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False memory and aging: an event-related potential study

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Abstract

The DRM paradigm is used to examine false memory—when a list of highly associated words (e.g. SEWING, THREAD, THIMBLE) is studied, a nonpresented but associated false target (e.g. NEEDLE) is often confidently (but incorrectly) identified as having been studied. An ERP study was conducted with a sample of young and older adults to examine age differences in false memory and neurological distinctions between true and false recognition. DRM words were presented in a lateralized fashion, with the prediction that a contralateral sensory signature would be present for true but not false memories. ERP data was largely inconclusive, but does suggest that processing during the DRM paradigm may largely be carried out in the left hemisphere.

False memory and aging: an event-related potential study

False memories occur when individuals believe they remember events that did not actually take place. The Deese-Roediger-McDermott (DRM) paradigm is a common laboratory technique used to elicit false memories, and it entails presenting participants with a list of study words that are associatively related to a nonpresented critical target. For example, the words THREAD, PIN, SEWING, SHARP, POINT, and PRICK are all related to the critical target NEEDLE. When participants are tested on their recognition of words from these study lists, they often incorrectly recognize the nonpresented false target word (NEEDLE) as having been on the study list (Roediger & McDermott, 1995). Participants also report being equally confident when making true and false recognition judgments, making it difficult to differentiate between the two cases from a behavioral standpoint (Lampinen, Neuschatz, & Payne, 1998; Payne, Elie, Blackwell, & Neuschatz, 1996; Roediger & McDermott, 1995).

Consequently researchers have searched for neurological indices to help discriminate between true and false memories. Previous neurological research of the DRM paradigm has had mixed results, often finding more similarities than differences between the two (for a review see Gallo, 2006). The neurological differences that were found generally related to manipulations of sensory information during the time of encoding. For true memories, sensory information available during the processing of an event is reactivated during the retrieval of that event; this activation is known as a sensory signature. Therefore, no sensory information should be reactivated during the retrieval of false memories since false memories do not involve actual events.

Schacter et al. (1996) conducted the first neuroimaging study of the DRM task; they used positron emission tomography (PET) to analyze auditorily presented words in a blocked design, that is test trials consisted of words all in the same experimental condition. They found that true recognition elicited more activity than false recognition in the auditory cortex, suggesting the presence of a sensory signature for auditory information encoded during time of study. However, these differences were not replicable in a subsequent event-related functional magnetic resonance imaging (fMRI) study using randomized word presentation (Schacter, Buckner, Koutstaal, Dale, & Rosen, 1997). Nonetheless, a later fMRI study by Slotnick and Schacter (2004) using abstract visual shapes as stimuli found greater activity in the early visual processing regions for true compared to false recognition. This difference was not found in later visual processing areas, which further suggests that the early visual regions may be sensitive to sensory differences that can differentiate between true and false information.

One problem with these studies is that sensory signatures may only be seen in transient brain activity, which may not be visible with the slower hemodynamic response measures of PET and fMRI. Event-related potential (ERP) has a much greater temporal resolution, making it a more ideal method for measuring transient brain activity, like sensory signatures. In ERP studies, lateralization of visual study stimuli has been shown to be an effective manipulation of sensory information at time of processing to illicit sensory signatures. Due to the contralateral organization of the human visual system, stimuli viewed to the left of a central fixation point (in the left visual field) are received and processed exclusively by the right hemisphere of the brain; conversely, stimuli viewed in the right visual field are received by the left hemisphere (Evans & Federmeier, 2007).

The result of such manipulation during study is the presence of a contralateral sensory signature during retrieval (Gratton, Corballis, & Jain, 1997). That is, if a study item is presented in the right visual hemifield, the left hemisphere of the brain shows greater activity during a recognition task compared to a control condition in which the words are not presented in a lateralized fashion. Fabiani, Stadler and Wessels (2000) applied this technique to the DRM paradigm and found contralateral sensory signatures at electrode sites T5 and T6 for true recognition of study words that had been presented in this lateralized fashion. As expected, no sensory signatures were present in the case of false recognitions, even though there was a robust false memory effect. This suggests that true but not false memories generate sensory signatures in lateralized brain activity.

Previous research with false memory paradigms has largely focused on younger adults, and there is little research examining the brain indices of true and false memories in an older adult sample. In general, older adults show a general decline in memory abilities, however it is not certain if this is attributed to problems encoding or problems retrieving information (Salthouse, 2003). Along with general memory declines, older adults have also shown to be much more susceptible to the false memory effect than younger adults (Kensinger & Schacter, 1999; Norman & Schacter, 1997). This suggests that older adults might show less of a sensory signature for true memories, which would lead to a retrieval deficit for properly encoded words, or a larger (false) sensory signature for false memories, would lead to retrieval of incorrect words.

An experiment similar to that of Fabiani et al. (2000) was conducted in which ERPs were measured while participants were presented lateralized DRM lists. A sample of older adults was included to study the effects of aging on the presence of sensory signatures during a false recognition task. As in Fabiani et al. (2000) we expect the signature to emerge at around 500-600 m-sec after stimulus onset, and this effect is measured most reliably at temporal sites T7 (left hemisphere) and T8 (right hemisphere). For words studied to the right, it was expected that activity in electrode T7 would be greater than for words studied to the left (a contralateral sensory signature). For words studied to the left, it was expected that activity in electrode T8 would be greater than for words studied to the right. For associated words not studied (false targets), no sensory signatures should be evident. If lateralized brain activity is found for true memories and not false memories with an older adult sample, it will show further indication that true memories may leave a sensory signature which makes each memory trace distinctive.

Method

Participants

Participants were 10 young adults (4 females, age range 18-22 years, M = 19.1) and 9 older adults (2 females, age range 60-71 years, M = 65.9). Young adults were recruited from the Georgia Institute of Technology through Experimetrix and compensated with class credit for their participation; older adults were recruited from the metro-Atlanta area and compensated $25 for their participation. All participants had normal or corrected-to-normal vision and gave informed consent before participating.

Design

The experiment was set up as a within subject design, with each participant completing all conditions. In the study phase there were two stimuli conditions: presentation in the left visual hemifield and presentation in the right visual hemifield. In the test phase, there were three test stimuli: true targets (i.e. words that were present in the study phase), false targets (i.e. the nonpresented lures associated with the study words), and controls (words from unstudied lists and their accompanying false targets). The dependent variables measured were key response (“old” or “new”), response latency and event-related potentials during the time of test.

Materials

As in Fabiani et al. (2000), the study and test stimuli were the 36, 15-word associative lists taken from Stadler et al. (1999).The lists were sorted by associative strength (Appendix) according to Stadler's norms so that lists that reliably produce false memory effects were considered to have a greater associative strength. To ensure a robust false memory effect, the 24 lists with the greatest associative strength were chosen as the study stimuli; the remaining 12 lists were used as control stimuli during the test phase. The 36 lists were split between six different study-test blocks so that each study phase contained the words from four of the highly associated lists (60 words total), and each test phase contained 24 words total: twelve previously studied words as true targets (3 taken from each list), their accompanying lures as false targets and eight words taken from two control lists (3 words from each list and their accompanying lures).

Procedure

Upon entering the lab, participants completed a demographics questionnaire and two standard cognitive tests: Shipley's vocabulary test and the symbol-digit modalities test (SDMT). After completion of these paper and pencil tasks, participants were then hooked to the EEG machine. To record EEG, a modified swimming cap with 32 small plastic connectors was placed on the participant's head. The plastic connectors were then filled with a conductive gel before the electrodes were connected to the cap. The gel was necessary to obtain an accurate EEG recording through the hair. In addition to the cap, six small electrodes were positioned on the face, around the temples and forehead as well as behind the ears. These additional electrodes on the face monitored any blinks or eye movements made by the participant, and the mastoid electrodes were averaged off-line to be used as reference.

While hooked to the EEG, participants then completed the computer portion of the experiment which consisted of two alternating parts: a study phase and a test phase. During each study phase, all 15 words from four associative lists were presented in random order for 250m-sec with an interstimulus interval (ISI) of 1,500 m-sec. Words were presented in random order to either the left or right side of a central fixation cross with the contingency that words from the same associative list were always displayed on the same side of the screen (Figure 1). Participants were instructed to fixate on the central cross, and a 250-msec stimulus duration was chosen to help further prevent participants from performing saccadic eye movements toward the laterally presented stimulus. There were six study blocks in total (four lists in each block), and the participants were tested on their recognition of the study words directly following each study block.

During the test phase, participants were presented with 24 words in random order for 250-msec with a 2,000-msec response-stimulus interval (RSI) between words. Twelve of the words were true targets (three words taken from each of the study lists), four words were false targets, six were true target controls, and two were false target controls (Figure 2). Words were presented in the center of the screen underneath a central fixation cross, and participants were asked to indicate if the word was "old" (present in the study phase) or "new" (not present in the study phase) by pressing the corresponding computer keys.

ERP Recording and Analysis

To examine hemispheric activation during memory retrieval, ERPs were recorded during the test phase of the experiment. ERPs were recorded using a BioSemi system with a 32+8 electrode configuration. The data was digitized at an on-line sampling rate of 512Hz, with a decimation rate of ¼, and was filtered on-line using a bandpass of .16-100Hz. The left and right mastoids were averaged off-line and used as reference electrodes. Vertical eye movements and blinks were monitored via electrodes placed above and below the left eye. Horizontal eye movements were monitored via electrodes placed on the temples

ERP data recorded at test was averaged separately for each participant and experimental condition. Due to jumps in the waveforms between blocks, each participant's data had to be split by block to be analyzed. To correct for drift within the block, waveforms were detrended using a third order polynomial function; an off-line band-pass filter of .01-70 Hz was also applied. Blinks and other vertical eye movements were corrected before averaging according to the electro-oculogram correction method of Gratton, Coles and Donchin (1983).

Trials were averaged by both study condition (lateralization left or right) and test condition (true target, false target, and controls), so that there were five experimental conditions total: true targets studied left/right, false targets from lists presented left/right, and controls. Each trial epoch started 200 m-sec before stimulus presentation and lasted 1,200 m-sec.

To examine lateralization effects, the contralateral-control method created by Gratton (1998) was used to isolate brain activity that systematically occurred in the left or right hemisphere. Lateralized waveforms were computed in a two-step procedure. First, the ERPs recorded at homologous electrode sites over the left and right hemisphere (electrodes T7 and T8 respectively) were subtracted from each other so that activity from the electrode ipsilateral to the condition was subtracted from activity recorded at the contralateral site (i.e., for true targets studied right, T8 activity (right hemisphere) was subtracted from T7 activity (left hemisphere)). This subtraction eliminates any activity that occurs symmetrically in both hemispheres. Next these lateralized waveforms for the left and right test conditions were averaged together to eliminate any activity that was independent of the experimental manipulation (Gratton, 1998).

The result of this process is a composite lateralization waveform for both hemispheres that was predicted to show greater activity for true targets compared to false targets.

Results

Accuracy

The data from one young adult was excluded from behavioral analysis because the participant informed the experimenter that he recognized the false memory paradigm. The main behavioral hypothesis predicted a robust false memory effect for young and older adults, with older adults showing greater susceptibility. The false memory effect was examined in several ways. First the percentage of “old” responses to false targets and controls (false alarm rates for both conditions) was compared (Figure 3). The false alarm rate for false targets was significantly greater than that for controls for both younger, $t(8) = 9.95$, $p < .001$, and older adults, $t(8) = 12.62$, $p < .001$. This shows a false memory effect in that both younger and older adults responded incorrectly significantly more for false targets compared to the controls.

Next, the percentage of “old” responses to true targets (hits) and false targets (false alarms) was compared (Figure 3). For younger adults, the difference between these two conditions was significant, $t(8) =2.87$, $p < .05$, with participants responding “old” greater for true targets than false targets; for older adults, this difference was not significant, $t(8) < 1$. This shows that behaviorally, older adults were responding “old” at the same rate for true and false targets whereas younger adults showed a significant difference between “old” responses for these two conditions. However, a 2 x 2 ANOVA did not find an age effect for either true targets $F(1,16) < 1$, or true targets, $F(1,16) = 1.56$.

Finally, a false memory variable was created to determine if the proportion of false target false alarms to true targets hits varied by age group; false memory was calculated as “old” responses to false targets over “old” response to true targets and then t-tested against a value of one. This proportion was greater for older adults (.96) compared to younger adults (.83); however, there was not a significant age effect for this false memory variable, $F(1, 16) < 1$. Overall, these accuracy results show that a memory effect was present for both younger and older adults, with older adults showing a slightly (but not significantly) greater susceptibility to false recognition than young adults.

Response Latency

Response latency was also examined by test condition and age group with a 2 x 3 ANOVA. Overall, older adults showed a greater response latency than younger adults, but this difference was not significant, $F(1, 16) = 3.83$. Within each age group, there were no significant differences between conditions; younger adults exhibited fairly stable response latency across conditions, while older adults showed a slightly greater response latency for false targets (Figure 4). A 2 x 3 ANOVA of age group by condition found a significant difference for response latency for false targets, $F(1,16) = 6.48$, $p < .05$, with older adults responding slower than young adults. Unlike Fabiani et al. (2000), no difference in response latency was found between words that had been studied to the left compared with words that had been studied to the right.

To further examine this age effect for response latency, a post hoc analysis was completed that included the results of the symbol-digit modalities test (SDMT) as another variable to consider to account for age differences. As expected, a univariate ANOVA found an effect of age for SDMT, with older adults performing significantly lower than young adults, $F(1, 16) = 13.3$, $p < .005$. Regarding response latencies, a Pearson’s correlation found that for younger adults the SDMT correlated negatively with response latency for true targets, $r(7) = -.72$, $p < .05$, and false targets, $r(7) = -.84$, $p < .005$. This negative correlation is to be expected since the SDMT measures processing speed and a higher score (higher processing speed) should correspond with lower response latencies. Surprisingly, for older adults, all the correlations between the SDMT and response latencies were positive, and the positive correlation for false target response latency was significant, $r(7) = .73$, $p < .05$. However, when plotted it becomes clear that this positive correlation is due to two older adults who responded very slowly, yet had high SDMT scores (Figure 5). Since sample size is small for each group, it is difficult to draw conclusions from this finding.

ERP analysis

The main ERP hypothesis concerned the occurrence of lateralized sensory signatures for true but not false targets. Lateralization was measured using the contralateral-control method, as described in the Method section. As in Fabiani et al. (2000), it was predicted that a lateralization effects would emerge around 500-600 m-sec after stimulus onset. For true targets studied to the right, it was expected that activity in electrode T7 (left hemisphere) would be greater than for words studied to the left. For true targets studied to the left, it was expected that activity in electrode T8 (left hemisphere) would be greater than for words studied to the right. For false targets, no lateralization should be evident, and therefore no differences between words studied right and left were predicted.

Data from several young and older participants had to be rejected due to high noise levels; this data analyzed includes a sample of seven young adults and five older adults. Due to the constraints of the DRM paradigm, there were a limited number of trials for each condition; for each participant there was a maximum total of 36 true targets left, 36 true targets right, 12 false targets associated left, and 12 false targets associated right that could be averaged. Because of these small numbers in each condition, it was imperative to average as many trials as possible and to have a low trial rejection rate.

First, grand averages were calculated for individual participants for each test condition (true targets studied left/right, false targets associated left/right, and controls). Each trial epoch started 200 m-sec before stimulus presentation and lasted 1,200 m-sec. When averaging, a trial rejection magnitude limit of -6e5 to 6e-5Hz was applied to all scalp electrode channels to ensure noisy trials were not included in the grand average. Finally the averaged waveform was detrended using a zero order polynomial fit. Due to noise in the data, there was a high rejection rate, so the rejection limits were decreased to -6e8 to 6e-8 to increase the number trials included in the average.

When the contralateral-control method was applied, no clear lateralization effect was seen for either younger or older adults; there is no differentiation between the true and false target waveforms (Figure 6). When examined by electrode, younger adults appear to show difference in ERPs for the lateralization study condition—words studied in the right visual field are more positive going than ERPs associated with words studied in the left visual field (Figure 7);. For electrode T8 (right hemisphere) no such difference can be seen between words studied right and words studied left. This hints at some hemispheric differences in processing the stimuli of this task.

For younger adults, when comparing true versus false targets in the same hemisphere the waveforms appear quite similar—for electrode T7, the ERP for true targets presented right and false targets associated right are similar, and likewise for those studied and associated left (Figure 7). This suggests that in the left hemisphere, there was a similar pattern of processing for true and false targets from the same visual field. For older adults, lateralization effects are not clear when examined by electrode (Figure 8), and this may be due to the smaller sample size and higher rejection rate with this age group.

Discussion

Though no significant age differences were found for false memory effect, older adults exhibited a slightly greater susceptibility to false recognition, which supports prior research (Kensinger & Schacter, 1999; Norman & Schacter, 1997). When looking at response latency it is interesting to note that older adults did not perform significantly slower than younger adults for true targets and controls, even though they showed significant differences in speed when comparing the symbol-digit modalities task.

The only condition with significant age differences in response latency was false targets, which suggests that when confronted with these lures, older adults are slowed by some additional cognitive processing. Balota et al. (1999) propose that false memories in the DRM paradigm may partly result from an automatic spread of activation from studied words to the nonpresented but strongly associated false targets. Avoiding false memories requires distractor suppression—a participant must be able to differentiate between these highly activated but nonpresent words (distracters) and the actual words from the study list. In our study, older adults appear to be showing greater effects of distractor suppression which thereby increases response latency.

ERP analysis reveals two findings for younger adults: first, for electrode T7 (left hemisphere), ERPs for true targets studied right and false targets associated right are more positive than those studied and associated with the left visual field; second, this distinction between words from the left visual field versus words from the right visual field was not present for electrode T8 (right hemisphere). This suggests some hemispheric differences in processing of the word lists during the task.

It is well established that the left hemisphere is favored in the processing of verbal material; however it is an oversimplification to assume that verbal memory is housed solely in the left hemisphere. Recent research suggests that the hemispheres may differ in the sort of information that each extracts from verbal stimuli. The left hemisphere has been implicated in encoding verbal stimuli in a more abstract manner by focusing more on semantic similarities between words. The right hemisphere, on the other hand, may employ more holistic encoding by focusing on stimulus-specific information (e.g., font, letter capitalizations) (Evans & Federmeier, 2007). In the current experiment with lateralized DRM lists, the false memory effect relies on the semantic similarity between the words. Given this, the semantic processing underlying the DRM effect may be carried out predominately by the left hemisphere, and therefore may be more readily elicited for words presented in the right visual field; this may account for the hemispheric differences seen in the data of the current study. Previous research with false recognition in split-brain patients has found that the right hemisphere is better able to reject false targets (Metcalfe, Funnell, & Gazzaniga, 1995), further supporting this argument.

Future Direction

To get clearer lateralization effects in the ERP data, more trials per participant need to averaged. To increase the number of trials averaged per participant, a new analysis would get grand averages only from electrodes T7 and T8, since those are the electrodes of primary concern. In the current analysis, grand averages from all scalp electrodes were calculated, meaning that the rejection limits took all electrodes into account when discarding trials outside the limits; for example, if activity at a central electrode was outside the limits, the trial would be rejected from averaging, even if activity was within the limit for T7 and T8. By eliminating the other electrodes from averaging, fewer trials should be rejected because noise from other electrodes will be taken into account when rejection is conducted. Due to time limitations, a second analysis of the ERP data could not be conducted for this paper, but one will be conducted over the course of the next few weeks.

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Appendix

DRM word lists sorted by associative strength (high to low) according to Stadler et al. (1999)

1 WINDOW: door, glass, pane, shade, ledge, sill, house, open, curtain, frame, view, breeze, sash, screen, shutter
2 SLEEP: bed, rest, awake, tired, dream, wake, snooze, blanket, doze, slumber, snore, nap, peace, yawn, drowsy
3 SMELL: nose, breathe, sniff, aroma, hear, see, nostril, whiff, scent, reek, stench, fragrance, perfume, salts, rose
4 DOCTOR: nurse, sick, lawyer, medicine, health, hospital, dentist, physician, ill, patient, office, stethoscope, surgeon, clinic, cure
5 SWEET: sour, candy, sugar, bitter, good, taste, tooth, nice, honey, soda, chocolate, heart, cake, tart, pie
6 CHAIR: table, sit, legs, seat, couch, desk, recliner, sofa, wood, cushion, swivel, stool, sitting, rocking, bench
7 SMOKE: cigarette, puff, blaze, billows, pollution, ashes, cigarette, chimney, fire, tobacco, stink, pipe, lungs, flames, stain
8 ROUGH: smooth, bumpy, road, tough, sandpaper, jagged, ready, coarse, uneven, riders, rugged, sand, boards, ground, gravel
9 NEEDLE: thread, pin, eye, sewing, sharp, point, prick, thimble, haystack, thorn, hurt, injection, syringe, cloth, knitting
10 ANGER: mad, fear, hate, rage, temper, fury, ire, wrath, happy, flight, hatred, mean, calm, emotion, enrage
11 TRASH: garbage, waste, can, refuse, sewage, bag, junk, rubbish, sweep, scraps, pile, dump, landfill, debris, litter
12 SOFT: hard, light, pillow, plush, loud, cotton, fur, touch, fluffy, feather, furry, downy, kitten, skin, tender
13 CITY: town, crowded, state, capital, streets, subway, country, New York, village, metropolis, big, Chicago, suburb, county, urban
14 CUP: mug, saucer, tea, measuring, coaster, lid, handle, coffee, straw, goblet, soup, stein, drink, plastic, sip
15 COLD: hot, snow, warm, winter, ice, wet, frigid, chilly, heat, weather, freeze, air, shiver, Arctic, frost
16 MOUNTAIN: hill, valley, climb, summit, top, molehill, peak, plain, glacier, goat, bike, climber, range, steep, ski
17 SLOW: fast, lethargic, stop, listless, snail, cautious, delay, traffic, turtle, hesitant, speed, quick, sluggish, wait, molasses
18 RIVER: water, stream, lake, Mississippi, boat, tide, swim, flow, run, barge, creek, brook, fish, bridge, winding
19 SPIDER: web, insect, bug, fright, fly, arachnid, crawl, tarantula, poison, bite, creepy, animal, ugly, feelers, small
20 FOOT: shoe, hand, toe, kick, sandals, soccer, yard, walk, ankle, arm, boot, inch, sock, knee, mouth
21 PEN: pencil, write, fountain, leak, quill, felt, Bic, scribble, crayon, Cross, tip, marker, red, cap, letter
22 CAR: truck, bus, train, automobile, vehicle, drive, jeep, Ford, race, keys, garage, highway, sedan, van, taxi
23 MUSIC: note, sound, piano, sing, radio, band, melody, horn, concert, instrument, symphony, jazz, orchestra, art, rhythm
24 BLACK: white, dark, cat, charred, night, funeral, color, grief, blue, death, ink, bottom, coal, brown, gray
25 RUBBER: elastic, bounce, gloves, tire, ball, eraser, springy, foam, galoshes, soles, latex, glue, flexible, resilient, stretch
26 GIRL: boy, dolls, female, young, dress, pretty, hair, niece, dance, beautiful, cute, date, aunt, daughter, sister
27 BREAD: butter, food, eat, sandwich, rye, jam, milk, flour, jelly, dough, crust, slice, wine, loaf, toast
28 FLAG: banner, American, symbol, stars, anthem, stripes, pole, wave, raised, national, checkered, emblem, sign, freedom, pendant
29 SHIRT: blouse, sleeves, pants, tie, button, shorts, iron, polo, collar, vest, pocket, jersey, belt, linen, cuff
30 HIGH: low, clouds, up, tall, tower, jump, above, building, noon, cliff, sky, over, airplane, dive, elevate
31 ARMY: Navy, soldier, United States, rifle, Air Force, draft, military, Marines, march, infantry, captain, war, uniform, pilot, combat
32 MAN: woman, husband, uncle, lady, mouse, male, father, strong, friend, bear, person, handsome, muscle, suit, old
33 THIEF: steal, robber, crook, burglar, money, cop, bad, robber, jail, gun, villain, crime, bank, bandit, criminal
34 LION: tiger, circus, jungle, tamer, den, cub, Africa, mane, cage, feline, roar, fierce, bears, hunt, pride
35 FRUIT: apple, vegetable, orange, kiwi, citrus, ripe, pear, banana, berry, cherry, basket, juice, salad, bowl, cocktail
36 KING: queen, England, crown, prince, George, dictator, palace, throne, chess, rule, subjects, monarch, royal, leader, reign

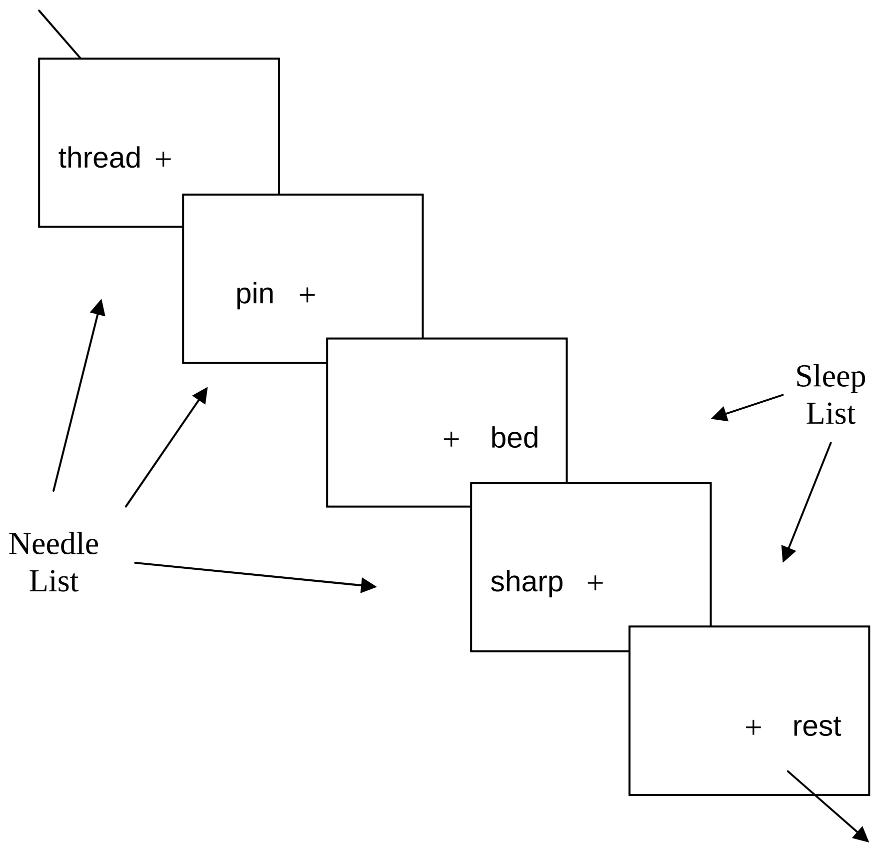


Figure 1. Schematic representation of study phase. Stimulus duration was equal to 250 m-se, and ISI was equal to 1,500 m-sec.

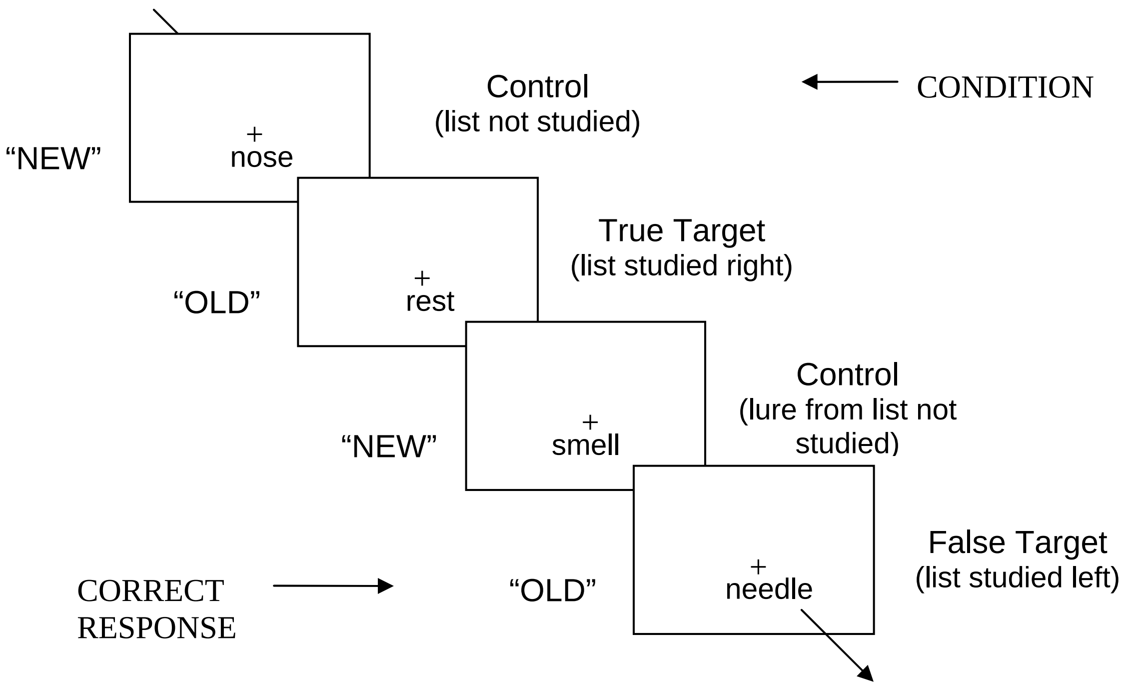


Figure 2. Schematic representation of test phase. Stimulus duration was equal to 250 m-se, and RSI was equal to 2,000 m-sec.

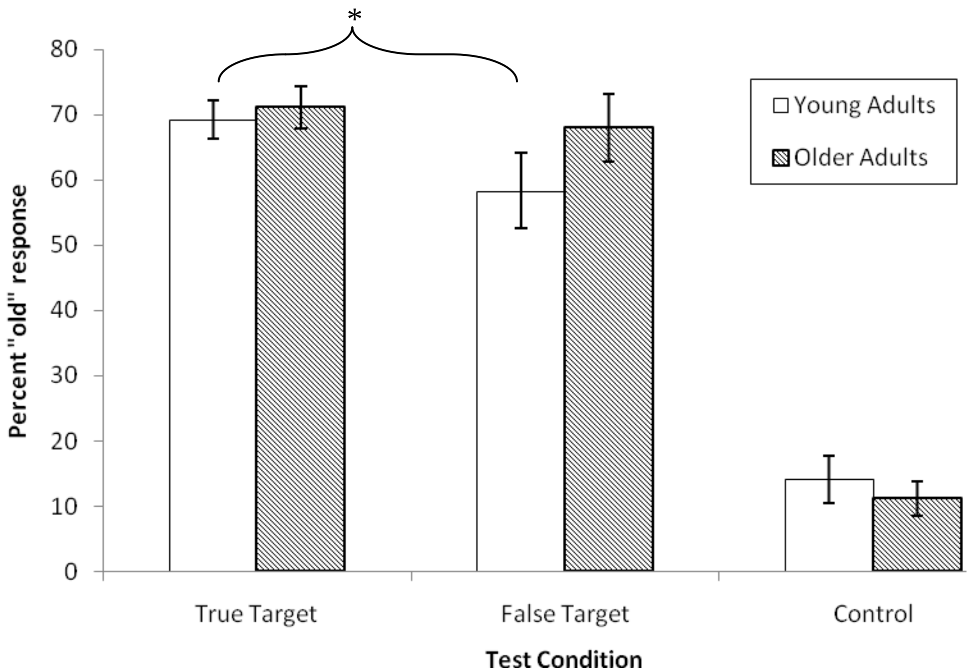


Figure 3. False memory effect as percentage of “old” responses given to true targets, false targets and controls. “Old” responses to true and false targets were significantly greater than for controls for both young and older adults. Young adults showed a significant difference between responses to true and false targets, while older adults did not.

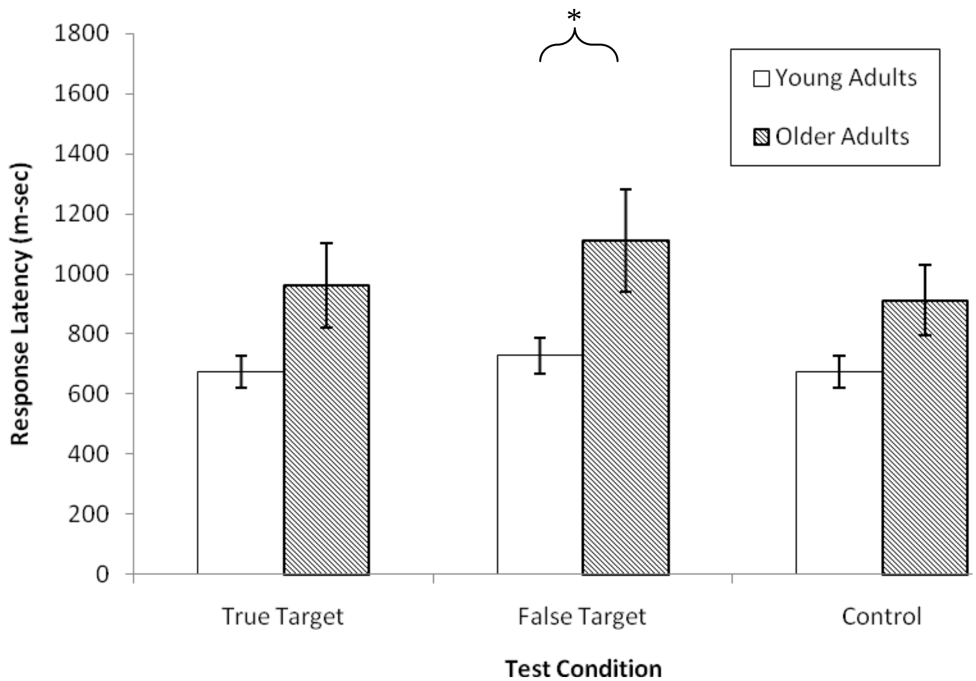


Figure 4. Response latency by condition. For false targets, response latency was significantly greater for older adults.

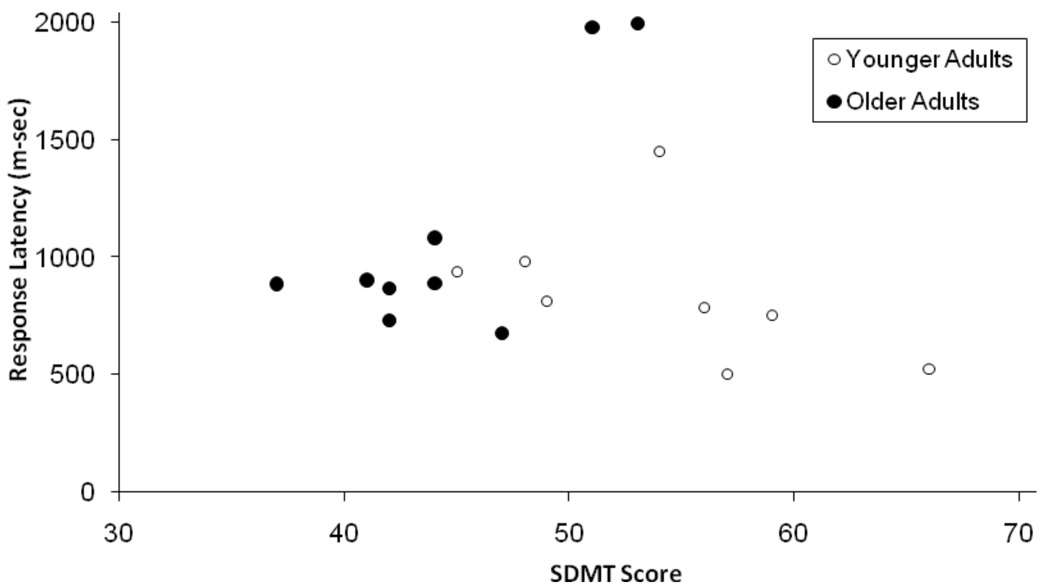


Figure 5. Correlation between response latency and SDMT scores. For young adults there is a significant negative correlation, and for older adults there is a significant positive correlation.

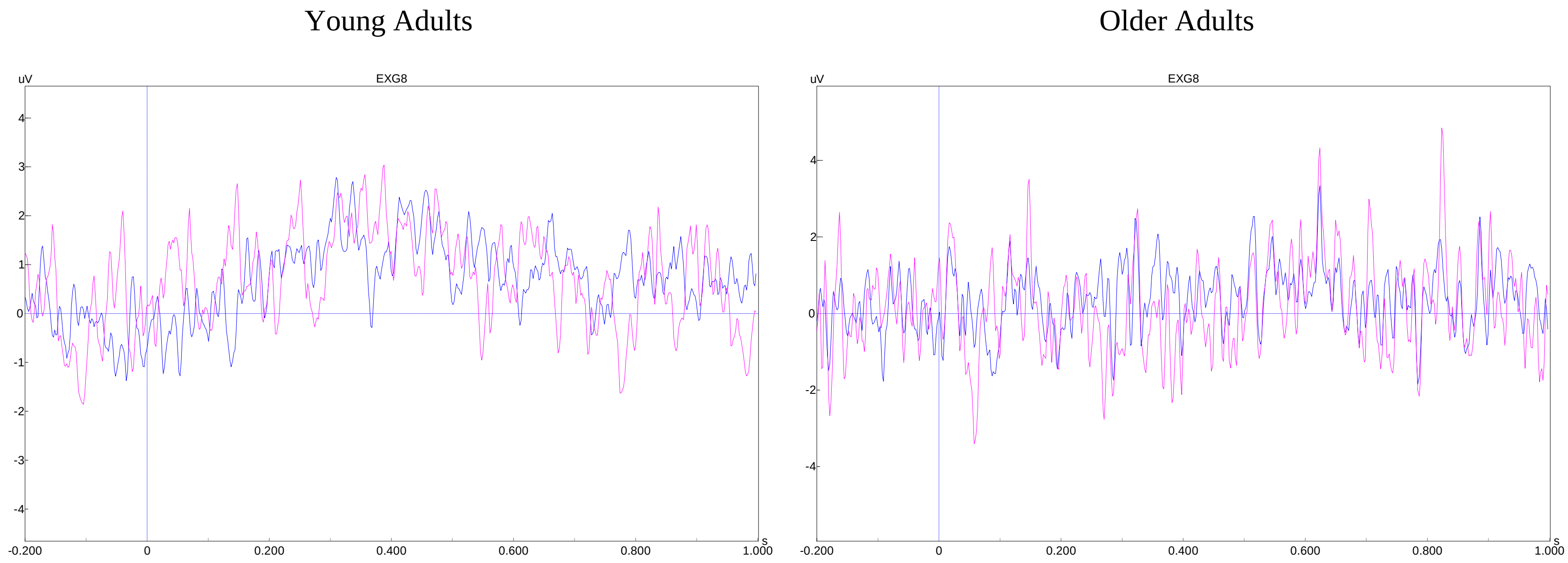
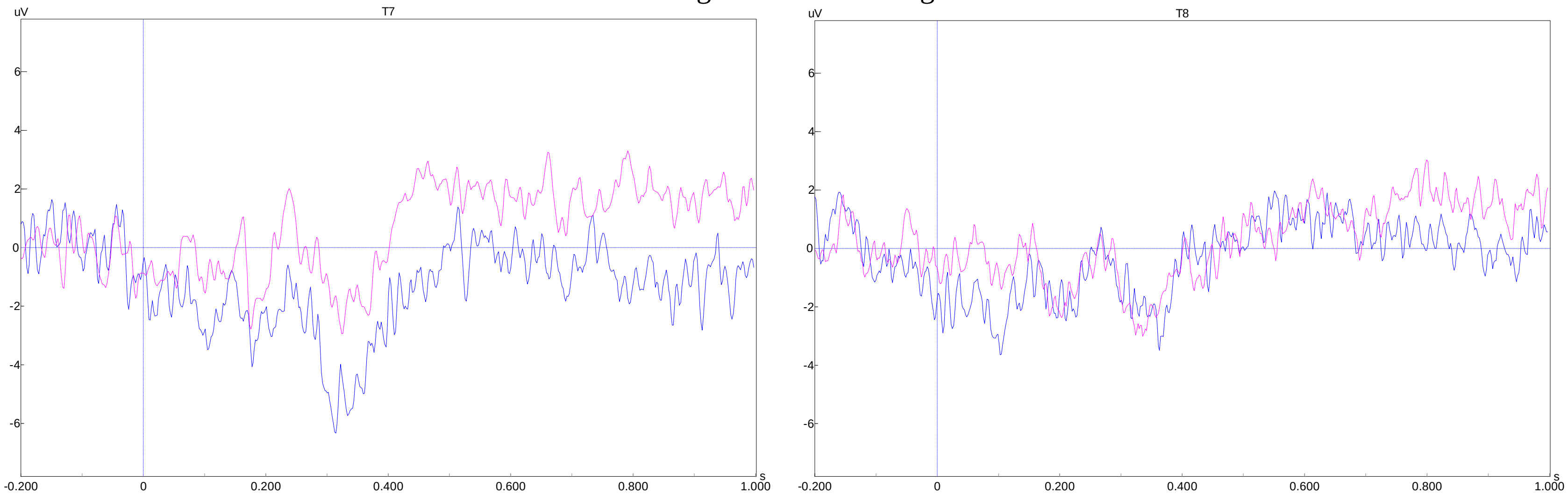


Figure 6. Lateralization waveforms creating using the contralateral-control method. Blue indicates true targets and Pink indicates false targets. The dotted vertical line represents stimulus onset.

Young Adults: True Targets



Young Adults: False Targets

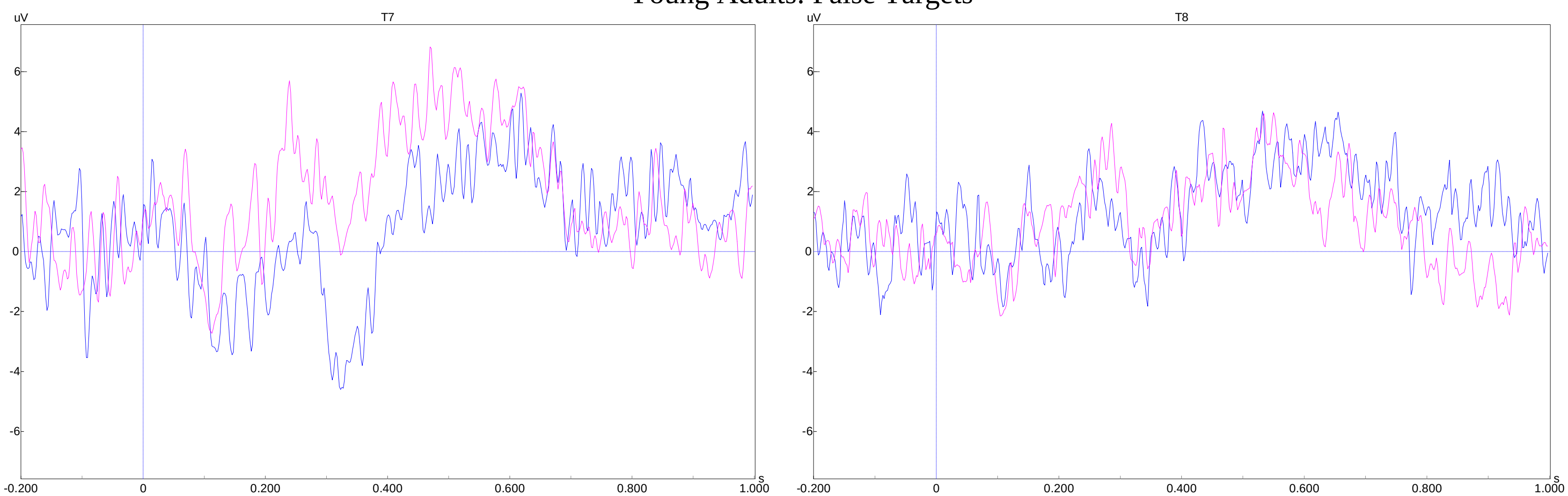
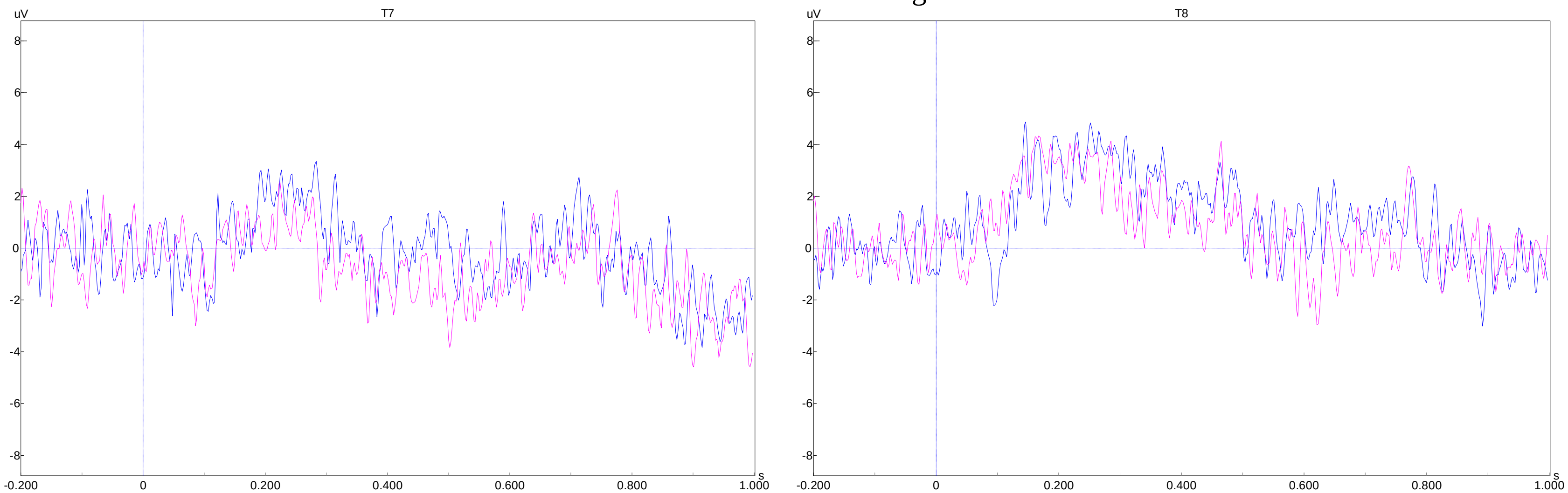


Figure 7. Grand average ERPS at test for electrode T7 (left hemisphere) and T8 (right hemisphere) for younger adults (N=7). Pink indicates words studied to the right; blue indicates words studied to the left. The dotted vertical line represents stimulus onset.

Older Adults: True Targets



Older Adults: False Targets

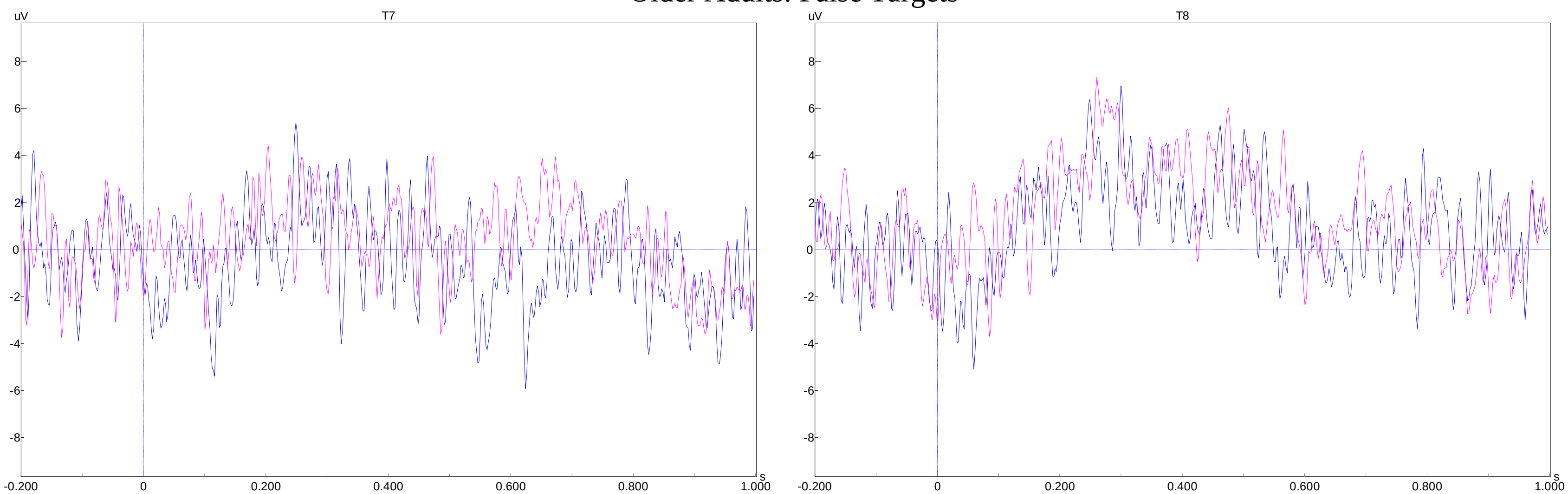


Figure 8. Grand average ERPS at test for electrode T7 (left hemisphere) and T8 (right hemisphere) for older adults (N=5). Pink indicates words studied to the right; blue indicates words studied to the left. The dotted vertical line represents stimulus onset.