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RESEARCH ARTICLE

Behavioural and electrophysiological effects of visual paired associate context manipulations during encoding and recognition in younger adults, older adults and older cognitively declined adults

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Abstract The current study examined the EEG of young, old and old declined adults performing a visual paired associate task. In order to examine the effects of encoding context and stimulus repetition, target pairs were presented on either detailed or white backgrounds and were repeatedly presented during both early and late phases of encoding. Results indicated an increase in P300 amplitude in the right parietal cortex from early to late stages of encoding in older declined adults, whereas both younger adults and older controls showed a reduction in P300 amplitude in this same area from early to late phase encoding. In the right hemisphere, stimuli encoded with a white background had larger P300 amplitudes than stimuli presented with a detailed background; however, in the left hemisphere, in the later stages of encoding, stimuli presented with a detailed background had larger amplitudes than stimuli presented with a white background. Behaviourally, there was better memory for congruent stimuli reinstated with a detailed background, but this finding was for older controls only. During recognition, there was a general trend for congruent stimuli to elicit a larger amplitude response than incongruent stimuli, suggesting a distinct effect of context reinstatement on underlying patterns of physiological responding. However, behavioural data suggest that older declined adults showed no memory benefits associated with context reinstatement. When compared with older declined adults, younger adults had larger P100 amplitude responses to stimuli presented during recognition, and overall, younger adults had faster recognition reaction times than older control and older declined adults. Further analysis of repetition effects and context-based hemispheric asymmetry may prove informative in identifying declining memory performance in the elderly, potentially before it becomes manifested behaviourally.

Keywords Memory · Ageing · EEG · ERP

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Introduction

Older adults appear to have more difficulty than young adults when it comes to placing remembered events into the appropriate context with respect to time and place (Craik and Jennings 1992; Friedman and Johnson 2000). The term context is quintessentially adopted to refer to spatial, temporal or cognitive information that is present in the environment and surrounds the memory task target but is irrelevant or at most incidental to the cognitive task being performed. The association between viewed items and the context in which they appear has been termed contextual binding (Mitchella et al. 2000). Prior research has established that contextual details are bound to item information (Chalfonte and Johnson 1996) and facilitate object identification (Biederman et al. 1982). Thus, it appears that context is an integral component of episodic memory. It is, however, more than just a component of such memory. It also seems to play a determining role in the dynamics of the episodic memory system as a whole. To the extent to which this is

the case, further study concerning how context is represented physiologically should greatly enhance our understanding of human memory and age-related cognitive decline.

The current study examined behavioural and electrophysiological effects of context during the encoding and recognition of visual paired associates (VPA) in a sample of younger adults, older adults and older declined adults (adults who performed 1 standard deviation (SD) below age- and education-matched peers on standardised tests of memory). While a number of electrophysiological studies have pointed to changes in frontal and parietal activations associated with memory decline in older adults (Gutchess et al. 2007; Lawson et al. 2007; Wolk et al. 2009), less is known about the brain changes that moderate contextual binding problems in older adults.

Contextual binding

Context information is a central component of episodic memory. Every episode we experience consists of two parts: a focal element and a setting (Tulving 1974). The focal element can be thought of as the part of the episode where attention is actively focused, whereas the setting is the environment, or the context, in which the focal element is experienced (Dougal and Rotello 1999). Contextual information is thought to act as a retrieval cue for the focal elements of a memory. Thus, focal memories are easier to retrieve to the extent that the context present during retrieval matches the context that was present when the event occurred (Tulving 1974; Tulving and Thomson 1973). This memory benefit is called context-dependent discrimination (Smith and Vela 1992; Dougal and Rotello 1999).

Brain researchers have argued that memory traces of an episode probably consist of those related to the content, those that represent event-specific contextual information, and binding codes linking several features of the content of the event with each other and with event-specific contextual information (Damasio 1989; Fujii et al. 1999, 2000, 2002; Kapur 1997). Howard et al. (2006) proposed that the hippocampus is responsible for binding items to the contexts in which they are presented, and evidence suggests that ageing affects hippocampal functions (Craik et al. 1990; Small et al. 1999).

Hippocampus and VPA

Brain lesion research has implicated the hippocampus in context processing (e.g. see Smith and Mizumori 2006; Rudy et al. 2004; Myers and Gluck 1994). One theory of hippocampal function holds that the hippocampus is involved in processing the background 'contextual' information present in any learning situation. Data from Smith and Mizumori (2006) indicate that hippocampal place fields and neuronal responses to task-relevant stimuli are highly sensitive to the context. Lesions of the hippocampus or entorhinal cortex (EC) render subjects insensitive to changes in the context (Penick and Solomon 1991; Freeman et al. 1997).

Smith and Mizumori (2006) note that although a growing body of data supports the context processing account of hippocampal function, impairment of episodic memory is also a well-documented consequence of hippocampal damage in humans (Vargha-Khadem et al. 1997; Tulving and Markowitsch 1998), and the effects of lesions in animals are consistent with this idea (Agster et al. 2002; Ergorul and Eichenbaum 2004). One possible explanation is that these episodic memory impairments are secondary to context processing deficits. The hippocampus appears to be vital for remembering the relations among objects in a scene and also for remembering relations among items that are arbitrarily paired (Hannula et al. 2006).

The current study examines behavioural and electrophysiological effects of context during encoding and recognition of VPA. Performance on the VPA task measures a form of declarative memory (Manns et al. 2000). The hippocampal region has been identified as central to our capacity for declarative memory (Eichenbaum 2000). According to the revised formulation of the declarative memory hypothesis, the hippocampus is needed for episodic memory but not for semantic memory (Tulving and Markowitsch 1998). The VPA task is dependent upon the hippocampus in that no discrimination between old and new stimuli is observed following hippocampal damage in humans (McKee and Squire 1993; Manns et al. 2000; Pascalis et al. 2004), and the monkey (Bachevalier et al. 1993; Pascalis and Bachevalier 1999). Additionally, in the rat, hippocampal lesions impair performance on an object-exploration task that is analogous to the VPA task (Clark et al. 2000).

Thus far, in vivo demonstrations of hippocampus activations during binding operations have used paradigms that required effortful encoding (Henke et al. 1997, 1999). However, behavioural data suggest that these processes operate without explicit intention (Luck and Vogel 1997; Cohen et al. 1999). The current study aims to identify behavioural and electrophysiological correlates of contextual binding without explicit instruction to bind items with contexts in an episodic visual paired associates task. While previous research has demonstrated this type of task to be hippocampally mediated, this study will examine the processing of context in general cortical areas.

Many ERP studies of recognition memory have been interpreted within dual-process frameworks that differentiate between familiarity and recollection (Brainerd et al.

1995; Hintzman and Curran 1994; Jacoby 1991). Though details differ between theories, familiarity is generally considered to reflect an assessment of the global similarity between study and test items (Hintzman 1988; Gillund and Shiffrin 1984), whereas recollection allows for the retrieval of detailed information concerning study items such as physical attributes or associative/contextual/source information. Within the context of such theories, studies indicate that an ERP old/new effect occurring between 400 and 800 ms is related to putative memory retrieval processes (Johnson 1995; Rugg 1995a, b). The earlier right frontal aspect of the ERP old/new effect (300–500 ms) may be related to unconscious familiarity, whereas the later left parietal aspect (400–800 ms) may be related to conscious recollection (see Friedman and Johnson 2000; Mecklinger 2000 for reviews; Düzel et al. 2001; Guillem et al. 2001; Nessler et al. 2001; Rugg et al. 1998a). The 300–500 ms familiarity-related effect has been termed the 'FN400 old/new effect' (Curran 1999, 2000) and is identifiable by a positive shift which is maximal over right frontal electrodes. Rugg et al. (1996) obtained direct evidence from positron emission tomography (PET) that the activity of the right prefrontal cortex varies in accordance with the probability of successful retrieval, thereby demonstrating that neural activity within this region is greater during the processing of 'old' as opposed to 'new' recognition memory test items. The 400–800 ms recollection-related ERP effect has been termed the 'parietal' old/new effect (Allan et al. 1998; Rugg et al. 1998a, b; Wilding and Rugg 1996, 1997) and is characterised by a positive shift in ERPs for correctly identified old recognition test items relative to new items. Thus, on the basis of functional neuroimaging (Cabeza et al. 1997) evidence, it is suggested that the frontal effect is sensitive to item retrieval (i.e. familiarity), whereas the parietal effect is sensitive to context retrieval (i.e. recollection).

Electrophysiological correlates of contextual binding

FMRI studies have offered evidence of hippocampal dysfunction associated with memory decline in the elderly (Small et al. 1999). However, less is known about the electrophysiological correlates of contextual binding in younger and older adults. A number of electrophysiological studies have pointed to changes in both frontal and parietal activations being associated with memory decline in older adults. Lawson et al. (2007) found that older adults had poorer working memory performance as well as a lower level of frontal scalp electrical activation in comparison with younger adults. Wolk et al. (2009) used EEG to examine age-related changes in item recognition memory, finding that early frontal area activity was markedly lower for the poorer-performing older group. Gutchess et al. (2007) compared young and old participants' abilities to recall a scene from memory, finding that recognition levels were unaffected by age, but that the older groups showed lower activations in frontal and parietal areas.

The current study

The current study used a 64-channel ERP array to investigate scalp waveform componentry associated with context encoding and recognition during a visual paired associate (VPA) learning task in 3 groups: younger adults, older adults and older declined adults. The unique aspect of this study involved the presentation of different contextual backgrounds with each pair. During the encoding phase, half of the VPA were presented with a rich contextual background (i.e. colourful landscape) and the other half were presented without a background (i.e. white background). Participants were given no explicit instructions to memorise these detailed backgrounds. Furthermore, stimuli that were the focus of learning were presented a number of times throughout the encoding phase. This allowed us to examine repetition effects for both context-rich and context-poor stimuli. In the recognition phase, pairs of images were presented to participants either with or without a rich contextual background and were presented either in 'congruous' or 'incongruous' form (i.e. with or without the original encoding context). The current study examined, first, whether or not there are different physiological responses to context-rich versus context-poor stimuli across the three groups. Second, whether or not those physiological differences between context-rich and context-poor stimuli alter as a result of stimulus repetition during encoding. Working on the assumption that younger adults encode more fully the context in which stimuli are presented, we hypothesised that, relative to older adults and older declined adults, younger adults would demonstrate a more significant ERP difference between context-rich and context-poor stimuli during encoding. We also explored the possibility that younger adults would show a more significant ERP difference as a result of repetition during encoding. During recognition, we hypothesised that younger adults would show more differential ERP activation to congruent versus incongruent context reinstatement, particularly in frontal and parietal regions. Finally, we hypothesised that, relative to younger adults and older adult controls, older declined adults would show the lowest levels of context discrimination during encoding and the lowest levels of differential frontal and parietal activation to congruent versus incongruent context reinstatement during recognition.

Table 1 Means and standard deviations (SD) for performance on neuropsychological assessment tasks for young, old, and old decline adults

	Young ($N = 19$)		Old ($N = 17$)		Old decline ($N = 15$)	
	Mean	SD	Mean	SD	Mean	SD
Education (years)	15.8	2.3	12.9	3.2	12.5	3.1
NART	19.0	6.9	18.8	10.4	19.1	8.0
Fluency	24.9	8.0	17.2	5.6	18.9	4.7
WRAT	47.1	3.7	45.4	6.5	45.3	6.8
Wechsler memory subscales (z-scores)						
Logical memory	1.11	0.9	1.16	0.83	0.18	1.28
Faces	0.98	2.13	0.90	0.98	−0.31	0.87
Visual reproduction	1.47	1.22	0.98	0.98	0.58	1.08

Methods

Participants

Twenty-one younger adults, 19 older adults and 19 older declined adults who performed 1 SD below age- and education-matched peers (mean age = 21.3, 73.6 and 71.9 years; education = 15.8, 12.9, 12.5 years, respectively) were recruited with informed consent. All participants had normal or corrected-to-normal vision. Older adults were recruited from the National University of Ireland, Galway, database of well elderly volunteers. Younger adults were students studying Psychology at the same institute. The study was approved by the NUI, Galway ethics committee and was carried out along the principles laid down in the Helsinki Declaration. All participants received a comprehensive medical and neuropsychological assessment (Swanwick et al. 1996; Hogan et al. 2003). Individuals were excluded if they were smokers or if they were taking medication with CNS-effects. Also excluded were left-handed people, those who did not speak English as a first language, and those with epilepsy, diabetes or a history of head injury, strokes or TIAs. Those with a history of depression but who were currently not affected were considered for inclusion, as were those who had thyroid problems or hypertension that had been stably controlled for 3 months or more. Neuropsychological screening tests included: the mini-mental state exam (MMSE; Folstein et al. 1975), a memory self-rating scale, the hospital anxiety depression scale (HADS; Zigmond and Snaith 1983), the national adult reading test (NART; Nelson 1982), a test of fluency (animal naming), the word reading subtest of the Wide Ranging Achievement Test (WRAT; Jastak and Jastak 1978), the Stroop task and three subscales of the Wechsler Memory Scale (WMS): Logical Memory, Faces and Visual Reproduction (Wechsler 1987). To allocate older adults into the 'normal' and 'declined' groups, scores on WMS subscales were used. Specifically, scores on these indices were compared to scores on the NART. Scores on the NART provide an estimation of premorbid IQ (Baltes and Lindenberger 1997). Older adults were placed in the 'control' group if their WMS memory score was not more than 1SD lower than their NART score; allocation to the 'declined' group was made if the memory score was 1SD or more below the NART score. This system of measurement allowed for the identification of those older adults whose memory function was in the early stages of decline relative to age- and education-matched peers.

The number of years in formal education was significantly longer in the younger group compared with the other two groups ($P < .01$; see Table 1 for means and standard deviations). There was no difference between the three groups on either the NART or WRAT tests of verbal ability. Younger adults scored higher than both older adult groups on the three subscales of the WMS ($P < .001$ for all six comparisons). Young adults had higher MMSE scores when compared with the older declined group ($P < .05$), but no other differences were observed. Older controls scored significantly higher than the older declined group on the logical memory subscale ($P < .01$; see Table 1).

EEG task

The task used for this study was a standard VPA task which was created using the E-Prime experimental presentation program. The VPA task had both an encoding and recognition phase. During the encoding phase, participants were presented with 12 pairs of abstract, non-verbalisable stimuli on screen for 3,500 ms, with an inter-stimulus interval of 750 ms consisting of a fixation cross. Six of the pairs were presented on a white background (no context) and six were presented on a detailed background (context; colourful landscape). Each pair of stimuli was presented six times, three times during the earlier stage of encoding and three times during the latter stage of encoding (early/late), yielding a total of 72 trials in the encoding phase. Participants

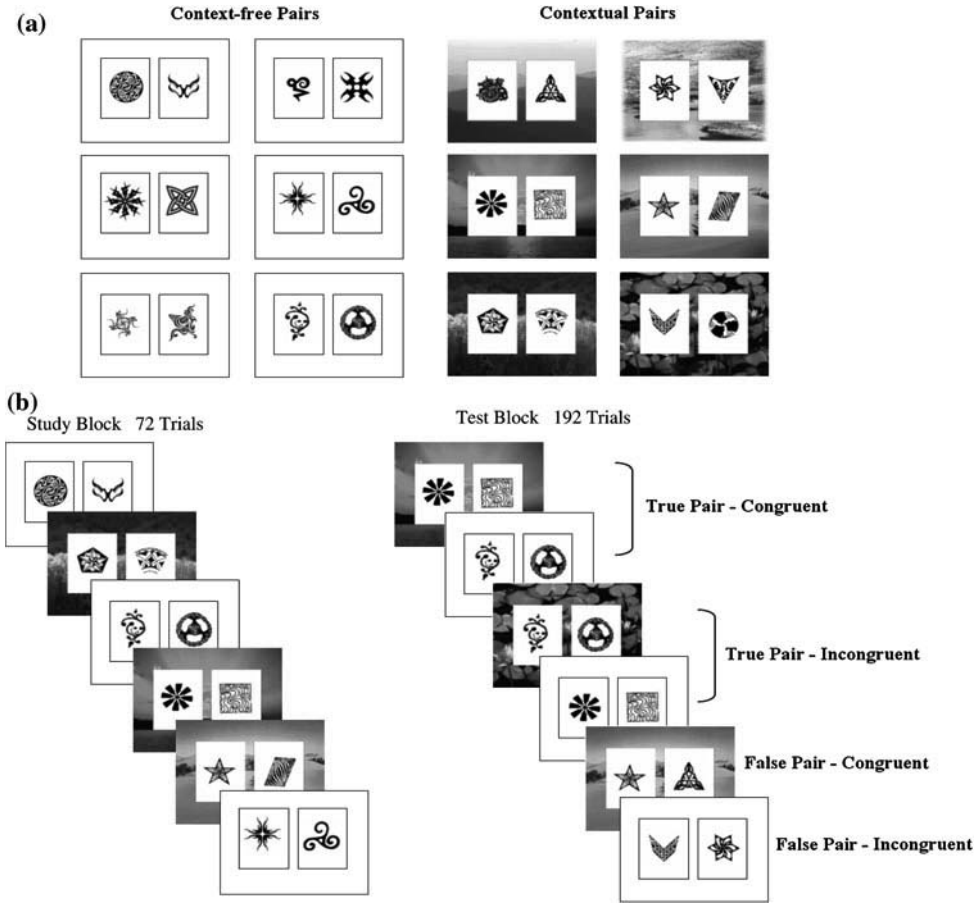

Fig. 1 **a** Contextual and context-free visual paired associate stimuli used in the study. **b** Stimulus presentation sequence in Study and Test Blocks (*Note* Fixation stimuli are omitted from this figure)

did not have to make any responses during the encoding phase. They were instructed to try to remember which stimuli formed pairs.

During the recognition phase, pairs of images were presented to participants (stimulus pairs remained on screen until a button-press response was made, up to a maximum of 3,500 ms) either with or without a contextual background. Test stimuli were again separated by a fixation cross, which was presented for 750 ms. Participants were asked to decide whether the images form a 'true' pair (i.e. a previously learned pair) or a 'false' pair (i.e. two images that were not previously matched). Pairs were either presented in front of a 'congruent' or 'incongruent' background; that is, the same background as in the test phase (detailed or blank/white) or the opposite background (white or detailed). This allowed us to examine effects of both contextual background (detailed/white) and congruence (congruent/incongruent) during recognition (see Fig. 1b). The side of presentation was counterbalanced, so either the right or left symbol of a pair could appear first. Either both elements of the pair were congruent with the background or neither were—there was never a situation where the left symbol was congruent with the background, but the right symbol was incongruent, or vice versa.

Correct responses and reaction times were recorded during the recognition phase of the task. A correct response was recorded if the participant pressed the left mouse button when an 'old' stimulus pair appeared and the right mouse button when a 'new' stimulus pair appeared. Pressing the opposite button than required or failure to respond resulted in an incorrect response. Reaction times were measured as the interval between presentation of the stimulus pair and the response and were recorded for both correct and incorrect trials. E-prime© logged accuracy and RT data for each participant and sent triggers to the EEG acquisition PC to allow stimulus presentations and responses to be logged in real time on the continuous EEG recording.

EEG recordings

The EEG activity was recorded with silver/silver-chloride (Na/NaCl) electrodes (BrainVision©) mounted in an elastic cap fastened with a chin strap (Easy-Cap©). EEG data were collected from 64 scalp sites, with Cz and AFz acting as reference electrodes, using the extended version of the International 10–20 system for electrode placement. Vertical and horizontal eye movements were recorded using

electro-oculography (EOG). VEOG was recorded from electrodes located above and below the left eye, and HEOG was recorded from electrodes positioned at the outer canthus of each eye. Blinks were averaged offline, and a blink reduction algorithm was applied to the data. This algorithm involved automatic artefact correction (Berg and Scherg 1991; Ille et al. 2002). The impedance level was kept to below 10 kΩ in all cases. EEG activity was amplified using a band pass of 0.16–100 Hz and a gain of 1,000. The conversion rate was 2,000 Hz per channel, and the range was 150 mV. The amplifier used was supplied by BrainVision©. After electrophysiological preparation, participants were seated approximately 50 cm from an LCD computer screen on their own in a darkened, electrically shielded and sound attenuated testing cubicle, measuring 200 cm × 300 cm with access to a mouse for responses.

Procedure

Medical/neuropsychological and electrophysiological/information processing assessments took place on two separate days. On first arriving in the testing room, participants completed the paper and pencil and memory tests. During the second session, participants were prepared for the EEG tasks and provided with an opportunity to practice using the computer interface prior to the task. Participants were debriefed after the experiment.

Electrophysiological data analysis

Large artefacts were rejected by visual inspection and data were filtered in the frequency range 0.5–30 Hz. The prestimulus window of 200 ms was used as a baseline for baseline correction. Data were epoched for an interval of −200 to 800 ms for the encoding block. While participants had a behavioural response window of 3,500 ms, an interval of −200 to 1,000 ms was epoched for the recognition block as this study focused on P100 and P300 ERP components. Average ERPs were then calculated for each condition. BESA was used to compute overall grand-mean waveform at each of the electrodes by collapsing across the conditional ERPs. From this, the mean amplitude (MA) of the components of interest could be investigated by visual inspection using BESA. From visual inspection, the time-window for each of the components of interest (P100 & P300) in each of the ERPs was determined. Following visual inspection of the ERPs and topographical maps, electrodes closest to the area of maximal amplitude (for positive components) were selected for inclusion in the inferential statistics. These sites are representative of the centre of activity seen in the topographical maps generated. MA in the components of interest was extracted for statistical analysis.

Statistical analysis strategy

A 2 (context: detailed background, white background) × 2 (time: early, late) × 3 (group: young, old, old declined) ANOVA was conducted to examine MA differences across groups and conditions during encoding. A 2 (context) × 2 (congruence: congruent, incongruent) × 3 (group) ANOVA was conducted to examine behavioural (recognition memory) and electrophysiological (MA) differences across group and conditions during recognition. Recognition memory performance on the VPA task was calculated as the percentage of hits minus false alarms.

Results

Recognition memory

There was a main effect of group, $F(2, 50) = 15.41$, $P < .001$, with significant differences found between the young and old group, ($P < .001$) and between the young and old declined group ($P < .001$; M young = 68.7, SD = 21.5; M old controls = 33, SD = 21.6, M old declined = 36.5, SD = 20.1). Although there was no significant difference in overall performance between the older control group and the older declined group, post hoc analyses revealed one important effect. Specifically, older declined adults showed no memory benefits associated with context reinstatement, whereas compared with memory to congruent stimuli reinstated with a white background, older controls showed significantly better memory to congruent stimuli reinstated with a detailed background ($P < .05$; see Fig. 2). Data on hit rates and false alarms can be found in Table 2.

Recognition reaction time

There was a main effect of group, $F(2, 50) = 28.65$, $P < .001$, with younger adults ($M = 1109.23$, SD = 254.65) significantly faster and older adults ($M = 1700.77$, SD = 318.68) and older declined adults ($M = 1641.71$, SD = 389.22; $P < .001$ for both comparisons). No significant differences were observed between old and old declined groups.

Encoding ERPs

Posterior P100 components

The MA for P1 was recorded within a time-window of 70–140 ms. Visual inspection of the waveforms for the encoding phase indicated maximal P100 componentry at bilateral occipito-parietal electrodes PO7 and PO8. For P07, there

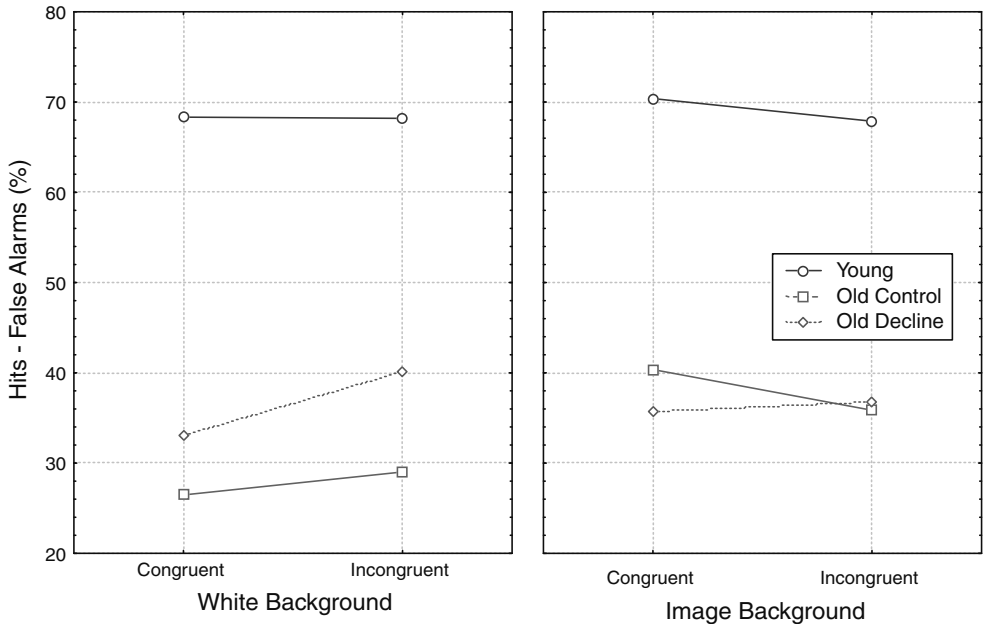

Fig. 2 Recognition memory performance in younger, older and older declined adults

Table 2 Hit rate and false alarm rate for congruent and incongruent pairs on white and detailed backgrounds for young, old and old declined adults

	Young		Old		Old decline	
	Mean	SD	Mean	SD	Mean	SD
Hit rate for congruent, white-background pairs	84.7	16.3	74.5	13.9	72.3	19.9
False alarm for congruent, white-background pairs	15.6	12.8	46.8	21.1	44.2	19.7
Hit rate for congruent, detailed-background pair	81.6	15.7	74.2	12.9	69.5	17.5
False alarms for congruent, detailed-background pair	9.7	6.8	33.3	18.8	38.9	19.7
Hit rate for incongruent pairs (white -> detailed)	84.1	15.6	73.3	15.2	75.2	17.3
False alarms for incongruent pairs (white -> detailed)	14.1	13.0	43.3	17.4	39.1	19.2
Hit rate for incongruent pairs (detailed -> white)	81/6	14.2	73.8	10.7	68.3	19.1
False alarm for incongruent pairs (detailed -> white)	11.4	10.9	39.0	21.5	37.8	19.0

was a main effect of group, $F(2,56) = 5.86$, $P < 0.01$, with younger adults ($M \pm \text{SE} = 3.63 \pm 0.35$) having greater positivity when compared with both older controls ($M \pm \text{SE} = 2.08 \pm 0.36$) and older declined participants ($M \pm \text{SE} = 2.18 \pm 0.38$; see Fig. 3). There was also a main effect of context at PO7, $F(1,56) = 8.26$, $P < 0.01$, with stimulus pairs presented with a detailed background ($M \pm \text{SE} = 2.93 \pm 0.24$) showing greater activation than stimulus pairs presented with a white-background pairs ($M \pm \text{SE} = 2.33 \pm 0.22$; see Fig. 4). There was Time × Context interaction effect at PO7, $F(1,56) = 9.50$, $P < 0.01$, with no difference between white-background ($M \pm \text{SE} = 2.46 \pm 0.32$) and detailed-background ($M \pm \text{SE} = 2.46 \pm 0.30$) stimuli in the early stages of encoding, but with larger MA for detailed-background stimuli ($M \pm \text{SE} = 3.40 \pm 0.25$) relative to white-background stimuli ($M \pm \text{SE} = 2.20 \pm 0.25$) in the latter stages of encoding.

For PO8, there was a main effect of group, $F(2,56) = 5.97$, $P < 0.01$), with younger adults ($M \pm \text{SE} = 4.12 \pm 0.38$) showing larger MA than both control older adults ($M \pm \text{SE} = 2.73 \pm 0.39$) and declined older adults ($M \pm \text{SE} = 2.31 \pm 0.41$). There was also a main effect of context at PO8, $F(1,56) = 4.60$, $P < 0.05$, with stimulus pairs presented with a detailed background ($M \pm \text{SE} = 3.26 \pm 0.28$) showing greater activation than stimulus pairs presented with a white background ($M \pm \text{SE} = 2.85 \pm 0.20$).

Posterior P300 component

The MA for P3 was recorded within a time-window of 280–500 ms. Visual inspection of the waveforms for the encoding phase indicated maximal P300 componentry at parietal electrodes PO4, PO7 and PO8 beginning pre-300 ms and lasting the duration of the epoch. For PO4,

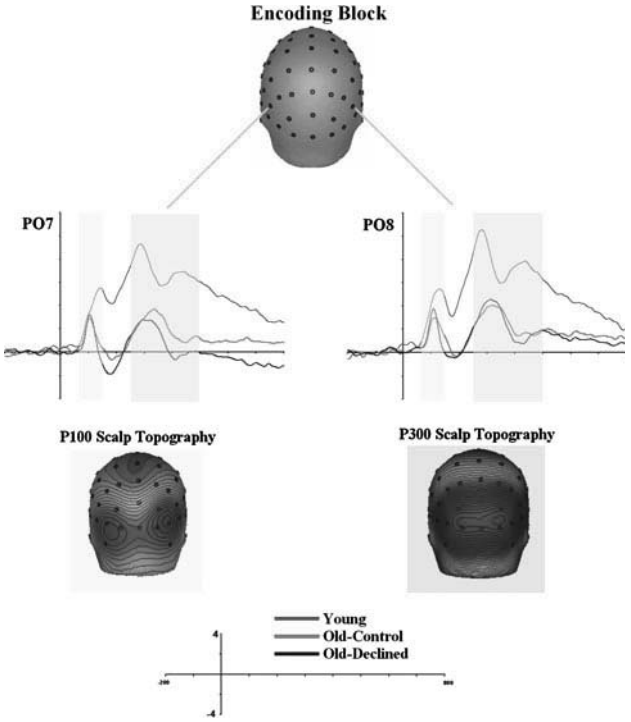

Fig. 3 Encoding block: P100 and P300 peak head maps and ERPs of significant electrodes PO7 & PO8. The head maps show activation across the 3 groups (young adults, older controls and older declined adults)

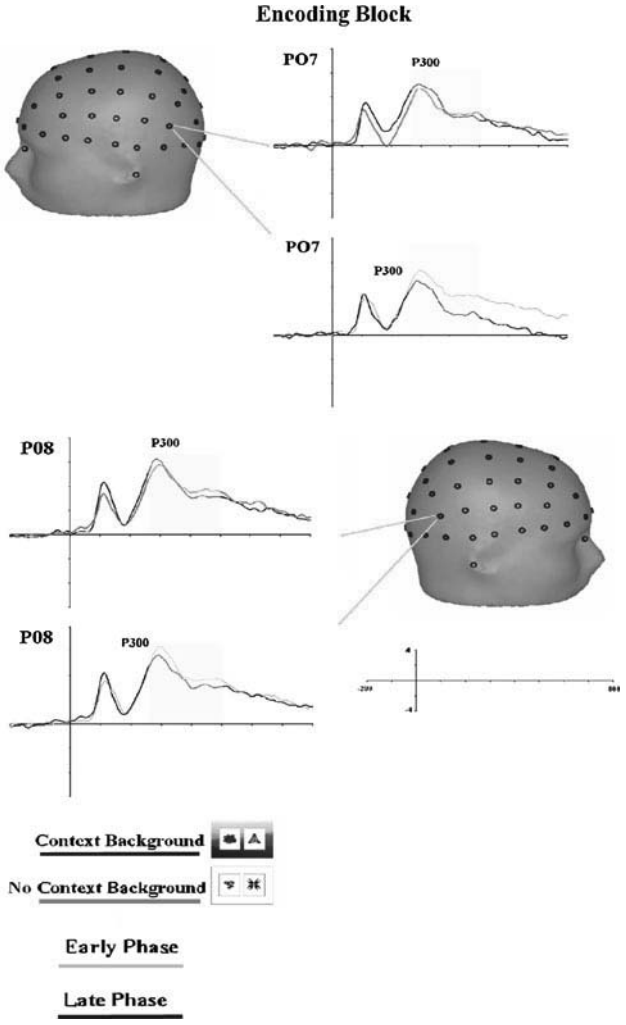

Fig. 4 Encoding block: P300 head maps and ERPs of context/no context and early/late comparisons for electrodes PO7 & PO8

there was a main effect of group, $F(2,56) = 4.16$, $P < 0.05$, with younger adults ($M \pm SE = 6.92 \pm 0.77$) showing greater activation than both older controls ($M \pm SE = 4.00 \pm 0.79$) and older declined ($M \pm SE = 4.35 \pm 0.83$). There was a Group $\times$ Time interaction effect, $F(2,56) = 3.89$, $P < 0.05$, with both younger adults and older controls showing a reduction in activation from early to late phase encoding ($M \pm SE = 8.06 \pm 0.94$–5.78 ± 0.92; and 4.60 ± 0.96–3.39 ± 0.95, respectively), whereas older declined participants showed an increase in activation from early ($M \pm SE = 3.40 \pm 1.02$) to late ($M \pm SE = 5.29 \pm 1.00$) phase encoding.

For PO7, there was a main effect of group ($F(2,56) = 10.07$, $P < 0.001$), with younger adults ($M \pm SE = 7.25 \pm 0.90$) showing greater positivity than both older controls ($M \pm SE = 2.81 \pm 0.92$) and older declined groups ($M \pm SE = 1.75 \pm 0.97$; see Fig. 3). There was a main effect of Time ($F(1,56) = 8.56$, $P < 0.01$), with greater activation in the early phase of encoding ($M \pm SE = 4.38 \pm 0.61$) when compared to late phase encoding ($M \pm SE = 3.50 \pm 0.50$; see Fig. 4). There was also a Time $\times$ Context interaction effect at PO7, $F(1,56) = 12.19$, $P < 0.01$: pairs with a white background ($M \pm SE = 4.71 \pm 0.64$) showed greater positivity than pairs with detailed background ($M \pm SE = 4.05 \pm 0.64$) in the early stages of encoding; pairs with a detailed background ($M \pm SE = 4.17 \pm 0.56$) showed greater activation than pairs with a white background ($M \pm SD = 2.83 \pm 0.57$) in latter stages of encoding.

PO8 showed a main effect of group ($F(2,56) = 6.00$, $P < 0.01$), with younger adults ($M \pm SE = 6.57 \pm 0.78$) showing larger MA than both older controls ($M \pm SE = 3.74 \pm 0.80$) and older declined groups ($M \pm SE = 2.83 \pm 0.84$; see Fig. 3). There was also a main effect of Time ($F(1,56) = 10.96$, $P < 0.01$), with greater positivity in the early ($M \pm SE = 5.00 \pm 0.55$) when compared to the later ($M \pm SE = 3.77 \pm 0.45$) stages of encoding. There was also a main effect of context at PO8, $F(1,56) = 8.50$, $P < 0.01$, with stimulus pairs presented with a white background ($M \pm SE = 4.95 \pm 0.50$) showing greater activation than stimulus pairs presented with a detailed-background pairs ($M \pm SE = 3.82 \pm 0.51$).

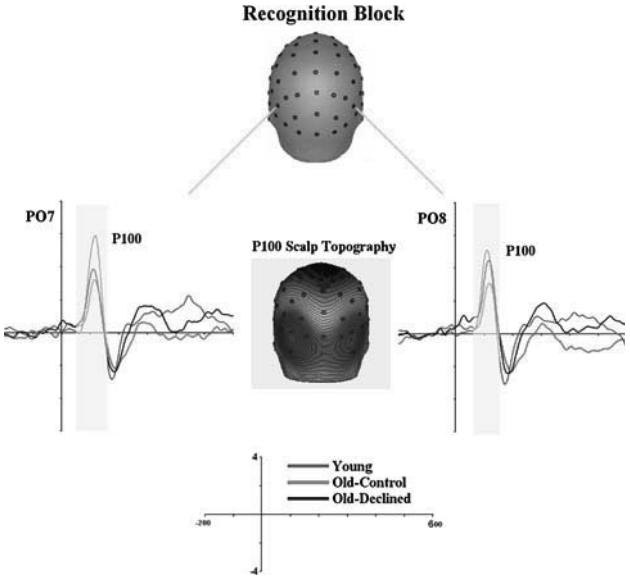

Fig. 5 Recognition block: P100 head maps and ERPs of significant electrodes PO7 & PO8

Recognition ERPs

Posterior P100 components

MA for P1 was recorded within a time-window from 70 to 140 ms. Visual inspection of the waveforms for the recognition phase revealed a maximal P100 at electrodes PO7 and PO8. For P07, there was a main effect of group, $F(2,54) = 4.30$, $P < 0.05$, with younger adults ($M \pm SE = 3.73 \pm 0.36$) having greater positivity when compared with both older controls ($M \pm SE = 2.24 \pm 0.37$) and older declined participants ($M \pm SE = 3.20 \pm 0.38$; see Fig. 5). There was a main effect of congruence, $F(1,54) = 8.57$, $P < 0.01$, with congruent stimuli ($M \pm SE = 3.31 \pm 0.26$) showing greater positivity than incongruent stimuli ($M \pm SE = 2.81 \pm 0.20$). There was a significant Context × Congruence interaction effect, $F(1,54) = 6.50$, $P < 0.05$; for white-background stimuli, congruent pairs ($M \pm SE = 3.41 \pm 0.24$) showed larger P100 amplitudes than did incongruent pairs ($M \pm SE = 2.54 \pm 0.18$). However, for detailed-background stimuli, incongruent pairs ($M \pm SE = 3.21 \pm 0.32$) showed greater positive deflections than did congruent pairs ($M \pm SE = 3.07 \pm 0.28$).

Analysis at electrode PO8 revealed a main effect of congruence, $F(1,54) = 8.93$, $P < 0.01$, with congruent stimuli ($M \pm SE = 3.63 \pm 0.25$) showing greater positivity than incongruent stimuli ($M \pm SE = 2.99 \pm 0.26$). There was a significant Context × Congruence interaction effect, $F(1,54) = 19.25$, $P < 0.001$, with congruent, white-background pairs ($M \pm SE = 3.95 \pm 0.28$) showing larger P100 amplitude than incongruent, white-background pairs ($M \pm SE = 2.65 \pm 0.28$). However, for detailed-background stimuli, there was no difference between incongruent ($M \pm SE = 3.31 \pm 0.29$) and congruent pairs ($M \pm SE = 3.30 \pm 0.29$). There was also a significant Context × Congruence × Group interaction effect, $F(2,54) = 6.25$, $P < 0.01$. For young adults: white-background, congruent pairs had larger P100 amplitudes ($M \pm SE = 4.67 \pm 0.47$) than did incongruent pairs ($M \pm SE = 30.2 \pm 0.47$). However, for detailed-background, incongruent pairs showed greater positive deflections ($M \pm SE = 3.82 \pm 0.48$) than did congruent pairs ($M \pm SE = 3.58 \pm 0.48$). In the older controls sample, white-background, congruent pairs ($M \pm SE = 2.92 \pm 0.49$) also showed larger P100 amplitudes than did incongruent pairs ($M \pm SE = 2.59 \pm 0.49$), but in this case detailed-background, congruent pair deflections ($M \pm SE = 2.93 \pm 0.48$) were larger than for incongruent pairs ($M \pm SE = 2.43 \pm 0.50$). Old declined showed a similar pattern to young adults: white-background, congruent pairs ($M \pm SE = 4.25 \pm 0.50$) had larger P100 amplitudes than did incongruent pairs ($M \pm SE = 2.35 \pm 0.50$); detailed-background, incongruent pairs ($M \pm SE = 3.75 \pm 0.52$) showed greater positive deflections than did congruent pairs ($M \pm SE = 3.41 \pm 0.51$).

P300 component

The P300 MA was taken for the duration of 300–500 ms. Visual inspection of the waveforms for the recognition phase revealed a P300 component at occipital-parietal electrodes P07 and P08. ANOVA revealed a significant Context × Congruence interaction effect at PO7 ($F(1,54) = 18.15$, $P < 0.001$). MA for white-background, congruent pairs ($M \pm SE = 1.02 \pm 0.35$) was greater than for white-background, incongruent pairs ($M \pm SE = -0.02 \pm 0.34$), whereas detailed-background, incongruent pairs ($M \pm SE = 0.76 \pm 0.32$) elicited greater positive deflections than did detailed-background, congruent pairs ($M \pm SE = 0.12 \pm 0.33$).

There was also a significant Context × Congruence interaction effect at PO8 ($F(1,54) = 31.04$, $P < 0.001$). MA for white-background, congruent pairs ($M \pm SE = 1.71 \pm 0.47$) was greater than for white-background, incongruent pairs ($M \pm SE = 0.41 \pm 0.51$), whereas detailed-background, incongruent pairs ($M \pm SE = 1.47 \pm 0.52$) elicited greater positive deflections than did detailed-background, congruent pairs ($M \pm SE = 0.46 \pm 0.48$). There was also a significant Context × Congruence × Group interaction effect for P08, $F(2,54) = 6.63$, $P < 0.01$. For younger adults, white-background, congruent pairs ($M \pm SE = 2.20 \pm 0.78$) had larger P300 amplitudes than did incongruent pairs ($M \pm SE = 0.85 \pm 0.85$); however, detailed-background, incongruent pairs ($M \pm SE = 1.95 \pm 0.87$) had larger P300 than did

congruent pairs ($M \pm SE = 0.57 \pm 0.80$). For older controls, white-background, congruent pairs ($M \pm SE = 0.49 \pm 0.81$) had larger P300 amplitudes than did incongruent pairs ($M \pm SE = 0.14 \pm 0.88$); detailed-background, congruent pairs ($M \pm SE = 0.24 \pm 0.82$) showed greater positive deflections than did incongruent pairs ($M \pm SE = 0.18 \pm 0.90$). Older declined adults showed a similar pattern to younger adults: for white-background, congruent pairs ($M \pm SE = 2.47 \pm 0.83$) showed larger P300 amplitudes than did incongruent pairs ($M \pm SE = 0.24 \pm 0.90$); detailed-background, incongruent pairs ($M \pm SE = 2.30 \pm 0.92$) showed greater positive deflections than did congruent pairs ($M \pm SE = 0.55 \pm 0.85$).

Discussion

The current study examined behavioural and electrophysiological effects of context during encoding and recognition of VPA in younger adults, older adults and older declined adults. Consistent with our expectations, the young adult group performed better than both old and old declined groups on the VPA task. Younger adults' recognition memory performance was significantly higher regardless of encoding context (detailed vs. white background) and regardless of whether or not encoding context was reinstated during the recognition phase. Although the two older adult groups differed significantly on the Wechsler Logical Memory Scale, they did not differ significantly on overall memory performance in the VPA task. However, while older declined adults showed no memory benefits associated with context reinstatement, older controls showed significantly better memory to congruent stimuli reinstated with a rich background.

We used ERP analysis to explore physiological differences between the three groups in response to manipulations of encoding context (detailed vs. white background) and stimulus repetition during encoding. We observed differential responses to stimulus repetition across the three groups during encoding. Specifically, while older declined adults showed an increase in P300 amplitude in the right parietal cortex (P04) from early to late stages of encoding, both younger adults and older controls showed a reduction in P300 amplitude in this same area from early to late phase encoding. One possible interpretation of these effects is that younger and older adults were habituating to stimulus properties over time, whereas older declined adults were increasingly invested in encoding stimulus properties over time.

A well-established phenomenon in electrophysiological studies of recognition memory is that presentation of 'old' (i.e. repeated) items tends to elicit more positive-going ERPs than does presentation of new or unrepeated items (reviewed in Johnson 1995; see also Rugg 1995a, b; Rugg and Allan 2000). Such 'old/new effects' typically onset around 300–400 ms post-stimulus, last for between 300 and 600 ms and—when words are used as stimuli—are generally of greatest magnitude at left parietal and adjacent centro-parietal electrodes. However, such effects are observed in the test phase of a study–test-type paradigm, and as such, the data reported here are more comparable to standard habituation paradigms wherein event-related responses to stimulus repetition over time (usually within-block) are evaluated. Considered to be a basic element of the orienting response (Sokolov 1963), amplitude reductions as a function of stimulus repetition—using a variety of different stimulus types—have been shown for early components such as the P1 (with emotional stimuli; see Carretié et al. 2003, 2004), the N1, P2 and N2 (using auditory stimuli; e.g. Sambeth et al. 2004, and abstract visual shapes; e.g. Bruin et al. 2000) and later waveforms including the P3 (e.g. Bruin et al. 2000; see also Kok 2000 for a review of repetition effects on P3 components); such effects have also been observed in rats as well as humans (Sambeth et al. 2004). In the light of these habituation effects, it appears that the older declined adults in this sample displayed evidence of a dysfunctional habituation system whereby stimuli that were repeatedly presented within a block were simply not identified as familiar. This deficit may be functionally related to the older declined adults' inability to benefit from the reinstatement of contextual information in the test block of the task.

Notably, this differential effect of stimulus repetition in the older declined group was unique to the P04 electrode, as results for the P07 and P08 revealed a significant reduction in P300 amplitude with stimulus repetition, but no interaction effect. At the same time, younger adults had larger amplitude activation in parietal areas (PO7, PO8) than both older controls and older declined adults for both early (P100) and later (P300) ERP components. Also, at these same electrode sites, stimuli presented with a detailed background had larger P100 amplitudes than stimuli presented on a white background, which suggests early stage elaborative processing of context-rich stimuli (Naveh-Benjamin 1987, 1988). However, P300 responses to stimuli presented with detailed or white backgrounds were more complex. Specifically, in the right hemisphere (P08), stimuli presented with a white background had larger P300 amplitudes than stimuli presented with a detailed background; however, in the left hemisphere (P07), stimuli presented with a white background had larger P300 amplitudes than stimuli presented with a detailed background only during the early stages of encoding—in the later stages of encoding, stimuli presented with a detailed background had larger amplitudes than stimuli presented with a white background.

This observed hemispheric asymmetry across parietal scalp may mirror the well-established local/global—left/right dissociation which has been consistently reported in relation to parietal attentional function (see Delis et al. 1986; Robertson et al. 1998; Malinowski et al. 2002: Fink et al. 1996; Heinze et al. 1998 for examples); it is well established that the left parietal region appears specialised for the processing of local features of visual stimuli, while the right parietal cortex is involved in global feature processing. Attending to local details often involves the inhibition or filtering out of distracting, global features; as such, in the contextually rich stimuli in the current task, attending to the stimulus pair in the foreground may have involved left parietal, 'local' processes in order to suppress the detailed-background information, yielding the larger P300 over left parietal scalp. Similarly, for the context-free, white-background stimulus pairs, no inhibition was necessary, allowing the entire screen to be processed globally, possibly recruiting right parietal processes to do so, resulting in enlarged P300 over PO8 and nearby electrodes. While speculative, this explanation would appear to explain the reported data in the context of an established anatomical phenomenon.

During recognition, there was a general trend for congruent stimuli to elicit a larger amplitude response than incongruent stimuli, suggesting a distinct effect of context reinstatement on underlying patterns of physiological responding. However, these effects of context reinstatement were largely accounted for by a difference between congruent and incongruent stimuli presented on a white background during recognition. The one exception to this rule was the pattern of effects observed on the older controls, where congruent stimuli elicited higher amplitude responses for both white-background and detailed-background stimuli. While these results distinguish older controls from older declined, they do not distinguish younger adults from older declined adults. However, younger adults did differ from older declined adults in another important way: they had larger P100 amplitude responses to stimuli presented during recognition, which may reflect better early stage recognition of stimuli as either 'old' or 'new' and as either congruent or incongruent, and this in turn may explain their overall better memory performance (Fig. 6).

In conclusion, the manipulation of context during a visual paired associates task revealed behavioural and electrophysiological differences between young, normal healthy older and older declined participants. Although overall accuracy on the task did not differ between the two older groups, older declined adults appeared less capable of benefiting from the reinstatement of context than were the other groups. Furthermore, analysis of the elicited event-related potentials revealed phenomena—habituation/repetition effects, context-based hemispheric asymmetry—which may prove informative in identifying declining memory performance in the elderly, potentially before they become manifested behaviourally.

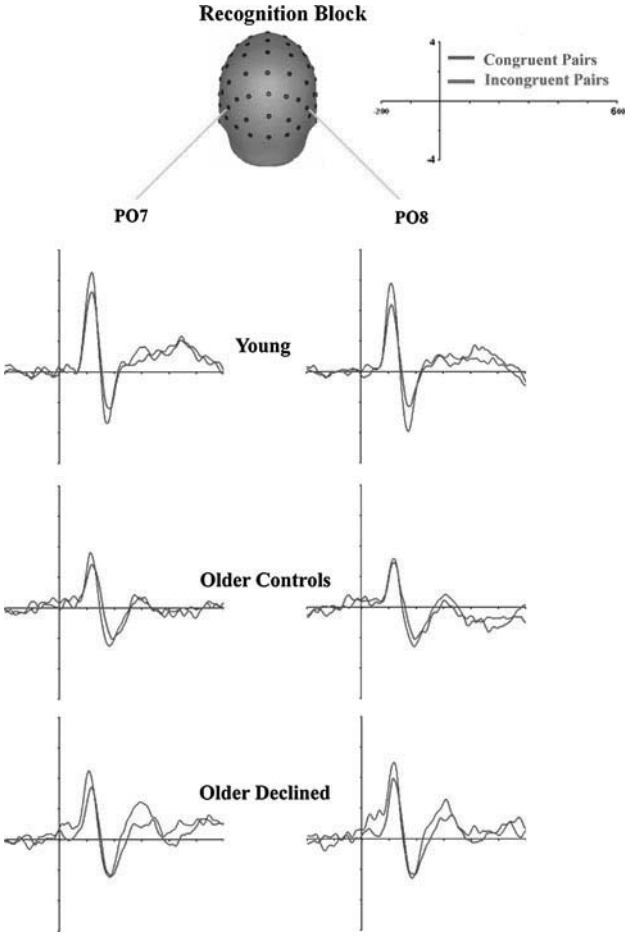

Fig. 6 Recognition block: P100 and P300 for congruent and non-congruent pairs for younger, older controls and older declined adults

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