read each word and then to identify previously presented items in a delayed recognition phase. Mathematical modelling revealed that relatively preserved memory function was specifically linked to a faster rate of memorial evidence accumulation (drift rate). Analysis of event-related potentials at encoding revealed that high-performing elderly exhibited signals over parietal regions that discriminated between words to be learned vs. read for an additional 300-ms compared to young subjects suggesting a compensatory encoding mechanism that was absent in the low-performing group. At recognition, parietal signals associated with recollection processes discriminated previously learned words from read words in the young and high-performing old but not in low-performing old. These results reveal that successful aging is associated with specific adaptive neural markers during both encoding and retrieval.

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1. Introduction

There is large variability in the extent to which aging impacts on episodic memory (Christensen et al., 1994, 1999; Habib, Nyberg, & Nilsson, 2007) with some individuals showing progressive decline with advancing age and others showing preservation of this essential cognitive ability. Increasingly, evidence suggests that both encoding and retrieval mechanisms undergo functional change with age that can be adaptive as well as deleterious (Buckner, 2004; Luo & Craik, 2008).

The focus of research on inter-individual variability in cognitive aging has been the identification of markers that carry risk or are predictive of the onset of neurodegenerative disease and cognitive decline (Oh & Jagust, 2013; Stoub, Detoledo-Morrell, & Dickerson, 2014; Wilson, Leurgans, Boyle, Schneider, & Bennett, 2010). By contrast, there has been less emphasis on older adults who show little or no decline in the domain of episodic memory and are successfully maintaining long-term memory function in old age (although see Habib et al., 2007). This is somewhat surprising

given that episodic memory, compared to other forms of memory, exhibits, on average, the largest degree of age-related decline (Nyberg et al., 2003; Ronnlund, Nyberg, Backman, & Nilsson, 2005) and, therefore, investigating successful elderly may help better elucidate the protective factors that reduce decline or promote maintenance of brain function in old age (Nyberg, Lovden, Riklund, Lindenberger, & Backman, 2012).

Research dissecting the heterogeneity of older adults according to high and low cognitive performance has been valuable for examining associated neural mechanisms underlying variation in function (Daselaar, Veltman, Rombouts, Raaijmakers, & Jonker, 2003; De Sanctis, Gomez-Ramirez, Sehatpour, Wylie, & Foxe, 2009; Friedman, de Chastelaine, Nessler, & Malcolm, 2010; Wiegand et al., 2014; Wolk et al., 2009). Nevertheless, differentiating individual differences in performance, based on the same dependent variable that is used to measure this performance, increases the statistical risk of regression towards the mean when attempting to divide subtypes of elderly. An alternative approach is to use standardised neuropsychological testing to classify participants into high and low performers, and then analyse their performance on a different test that was not used for this classification (see Daffner et al., 2012; Daselaar & Cabeza, 2005) Another advantage of using standardised classification is it can provide a benchmark

for examining inter-individual variability in the elderly across different studies and cohorts and is therefore a generalisable approach. Moreover, standardised testing across multiple cogntive domains allows one to capture the specificity of variation in one domain (e.g. memory) while controlling for variation in another (e.g. executive function).

To this end, in the current study, older participants were assigned to a low-performing (LP) group if their Weschler Memory Scale (WMS) logical-memory score was greater than 1 standard deviation (s.d.) below their premorbid IQ score. Participants whose logical-memory scores did not exceed this threshold were assigned to the high-performing group (HP). We reason that the difference between two standardised measures, one, a relatively stable measure of premorbid IQ, and the other, a measure of delayed recall that is susceptible to change with age, provides a meaningful discrepancy from which to classify individual differences. All participants were administered a neuropsychological battery and a test of episodic memory during electroencephalographic (EEG) acquisition in which participants were cued to learn or simply read each word and then to identify earlier presented items in a delayed recognition test. Thus, participants' capacity to exercise controlled, effortful and self-initiated processing (Luo & Craik, 2008) was tested under conditions of intentional cuing (learn cue) in contrast to incidental cuing (read cue) where such self-initiated processing is not required.

The first aim of the study was to test the prediction that the HP elderly, compared to the LP older group, would show greater accuracy, as measured by the sensitivity index of d', and faster response times under conditions of intentional vs. incidental learning. We hypothesised that HP older adults would engage greater controlled, effortful processing under conditions of intentional learning compared to LP elderly. The second aim was to conduct a diffusion model analysis (Ratcliff, 1978; Voss, Rothermund, & Voss, 2004) to dissociate components of response time for learn and read words. In contrast to signal detection indices, such as d' that measures the outcome of the cogntive process, diffusion modelling captures how this process unfolds to the point of decision. The diffusion model is a sequential sampling model for two-choice response time tasks, and has previously been applied to recognition memory judgements (Ratcliff, Thapar, Gomez, & McKoon, 2004). Importantly, diffusion modelling enables a separation of non-decision processes such as stimulus encoding and motor execution from a decision parameter in the model that comprises the rate of accumulation of evidence for arriving at an 'old' decision. The mean rate of approach to a decision boundary in the model is described as the drift rate and this represents the quality of information from memory entering the decision process as decoupled from other non-decision parameters. We predict a systematic decline in the efficiently of evidence accumulation, as measured by the drift rate, across young, HP and LP elderly, particularly for previously learned information.

Event-related potentials (ERPs) were also examined to measure the neural underpinnings of inter-individual variation in both encoding and retrieval processes in response to cues for learning vs. reading. Analysis of ERPs was constrained by well-characterised components in tasks of episodic memory carried out in previous investigations of younger and older adults and we briefly review these below.

A prominent ERP component seen at encoding is a centro-parietal positivity that is larger in amplitude for words that are later recognised (Mangels, Picton, & Craik, 2001) or recalled (Paller, Kutas, & Mayes, 1987) compared to words that are subsequently forgotten. Friedman and colleagues have shown that this component is diminished in the elderly compared to younger adults when initial learning is incidental (Friedman, Ritter, & Snodgrass, 1996) but is intact when learning is intentional, i.e. where there is expectation of a later memory test (Friedman & Trott, 2000). In younger adults the centro-parietal positivity at encoding also differentiates later confidence reports of recall accuracy, with larger amplitude responses for subsequent 'remember' judgments compared to 'familiar' judgments. By contrast, the parietal modulation in older adults does not differentiate encode items on the basis of later subjective confidence. Friedman and colleagues argue that age-related impairments in the retrieval of contextual information may be explained, in part, by poor item-specific processing of distinctive information at encoding. Greater attentional orienting to item distinctiveness may underpin the expression of the parietal positivity during memory encoding (Mangels et al., 2001) and therefore it may share characteristics with the P3b, a similar parietal scalp effect, evoked during target detection tasks (Ford et al., 1994; Picton, 1992).

Age-related decline in episodic memory has also been associated with reduced frontal ERP activity at encoding, specifically over left inferior regions (Nessler, Johnson, Bersick, & Friedman, 2006). Nessler and colleagues also found that both young and old groups showed greater negativity over left inferior prefrontal scalp while performing a high-compared to a low-selection version of a semantic encoding task. However, frontal ERPs in the old group were less negative, attenuated over time and were associated with poorer subsequent recognition compare to the young group. Similarly, neuroimaging research has demonstrated that older adults show reduced activation compared to young adults in left inferior prefrontal regions indicative of less engagement of self-initiated and elaborative encoding processes during memorisation (Cabeza et al., 1997; Grady et al., 1995; Logan, Sanders, Snyder, Morris, & Buckner, 2002; Nyberg et al., 2010).

During word recognition, retrieval processes are characterised by ERP components associated with familiarity-based processing (frontal episodic memory effect) and recollection-based processing (parietal episodic memory effect) in younger adults (Rugg & Curran, 2007). Such effects are consistent with dual-process models of recognition (Mandler, 1980; Yonelinas, 2002) that dissociate the feeling that an item has been experienced before (familiarity) from a detailed explicit memory of the event (recollection). Research has explored individual differences by categorising elderly samples into high and low performers (Friedman et al., 2010; Wolk et al., 2009) and have found preservation in recollection-based processing associated with parietal effects in the high performers and young but the absence of this parietal modulation in older low performers.

The third aim of study was, therefore, to examine the neural signatures of memory processes during encoding and recognition. Specifically, we examined how an encoding cue (learn, read) modulates ERPs associated with the encoding and recognition phases of the task as a function of age-related inter-individual variability. In this regard we investigated how younger adults, HP and LP older adults differed across three stages of neural processing: (i) the early deployment of visual attention for to-be-learned information (N1 component); (ii) the timing of sustained neural activity during encoding (centro-parietal and left frontal components) and (iii) the efficiency of retrieval processes as modulated by earlier encoding instruction (frontal FN400 and late parietal components). To this end, we test the alternate hypotheses that high performing older adults are able to produce better memory performance either by retaining the same cognitive processes seen in their younger counterparts or by showing evidence of compensatory neural mechanisms.