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Levels of Specificity in Episodic Memory: Insights From Response Accuracy and Subjective Confidence Ratings in Older Adults and in Younger Adults Under Full or Divided Attention

Nathaniel R. Greene, Sydney Chism, and Moshe Naveh-Benjamin
Department of Psychological Sciences, University of Missouri–Columbia

We propose that the specificity with which associations in episodic memory can be remembered varies on a continuum. Older adults have been shown to forget highly specific information (Greene & Naveh-Benjamin, 2020b), and in Experiment 1, we provide further evidence that older adults' deficits in associative memory scale with the amount of specificity that needs to be retrieved. In Experiment 2, we address whether depleted attentional resources, simulated in young adults under divided attention at encoding, could account for older adults' associative memory specificity deficits. Participants studied face-scene pairs and later completed an associative recognition test, with test pairs that were old, highly similar or less similar to old pairs, or completely dissimilar. Participants rated their confidence in their decisions. False positive recognition responses increased with the amount of specificity needed to be retrieved. Whereas older adults' associative memory deficits scaled with how much specific information needed to be remembered, younger adults under divided attention had a more general deficit in associative memory. Confidence-accuracy analysis showed that participants were best able to calibrate their confidence when less specific information was needed to perform well. While divided attention young adults were generally prone to high-confidence errors, older adults' high-confidence errors were most apparent when highly specific information needed to be remembered. These results provide further evidence for levels of specificity in episodic memory. Access to the most specific levels is most vulnerable to forgetting, in line with a specificity principle of memory (Surprenant & Neath, 2009). Further, depleted attentional resources at encoding cannot entirely explain older adults' associative memory specificity deficits.

Keywords: episodic memory, aging, metamemory, associative recognition, divided attention

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According to Surprenant and Neath's (2009) proposed specificity principle of memory, when individuals are tasked with retrieving specific information, they are liable to forget that information. These retrieval failures may occur because specific information is susceptible to interference and may be encoded in an unstable memory trace (e.g., a verbatim memory trace; Reyna & Brainerd, 1995). Failures to remember specific information about prior events can have profound implications—for example, in eyewitness situations where witnesses are asked to remember precise information about what transpired during a crime. Our focus is on understanding the conditions under which individuals are most susceptible to forgetting specific details of past events. We are especially invested in understanding how much specific information in episodic memory older adults can remember. Failures in remembering specific information may be especially pervasive among older adults (Castel et al., 2007; Greene & Naveh-Benjamin, 2020b; Koutstaal, 2003; Koutstaal et al., 1999; Koutstaal & Schacter, 1997; Luo & Craik, 2009; Naveh-Benjamin & Old, 2008; Reder et al., 1986; Schacter et al., 1997; Simons et al., 2004; Stark et al., 2013; Tun et al., 1998), and a hallmark of aging is a decline in the efficiency and precision of episodic memory (Zacks et al., 2000), memory for events that occurred in a specific time and place (Tulving, 1983).

Numerous studies measuring item memory have demonstrated that older adults are impaired in their ability to discriminate old items from similar foils (e.g., Kirwan & Stark, 2007; Koutstaal & Schacter, 1997; Koutstaal et al., 1999; Stark et al., 2010, 2013), which may be related to a failure of hippocampal pattern separation (Stark et al., 2013; Yassa et al., 2011). It has been suggested that older adults rely on a gist-based processing strategy (Tun et

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Nathaniel R. Greene https://orcid.org/0000-0001-6758-6761

The data and ideas in this article have not been disseminated previously. Data and analysis scripts are publicly available at https://osf.io/vkcgh/.

Correspondence concerning this article should be addressed to Nathaniel R. Greene, Department of Psychological Sciences, University of Missouri–Columbia, 9J McAlester Hall, Columbia, MO 65211, United States, or Moshe Naveh-Benjamin, Department of Psychological Sciences, University of Missouri–Columbia, 106 McAlester Hall, Columbia, MO 65211, United States. Email: ngwfm@umsystem.edu or navehbenjaminm@missouri.edu

al., 1998), which contributes to their poorer memory for specific details (for a recent review, see Devitt & Schacter, 2016). Yet remembering whether an item had been previously seen (e.g., "Did I see this red apple, or was it a green apple?") only captures one aspect of memory, and episodic memory is more multifaceted as it also contains information about where and when an item was encountered (Tulving, 1983). It is less clear how much specific information older adults can remember for more complex episodic memories, though some emerging evidence suggests that older adults may remember episodes at a less precise degree of representation (Greene & Naveh-Benjamin, 2020b; Rhodes et al., 2020).

Here, we aimed to explore in more depth how much specific information about episodic memories older adults can remember. More broadly, we sought to further test the ideas of Greene and Naveh-Benjamin (2020b) and Craik (2002) that episodic memories may be accessed on a *continuum of specificity*. We also considered other factors that might disrupt memory for specific details, thereby assessing whether deficits in memory specificity are unique to or extend beyond age-related changes. Specifically, we investigated whether dividing attention at encoding in young adults may disrupt the specificity with which associative episodic memories are remembered as a depletion of attentional resources may account for older adults' deficits in memory (Craik & Byrd, 1982), and dividing attention in young adults has been shown to produce pronounced deficits in item and associative memory (Naveh-Benjamin et al., 2003). Finally, we aimed to assess whether older adults or younger adults under divided attention would be aware of their memory deficits for specific information. In the following sections, we expand on relevant research motivating these aims.

Age-Related Differences Across Levels of Specificity in Episodic Memory

An episodic memory is a representation of a past event, in which event characteristics including contextual, spatial, and temporal features are bound together into a holistic unit (Jones, 1976; Tulving, 1983; Underwood, 1969). At its core, an episodic memory consists of associations among event features, which must be integrated together at encoding and reaccessed together at retrieval for successful remembering. Remembering associations among components of an event (e.g., between events features, such as time and location) is markedly affected by normal aging (Chalfonte & Johnson, 1996; Naveh-Benjamin, 2000; Old & Naveh-Benjamin, 2008). Deficits in associative memory contribute to errors like misremembering where a person was previously encountered (Chen & Naveh-Benjamin, 2012) and to older adults' source memory impairments (Boywitt et al., 2012). That is, older adults are more prone to forgetting the source of previously learned or studied information (Boywitt et al., 2012; Simons et al., 2004), and according to the *associative deficit hypothesis* (Naveh-Benjamin, 2000), these source memory failures arise from an impairment in binding item and source information.

Recently, Greene and Naveh-Benjamin (2020b) suggested that age-related associative memory deficits scale with the amount of specificity that needs to be retrieved, being greatest when highly specific information needs to be retrieved but being less pronounced as less specific information needs to be retrieved, extending on previous research on age differences in the specificity of item memory (e.g., Koutstaal & Schacter et al., 1997). The results from Greene and Naveh-Benjamin (2020b) also supported the idea that episodic memories may be accessed along a continuum of specificity, akin to Craik's (2002) hierarchical representation model of memory, which states that the precision with which information is represented in and retrievable from memory varies from highly specific details about the context in which a memory was formed to more general details, which may be devoid of contextual information. For example, remembering highly specific information about where you saw someone before, such as "I saw this old man in the deli aisle," exists at a more specific level of representation than remembering "I saw this old man in a grocery store," which in turn is more specific than "I saw this old man inside somewhere." According to Craik's (2002) model, there is no categorical break between episodic and semantic memory.[1] That is, semantic memories are memories that exist at a general state of representation in which associated details of the encoding context do not need to (and perhaps cannot) be retrieved.

As associations among components of an episode lie at the core of episodic memory, Greene and Naveh-Benjamin (2020b), who measured how much specific information about associations between faces and scenes young and older adults could remember, provided the most concrete evidence to date in favor of the hierarchical representational model that Craik (2002) proposed, in which episodic memories could be remembered at more or less specific levels of representation. They demonstrated that the ability to remember highly specific details about face-scene pairs (e.g., remembering that an old man was paired with a specific park) was most susceptible to forgetting, especially among older adults, but the ability to remember associations at a less detailed level (e.g., remembering that the old man had been paired with *some* park) was relatively more accurate in older adults. Participants sometimes remembered even less detailed representations (e.g., remembering that the old man had been paired with a nature scene but not remembering whether it was a park or a forest).

The findings of Greene and Naveh-Benjamin (2020b) went beyond earlier claims that older adults remember less specific information in episodic memory as most of that evidence has come from studies on item memory (e.g., Koutstaal & Schacter, 1997; Stark et al., 2013) rather than associative memory. There have been a few other studies suggesting that older adults can remember the gist of associations in memory, such as studies showing that older adults can rely on preexisting schematic support to aid with remembering the gist of associations (Castel, 2005; Castel et al., 2013). For example, older adults may rely on preexisting knowledge that a gallon of milk generally costs about $2 to $3, helping them to remember the general price range associated with a

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[1] This continuum view is distinct from other popular conceptualizations of memory, such as fuzzy-trace theory (Reyna & Brainerd, 1995), which posits that memory is processed in two parallel traces—a verbatim and a gist memory trace—which could reflect the operations of categorically distinct memory systems (e.g., episodic versus semantic; Brainerd & Reyna, 2015). Craik (2002) proposed that episodic and semantic memory exist on a continuum of specificity such that memories can be remembered with differing degrees of specificity (e.g., very specific and detailed, less specific and less detailed, etc.). This is also distinct from "hierarchies of gist" (Brainerd & Reyna, 2015), which are different ways in which semantic information is organized (e.g., nominally versus ordinally; Reyna & Brainerd, 1991).

studied gallon of milk. However, Greene and Naveh-Benjamin (2020b) used face-scene pairs, for which multiple conflicting preexisting associations could plausibly exist, such that in order to remember even less specific information about where a face had been encountered (e.g., "The old man was in *some* park"), an individual would have to retrieve some specificity about the encoding context pertaining to that specific association without relying on preexisting knowledge.

In another study, Simons et al. (2004) examined specific- and partial-source memory in young and older adults using a source monitoring task from Dodson et al. (1998). Participants heard sentences spoken by four different voices (two women and two men). During the test phase of their study, participants made "old/new" judgments for sentences, and when they responded "old," they then judged which voice spoke the sentence. Simons et al. (2004) found that older adults not only forgot specific-source information (e.g., whether a sentence had been spoken by Male 1 or Male 2), but they also forgot partial-source information (i.e., remembering whether a sentence had been spoken by a male or a female). Thus, in contrast to Greene and Naveh-Benjamin (2020b), Simons et al. (2004) showed that aging is associated with deficits in complex episodic memories even at less specific levels of representation.

Divided Attention Effects on Levels of Specificity

As Greene and Naveh-Benjamin (2020b) showed, older adults were especially impaired at remembering very specific information about associations in memory, but even the younger adults in their study performed worse at rejecting highly similar pairs in the test phase than any other type of recombined pair. As such, are the pronounced age-related differences in associative memory for highly specific information unique to aging, or might other factors that impair memory result in a similar pattern of deficits in associative memory specificity?

In the present study, we sought to answer this question by examining the effects of dividing attention during encoding in younger adults on later memory performance in an associative recognition task assessing associative memory specificity. Dividing attention at encoding affects memory performance across multiple tasks of memory, including free recall, cued recall, item recognition, associative recognition, and source memory (e.g., Baddeley et al., 1984; Craik et al., 1996; Greene et al., in press; Kilb & Naveh-Benjamin, 2007; Murdock, 1965; Naveh-Benjamin et al., 1998, 2003). Indeed, some research has shown that the effects of dividing attention at encoding are equivalent for item and associative measures of memory (Naveh-Benjamin et al., 2003; but see Castel & Craik, 2003). Thus, dividing attention seems to produce a more "general" deficit in memory than that associated with aging, which appears more restricted to associative than item memory (Naveh-Benjamin, 2000; Old & Naveh-Benjamin, 2008). If so, then in the present study, it could be that divided attention, but not aging, affects not just highly specific details in memory but even less specific information as well. Nevertheless, depleted attentional resources may play an important role in older adults' memory deficits in general (Craik & Byrd, 1982), and if so, we may expect younger adults' performance deficits under divided attention at encoding to mimic that of the older adults, being restricted mostly to the highest levels of specificity.

Metamemory for Different Levels of Specificity in Young and Older Adults

Are older adults aware of their deficits in associative memory, especially for highly specific information? This question speaks to older adults' *metamemory*, or knowledge about their memory, and some relevant research bearing on this question has come from studies in which participants rate their confidence in memory decisions, often used in eyewitness paradigms (Colloff et al., 2017; Dodson & Krueger, 2006). Dodson and Krueger (2006) showed that older adults were most likely to incorrectly claim to have seen events, which really had only been suggested in a questionnaire (i.e., suggestibility errors), when they were highly confident that their judgment was correct. In contrast, younger adults matched on overall rates of accuracy with older adults committed suggestibility errors only when they had low confidence in the accuracy of their judgments. Dodson et al. (2007) proposed a misrecollection account to explain these findings. Accordingly, older adults are prone to making high-confidence errors when probed with questions that require memory for specific details about recently learned events. Studies supporting this misrecollection account have demonstrated that older adults are prone to high-confidence errors on tasks of associative recognition (e.g., Fandakova et al., 2013) but not on tests of general knowledge (Dodson et al., 2007; for a recent review, see Dodson, 2017).

If episodic memory exists on a continuum of specificity, as proposed by Craik (2002) and Greene and Naveh-Benjamin (2020b), then an important question is whether older adults' high-confidence errors in associative recognition (e.g., Fandakova et al., 2013) occur at all levels of specificity or are restricted to the highest levels of specificity. That is, will older adults make high-confidence errors when misjudging any type of test foil, or will these high-confidence errors be restricted to incorrect judgments for those probes that require the greatest amount of specific retrieval to reject? In addition, to our knowledge, no studies have assessed whether younger adults under divided attention are able to gauge the (in)accuracies of their memories at different levels of specificity, and such knowledge can provide important insights into whether older adults' metamemory for levels of specificity could be driven by depleted attentional resources. These are important novel insights that the present study aimed to provide.

The Present Study

There were three aims of the present study. First, we extended on the framework of levels of specificity and sought to replicate the results from Greene and Naveh-Benjamin (2020b) with a modified paradigm. Greene and Naveh-Benjamin (2020b) used the simplified conjoint recognition paradigm (Stahl & Klauer, 2008), in which participants make "old," "similar," or "new" judgments to test probes (in Greene and Naveh-Benjamin's study, these were "intact," "related," and "unrelated" judgments). Here, we used a more standard "old/new" (i.e., "intact/recombined") format to examine whether participants' tendency to mistakenly endorse a recombined probe as "old/intact" depended on how similar those probes were to old pairs. In Greene and Naveh-Benjamin's (2020b) study, higher rates of "related" responses to test pairs that were similar to an original pair at a broad level (related-broad; e.g., from old man-park to old man-forest) than to test pairs that were dissimilar (unrelated; e.g., old man-kitchen) may have indicated that participants viewed related-broad pairs as similar, but not the same as, original pairs. In contrast, in an old/new task, employed here, higher rates of "old" responses to related-broad than unrelated pairs would provide concrete direct support for the notion that participants retrieved less specific (or "fuzzier") representations because they were more likely to judge related-broad pairs as truly "old."

Second, we aimed to investigate whether the patterns of age-related deficits in associative memory at highly specific levels, observed in Greene and Naveh-Benjamin (2020b), would replicate in young adults under divided attention. If so, this would support, among other things, the depleted attentional resources hypothesis of aging. Alternatively, it could be that divided attention at encoding would result in more general effects on the representational quality of associative episodic memory.

Third, we aimed to gain insight into the ability of older adults and younger adults under divided attention to gauge the accuracy of their memories and potential deficits in their ability to remember highly specific or less specific information via immediate retrospective confidence ratings. We used confidence-accuracy curves to assess whether young and older adults adjust their confidence ratings in accord with the amount of specificity needed to be retrieved to perform well. It is possible that older adults may make high-confidence errors only for test probes that require highly specific memory retrieval given their limitations in remembering associations at this level of specificity (Greene & Naveh-Benjamin, 2020b). If, however, older adults make more high-confidence errors for related-broad or unrelated probes than younger adults, this would suggest that they are less capable of gauging the accuracy of their memories even when retrieval of less specific information would suffice. More generally, measuring the confidence-accuracy relationship across test probes that vary in the amount of representational overlap with originally studied associations can provide valuable insight into individuals' metamemory for the retrieval of different levels of specificity.

Experiment 1

In Experiment 1, we investigated age-related differences in an associative recognition task, in which test pairs were either the same as studied pairs (intact), similar at a category-specific level (related-specific), similar at a broader level (related-broad), or dissimilar from original pairs (unrelated). We also probed young and older adults' metamemory by requiring participants to rate their confidence after indicating whether a test pair was intact (meaning old, as in intact pairs) or recombined (meaning new, as in related-specific, related-broad, and unrelated pairs).

Based on the work of Greene and Naveh-Benjamin (2020b), we hypothesized that older adults would be especially impaired at remembering very specific details of associations, which would manifest as age-related differences in response accuracy to related-specific probes and potentially smaller differences for related-broad probes. Further, based on the continuum of specificity theoretical view (Craik, 2002; Greene & Naveh-Benjamin, 2020b), we hypothesized that accuracy to recombined probes would improve from related-specific to related-broad to unrelated probes, that is, from the probes with the highest amount of representational overlap to previously studied pairs to those with the lowest amount. Regarding confidence ratings, we expected older adults to be more prone to high-confidence errors, in line with the misrecollection account (Dodson et al., 2007), but we made no specific hypotheses as to whether these high-confidence errors would only be restricted to highly similar foils (related-specific probes) or would extend to other test probes as well.

Method

Participants

Forty-seven young adults (age: M = 20.41, SD = 2.28, range 18–26) and 47 older adults participated, but two of the older adults were dropped for performance well below chance across all probe types, leaving a final sample size of 45 older adults (age: M = 70.07, SD = 3.93, range 63–79). Most participants in each age group self-identified as female (59.6% of the young adults and 66.7% of the older adults). As is quite typical in aging studies, the older adults had more years of education (M = 17.39, SD = 1.50) than the younger adults (M = 12.92, SD = .89), but most of the young adults were college students who had not yet completed their formal education. All participants self-reported to be in good physical and cognitive health, had no history of cognitive impairments or dementias, had normal or corrected-to-normal vision, consumed no more than 5 to 9 units of alcohol per week, and were native speakers of English.

Sample size was based on a Bayes factor design analysis (e.g., Schönbrodt & Wagenmakers, 2018) computed with the BFDA package for R (Schönbrodt & Stefan, 2018). Details of this analysis are available in the online supplemental materials, but briefly, we used an optional stopping rule, with a minimum sample size of 30 per group and a maximum sample size of 60 per group, and estimated a medium effect centered at d = .70 with a range from .60 to .80, based on effect sizes estimated from Greene and Naveh-Benjamin (2020b). We began our data collection in the laboratory, but due to the COVID-19 pandemic, we switched to online data collection via Prolific midway through. In total, 27 young and 22 older adults were recruited in the lab, with the remainder completing the study online. We included sampling site as a potential predictor in our models, discussed in the "Analyses" section below.

Materials

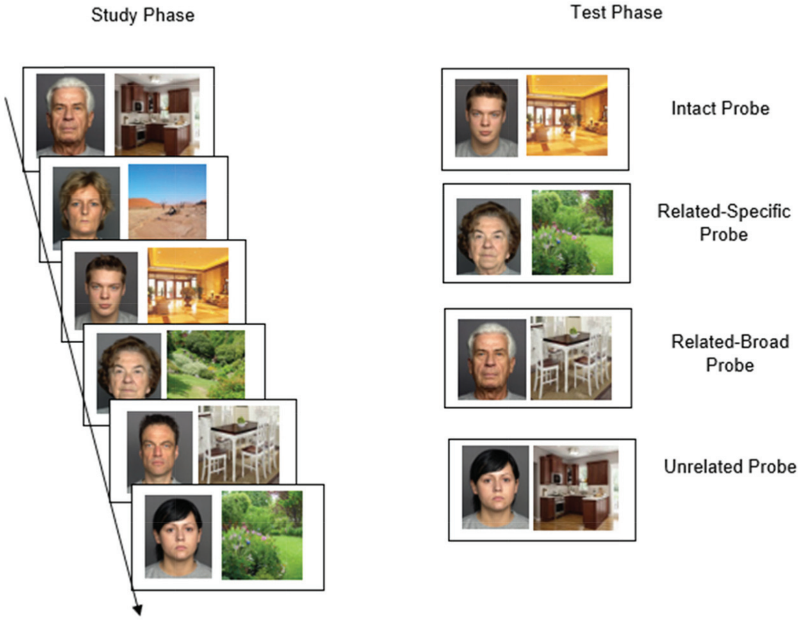
We paired 132 faces (evenly divided among old female, old male, young female, and young male faces) from the FACES database (Ebner et al., 2010) with 132 scenes from a categorized scene pool (Konkle et al., 2010), with two exemplars per category (e.g., two parks, two kitchens). Pairs were presented using E-Prime 2.0 (Schneider et al., 2012) for participants tested in the laboratory and via PsyToolkit (Stoet, 2010, 2017) for participants tested online.

Procedure

All procedures in both experiments were approved by the institutional review board of the University of Missouri. Participants completed one practice and 10 experimental blocks like the one depicted in Figure 1. Each block began with a study phase, in which participants viewed 12 unique face-scene pairs, one at a time, for 4 s each, with a 0.5-s interpair interval. Both exemplars of a scene category appeared in the same block, each paired with a different

Figure 1

Example of Procedure of One Block



Note. Participants studied 12 unique face-scene pairs for 4 s each (only six are shown in the figure). The test phase featured four types of test probes (intact, related-specific, related-broad, and unrelated) with "intact" and "recombined" as the response options. The depicted faces are reproduced from the FACES database (faces.mpdl.mpg.de/imeji/) and are permitted by the FACES Platform Release Agreement, Rule 7, to be displayed for purposes of illustrating research methodology. See the online article for the color version of this figure.

face (e.g., Young Woman 1-Desert 1; Old Man 2-Desert 2). Additionally, six scenes in a block came from one broader category (e.g., six nature scenes: two parks, two streams, two deserts), and the other six scenes came from a different broader category (e.g., six indoor scenes: two lobbies, two kitchens, two dining rooms).

After the study phase, as part of an interpolated activity, participants completed a U.S. geography task (in the laboratory) or a world geography task (online) for 60 s. The name of a city appeared, and participants had 5.5 s to respond with the name of the state or country in which they believed that city was located. The correct answer was then shown for 2 s.

Next came the test phase, where participants were shown 12 pairs, one at a time, and indicated whether each pair was intact (i.e., the same face was paired with the same scene in the study phase) or recombined (i.e., a face was repaired with a different scene from the study phase) by pressing the "I" or "R" key, respectively. They then rated their confidence in their decision as low, medium, or high by clicking on one of these options on the screen.

There were six intact and six recombined pairs per block. Recombined pairs were further divided into three types: related-specific, related-broad, and unrelated. Related-specific pairs featured a face recombined with a scene from within the same specific scene category (e.g., the old woman paired with a different park scene in the test phase in Figure 1). Correct identification of related-specific pairs as recombined relies, in part, on the retrieval of specific memory (Greene & Naveh-Benjamin, 2020b). Thus, individuals who fail to remember highly specific details about the original association are more likely to erroneously identify related-specific pairs as intact.

Related-broad pairs featured a face recombined with a scene from within the broader scene category (e.g., the old man paired with a dining room, a different type of indoor scene, in the test phase in Figure 1). Unrelated pairs featured a face recombined with a scene from the opposite broader scene category (e.g., the young woman paired with a dining room, an indoor scene, in the test phase in Figure 1, when she had been paired with a nature scene in the study phase). A higher rate of "intact" responses to related-broad than unrelated probes is expected if an individual retrieves an association at a fuzzier level of representation.

Analyses

Analyses were conducted within a Bayesian statistical framework. Data and analyses are available at https://osf.io/vkcgh/ (Greene & Naveh-Benjamin, 2020a). Accuracy differences between young and older adults were measured with hierarchical Bayesian logistic regression models, implemented in the R package brms (Bürkner, 2017; R Core Team, 2020). Logistic regression is more suitable than standard analyses, such as analysis of variance (ANOVA) on aggregated proportions, for measuring performance across trials nested within participants (e.g., Dixon, 2008). We first tested for effects of sampling site and found no credible evidence that response accuracy credibly differed between participants tested in the laboratory and those tested online, with the exception of performance on related-specific probes, but this did not meaningfully interact with age (see Figure S3 in the online supplemental materials). Therefore, in the main text, we focus on effects of age and probe type, collapsed across sampling site.

We tested for effects of age (coded as 1 = young, −1 = old) by probe, which was contrast coded, with unrelated probes set as the reference group, resulting in three effect-coded probe contrasts (1 = intact, −1 = unrelated; 1 = related-specific, −1 = unrelated; 1 = related-broad; −1 = unrelated). We adopted a decision rule based on whether the 95% highest density interval (HDI) of the population-level (i.e., "fixed" effect) slope of a predictor encompassed 0 on the log-odds scale. If the 95% HDI excluded 0, we concluded there was credible evidence for an effect. If the 95% HDI encompassed 0, we concluded that there was not credible evidence for an effect, though note that this is not the same as saying that there was credible evidence for a null effect. For priors on fixed effects, we specified weakly informative Cauchy (0, 2.5) priors (see Gelman et al., 2008), but we retained the program's half-*t* priors on the standard deviations of the random effects (there were random intercepts and random effects of probe for each participant). Posterior summaries of model parameters were computed from four independent Markov chain Monte Carlo chains, each with 2,000 iterations. For all parameters, convergence was obtained, all $\hat{R}$s ≤ 1.01.

To gauge whether participants could assess the likely accuracy of their memories, we computed each participant's average accuracy at each confidence level (high, medium, and low; see Mickes, 2015). For intact probes, accuracy was computed as Σ("intact" responses)/Σ("intact" + "recombined" responses), separately for each level of confidence. For all other probes, accuracy was computed as Σ("recombined" responses)/Σ("recombined" + "intact" responses) to those probes, separately for each level of confidence. We then tested for age and probe differences using Bayesian ANOVA models in JASP (JASP Team, 2020).

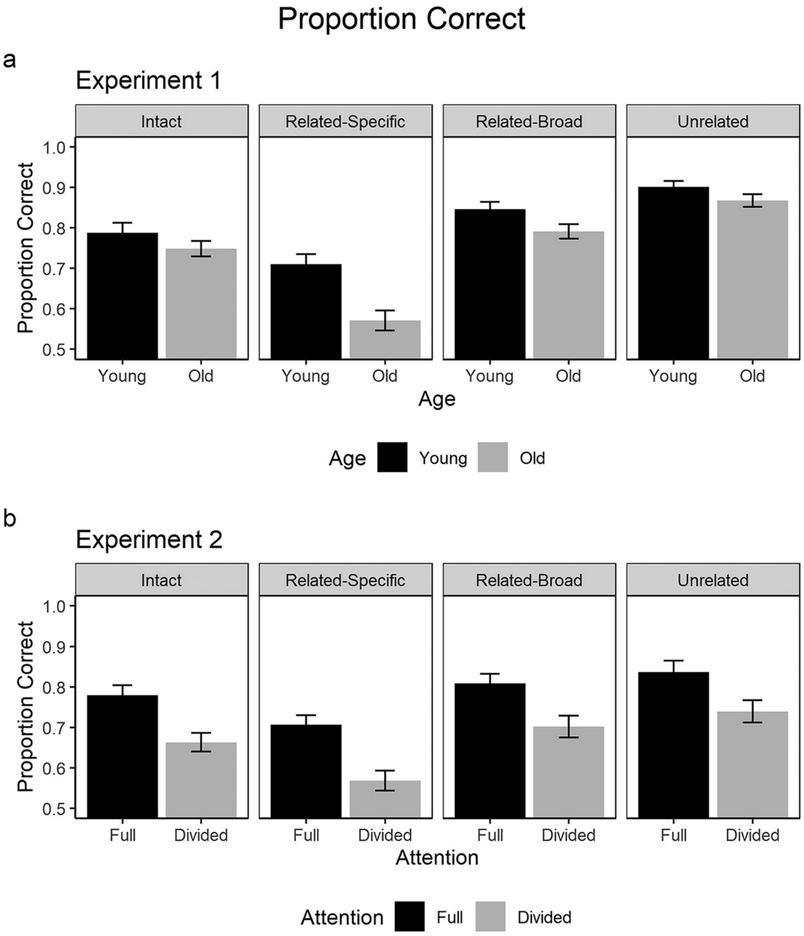
Results

Memory Accuracy Results

Older Adults Associative Memory Deficits Depend on the Amount of Specificity That Needs to Be Retrieved. Figure 2a shows the proportion of correct responses for each probe, separately for the young and older adults in Experiment 1. The results of the logistic regression analysis supported an Age × Probe

Figure 2

Mean Proportion Correct for Each Probe for Young and Old Adults in Experiment 1 (a) and for Young Adults Under Full or Divided Attention in Experiment 2 (b)



Note. Error bars are standard errors.

interaction for the contrast of related-specific and unrelated probes, $\beta_{\text{Age} \times \text{Probe}} = .11$, 95% HDI [.00, .23], though 0 appeared on the lower bound of the 95% HDI, but 97% of posterior samples were greater than 0.[2] The interaction qualifies the main effect of age from the model, $\beta_{\text{Age}} = .23$, [.07, .40]—that is, that young adults outperformed older adults—as being dependent on probe.

Model-implied proportions of correct responses and 95% HDIs are depicted in Figure 3 and clearly show credible evidence for an age difference in response accuracy on related-specific probes, but not unrelated probes, and potentially marginal evidence for age effects on intact and related-broad probes. Indeed, the largest age difference occurred for related-specific probes; young adults' accuracy (mean and 95% HDI) was .73 [.68, .78], and older adults' accuracy was .58 [.52, .64], with a difference of .15 [.08, .24]. The estimated age difference in response accuracy to related-broad probes was smaller, though the 95% HDI credibly excluded 0, with young adults' accuracy of .87 [.83, .90] and older adults' accuracy of .81 [.76, .85] and a difference of .06 [.01, .12]. However, for intact probes, the 95% HDI encompassed 0, with young adults' accuracy of .83 [.79, .87] and older adults' accuracy of .77 [.72, .82] and a difference score of .06 [−.01, .13]. For unrelated probes, the 95% HDI encompassed 0, with young adults' accuracy of .93 [.89, .95] and older adults' accuracy of .90 [.86, .94] and a difference score of .02 [−.02, .07]. These results clearly show that older adults' deficits in associative memory are greatest when highly specific information needs to be remembered (i.e., to classify related-specific probes), but these deficits also scale with the amount of specificity needed to be retrieved. That is, as individuals can rely on less specific details to judge a probe as intact or recombined, the age differences get smaller (i.e., for related-broad probes) and ultimately disappear (i.e., for unrelated probes).

Figure 3

Violin Plots of Posterior Density (Gray Distributions), Posterior Mean (Black Points), and 95% HDIs (Horizontal Black Lines) for Age Contrasts (Young Minus Older Adults) for Each Probe in Experiment 1

Note. Ninety-five-percent HDIs that overlap with the dashed line at 0.0 indicate no credible evidence for a difference in response accuracy between young and older adults.

Performance differences on the task could conceivably arise from memory deficits in the older adults or from different response strategies in the two groups. Because our design contained three types of recombined probes, which varied in how similar they were to original pairs, we could not derive standard estimates of sensitivity (e.g., d' from signal detection theory) as there may be multiple reasons why participants commit false alarms, such as failing to retrieve highly specific details, failing to retrieve less specific details, or random guessing.[3] However, as we probed participants' metamemory for their intact/recombined judgments by asking participants to rate their confidence in these decisions, we were able to account for potential random guesses from participants. In a separate model, we considered all "low" confidence responses to be random guesses, and we removed these responses, focusing instead on whether there were age differences in response accuracy when only "medium" and "high" confidence responses were considered. There were about equal numbers of low-confidence trials that were dropped per age group ($n = 464$ out of 5,760 trials for the young adults; $n = 473$ out of 5,400 trials for the older adults). Importantly, the results of the logistic regression analyses on the filtered data were equivalent to those reported previously, with age differences (young minus old) that scaled with the amount of specificity needed to be retrieved, being greatest for related-specific probes ($\Delta = .17$, 95% HDI [.08, .26]), smaller for intact ($\Delta = .06$, [.01, .13]) and related-broad ($\Delta = .06$, [.00, .12]) probes, and noncredibly different from 0 for unrelated probes ($\Delta = .03$, [−.02, .07]).

Errors to Recombined Probes Support Levels of Specificity in Associative Episodic Memory Among Younger and Especially Older Adults. Next, we assessed whether our data revealed a specificity gradient whereby accuracy would increase from related-specific to related-broad to unrelated probes. Figure 4a shows the proportion of erroneous "intact" responses to each type of recombined probe as a function of age group. As depicted, the proportion of errors decreased, in each age group, as a function of how dissimilar the recombined probes were to studied pairs. The logistic regression model provided credible evidence that participants were more accurate at classifying related-broad than

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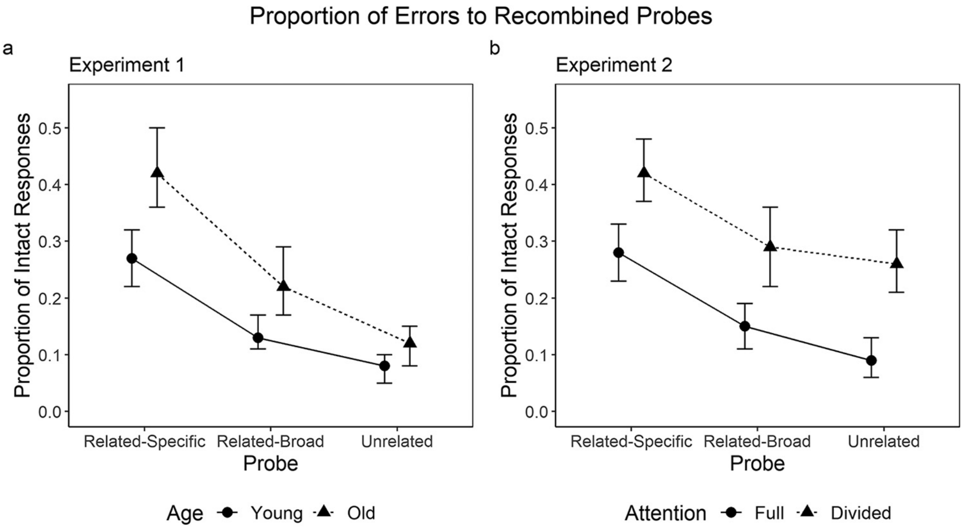
[2] As depicted in Figure 2a, the interaction is ordinal in nature (i.e., noncrossover). It is well-known that ordinal interactions can be transformed away in nonlinear models, like logistic regression (e.g., Loftus, 1978; Wagenmakers et al., 2012), such that we consider the evidence here, despite narrowly encompassing 0 on the lower bound of the 95% HDI, to be strongly in favor of the interaction effect as 97% of the HDI was greater than 0. Moreover, back-transforming the data to the probability scale showed clear evidence for an interaction (shown in Figure 3).

[3] Loiotile and Courtney (2015) proposed that signal detection can be used to simultaneously measure old-new and old-similar discrimination, but we disagree. A measure of memory sensitivity for the old-new contrast (e.g., d') is dependent on the hit rate to old items and the correct rejection rate to new items. However, the hit rate to old items can be reduced because of the presence of similar items (e.g., if an individual only has access to less specific information in memory, they must sometimes guess whether an old item is old or new). Consequently, the sensitivity index for old-new discrimination is not a pure measure of old-new sensitivity as it is influenced by participants' awareness of similar foils in the test phase.

Figure 4

Mean Proportion of "Intact" Responses to Each Type of Recombined Probe for Young and Old Adults in Experiment 1 (a) and for Young Adults Under Full and Divided Attention in Experiment 2 (b)



Note. Points correspond to estimated mean proportion and error bars to the 95% credible intervals, estimated from the logistic regression models. Points are offset horizontally between groups to avoid visual overlap.

related-specific probes, with model-implied differences in response accuracy of Δ(related-broad—related-specific) = .14, 95% HDI [.09, .17] for the young adults and Δ(related-broad—related-specific) = .23, [.18, .28] for the older adults. The model also provided credible evidence that participants were more accurate at classifying unrelated than related-broad probes, with implied differences in response accuracy of Δ(unrelated—related-broad) = .06, [.03, .09] for the young adults and Δ(unrelated—related-broad) = .09, [.05, .13] for the older adults. These results show that young and older adults made fewer errors to recombined probes the less similar these probes were to studied pairs. However, older adults were even more prone than younger adults to calling related-specific probes "intact."

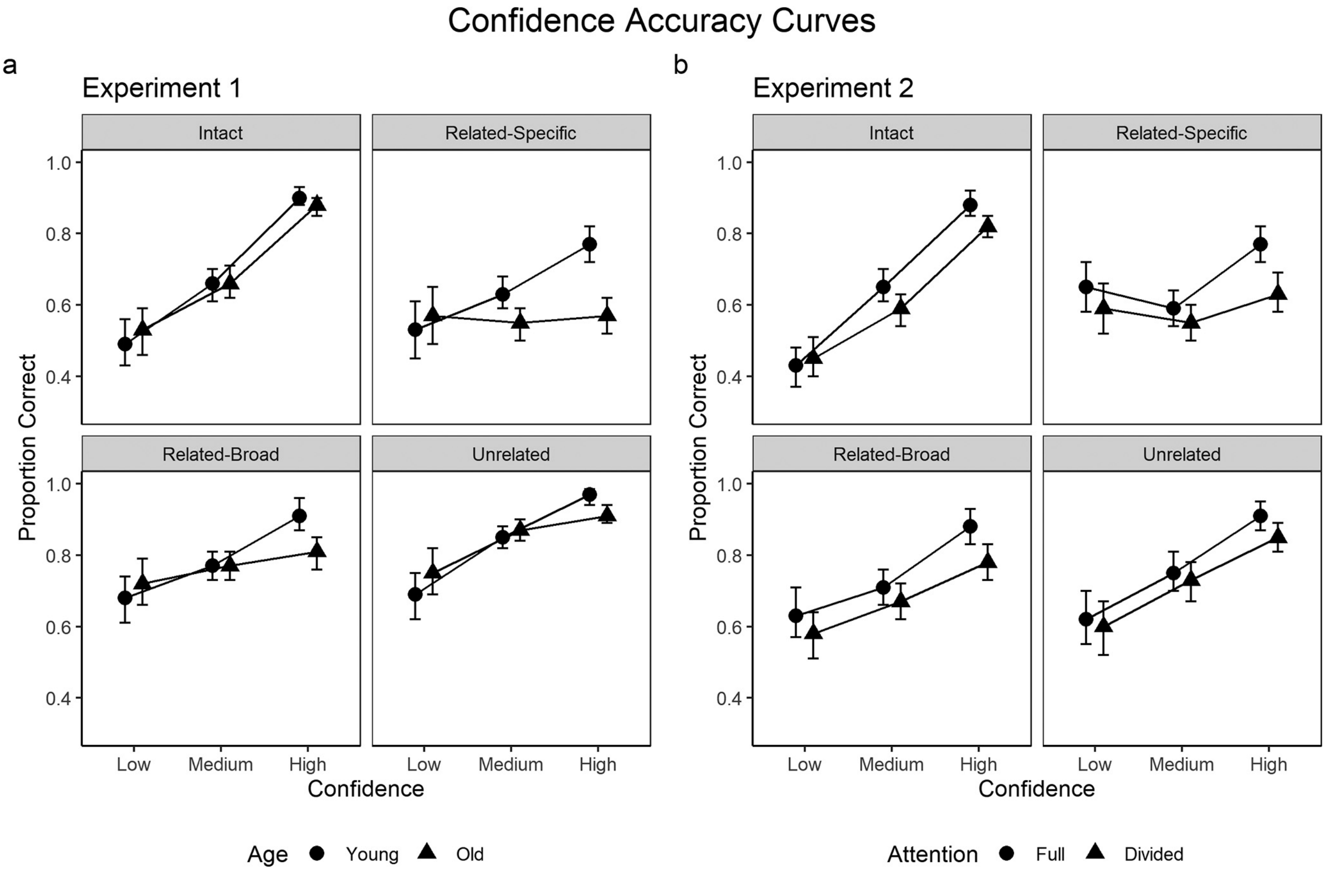
Confidence-Accuracy Results

Confidence-accuracy curves for Experiment 1 are depicted in Figure 5a (see Figure S4 in the online supplemental materials for curves separated by sampling site). The steeper the slope is between confidence and accuracy, the more capable participants were at calibrating their subjective confidence with their objective accuracy. The slopes were steepest for the intact and unrelated probes, indicating that participants in both age groups were effective at calibrating their confidence ratings for those probes that required the least effort in retrieving specific details (intact probes) or that could be successfully distinguished based on retrieval of any amount of information about the original pair (unrelated probes). The slope for the related-broad probes was shallower, especially among older adults, who were only about 81% accurate at high-confidence levels (vs. 91% among younger adults), showing that older adults were more prone to making high-confidence errors to those probes that maintain a fuzzier degree of representation to original pairs. Finally, the slope was shallowest for related-specific probes, those probes that require individuals to remember highly specific details about original pairs in order to classify these probes as being recombined rather than intact. Notably, older adults' accuracy was the same at all levels of confidence and was 57% at high confidence (vs. 77% for younger adults), demonstrating that older adults were especially prone to high-confidence errors on those probes requiring the greatest amount of specific retrieval.

Our a priori hypotheses concerned whether older adults' susceptibility to high-confidence errors depended on how much specific information needs to be retrieved. Therefore, we conducted a 2 (Age) × 4 (Probe) mixed-effects Bayesian ANOVA on the proportion of correct responses accompanied with high-confidence ratings. The Bayes factor in favor of the alternative hypothesis (BF_{10}) describes how much more likely the data are under the alternative than the null hypothesis. A Bayes factor greater than 3 is regarded as substantial evidence (Kass & Raftery, 1995). There was decisive evidence for the main effects of age ($BF_{10} = 1.32 \times 10^5$) and probe ($BF_{10} = 2.07 \times 10^{14}$) and for the interaction ($BF_{10} = 291.00$). We computed follow-up independent-samples *t* tests to test for age differences in proportion correct at high confidence to each probe, and this revealed decisive evidence for an age difference on related-specific probes ($BF_{10} = 690.18$), positive evidence for an age difference on related-broad probes ($BF_{10} = 7.19$), and anecdotal/weak evidence for an age difference on unrelated probes ($BF_{10} = 2.27$). For intact probes, there was positive evidence in favor of the null ($BF_{10} = .33$, corresponding to a Bayes factor in favor of the null of approximately 3). These results demonstrate that older adults were most prone to making high-confidence errors when they needed to remember highly specific details about original pairs in order to classify a probe as intact or recombined (i.e., for related-specific pairs). Also, post hoc tests for the main effect of probe demonstrated that proportion correct at high confidence credibly differed between all

Figure 5

Confidence-Accuracy Curves for Each Probe for Young and Old Adults in Experiment 1 (a) and for Young Adults Under Full and Divided Attention in Experiment 2 (b)



Note. Points correspond to the Bayesian empirical mean; error bars denote the 95% Bayesian credible interval.

probes, with the exception of intact and related-broad probes, for which the null hypothesis was favored ($BF_{10} = .18$).

Finally, we used a control comparison, with a 2 (Age) × 4 (Probe) mixed-effects Bayesian ANOVA model on "low" confidence responses, to ensure the obtained results at high confidence were not merely an artifact of older adults being susceptible to errors in general (i.e., regardless of their confidence in those decisions). The results of this control comparison were clear. While there was decisive evidence for an effect of probe ($BF_{10} = 2.05 \times 10^3$), the evidence was more strongly in favor of the null for the effect of age ($BF_{10} = .34$) and strongly favored the null for the interaction ($BF_{10} = .08$). Thus, the age differences in high-confidence errors, which scaled with the amount of specificity needed to be retrieved, cannot be explained by older adults being more error-prone in general, regardless of their rated confidence in their memory judgments.

Discussion

The central takeaways from Experiment 1 are as follows. First, using a somewhat different procedure, we replicated Greene and Naveh-Benjamin's (2020b) results by showing that older adults were especially impaired at classifying related-specific pairs, those pairs that require the greatest amount of specific retrieval in order to be rejected (i.e., not classified as intact), and somewhat less impaired at classifying related-broad pairs as recombined.

Second, our findings more broadly support Greene and Naveh-Benjamin's (2020b) specificity gradient as accuracy to recombined probes depended on how similar those probes were to studied pairs, being highest for the most dissimilar probes, intermediate for probes maintaining a fuzzier degree of representation, and poorest for probes maintaining a highly similar degree of representation to original pairs. This was true of both young and older adults, suggesting that levels of specificity in episodic memory may be a general phenomenon, not restricted to aging per se. That said, older adults, more than younger adults, were especially impaired in their memory for highly specific details, as indicated by the large age difference in response accuracy to related-specific probes.

Third, we demonstrated that older adults' tendency to make high-confidence errors was greatest for related-specific probes but also existed for related-broad probes, though the strength of evidence in favor of an age difference was smaller for related-broad probes. These findings suggest that older adults' high-confidence errors depend, in part, on how much specific information may be needed to be retrieved in order to perform accurately. This is in line with the misrecollection account (Dodson et al., 2007) but extends on earlier studies showing that older adults are prone to high-confidence errors in associative recognition tasks (Fandakova et al., 2013) by illustrating that these high-confidence errors are more noticeable at higher levels of specificity.

Experiment 2

In Experiment 2, we investigated whether dividing attention at encoding among young adults would result in the same pattern of effects on associative memory at different levels of specificity that we observed with older adults in Experiment 1 and in Greene and Naveh-Benjamin (2020b). One objective of this experiment was to test whether dividing attention at encoding in young adults would result in the same specificity deficits that were observed with older adults in Experiment 1. Such a finding could support the theoretical position that older adults' deficits in cognition, including those underlying deficits in episodic memory, are attributable to depleted attentional resources (e.g., Craik & Byrd, 1982). Specifically, older adults' observed deficits in associative memory at the most detailed levels of specificity may be attributable to limited attentional resources, necessary to encode information into memory (for evidence that older adults have lower encoding capacity in working memory, and that this is related to attentional limitations, see Greene et al., 2020). If so, we would expect that dividing attention in young adults would result in the same deficits in associative memory at highly specific levels of representation.

Dividing attention at encoding in young adults has been shown to produce comparable deficits in both item and associative memory (e.g., Naveh-Benjamin et al., 2003) such that the effects of dividing attention may be more general than those of aging, which are more pronounced for associative than item memory (Naveh-Benjamin, 2000; Old & Naveh-Benjamin, 2008). If divided attention has a more general effect on memory fidelity (e.g., as shown by its similar effects on item and associative memory, e.g., Kilb & Naveh-Benjamin, 2007), then it could affect different levels of specificity to the same degree.

Another objective of this experiment was to assess how pervasive the effects of divided attention at encoding are on the specificity with which episodic memories can be remembered. It is well established that divided attention during encoding affects memory performance (e.g., Baddeley et al., 1984; Craik et al., 1996; Greene et al., in press; Kilb & Naveh-Benjamin, 2007; Murdock, 1965; Naveh-Benjamin et al., 1998, 2003). What is less well understood is whether these effects on memory performance are attributable to deficits in memory at very specific levels of representation or if such effects extend to even less detailed information in memory. Some evidence suggests that divided attention may only affect very specific information in memory, as Dodson et al. (1998) showed using a source-monitoring task, in which a group of young adults who completed the test phase while simultaneously carrying out a concurrent task were impaired in their memory for specific source information (e.g., Was it Male 1 or Male 2 who spoke a sentence?) but not partial source information (e.g., Was it a male or a female who spoke a sentence?). However, the study by Dodson et al. (1998) manipulated divided attention at retrieval, and effects of divided attention at encoding are more pronounced than those of divided attention at retrieval (e.g., Craik et al., 1996, 2018). Thus, it is conceivable that divided attention at encoding may also affect less detailed information in memory.

Method

Participants

Ninety young adults participated in Experiment 2. Forty-four were randomly assigned to the full attention condition (age: M = 18.55, SD = .70, range 18–20) and 46 to the divided attention condition (age: M = 18.56, SD = .96, range 18–22). Most participants in each group self-identified as female (59.1% and 56.5% for the full and divided attention conditions, respectively), and the mean years of education were 12.32 for the full attention condition and 12.40 for the divided attention condition. Participants were recruited from undergraduate psychology courses to participate in exchange for research credits and completed the study online.

Materials, Procedure, and Analyses

The same materials from Experiment 1 were used, and the procedure was mostly identical. The only exception was for the divided attention group, who completed the study phase of the procedure while simultaneously completing an auditory choice reaction time (CRT) task used in previous divided attention paradigms (e.g., Naveh-Benjamin et al., 1998, 2003). For the CRT task, participants attended to a series of three different audible tones (low, medium, and high pitch). Tones were presented every 2 s during the study phase, and participants were instructed to respond as quickly and accurately as possible by pressing the “V,” “B,” or “N” key for low-, medium-, and high-pitched tones, respectively. Participants in the divided attention group also completed a baseline phase of the auditory CRT task before the first block and after the last block of the experiment. During this phase, participants completed the CRT task without simultaneously studying face-scene pairs. This phase was done both to familiarize participants with the CRT task and to obtain baseline measures of accuracy and response times to the CRT task. All other procedures were identical between the full and divided attention conditions. The analysis plan followed that from Experiment 1, with the exception that, rather than measuring age differences, we measured attention differences (coded as −1 = divided, 1 = full).

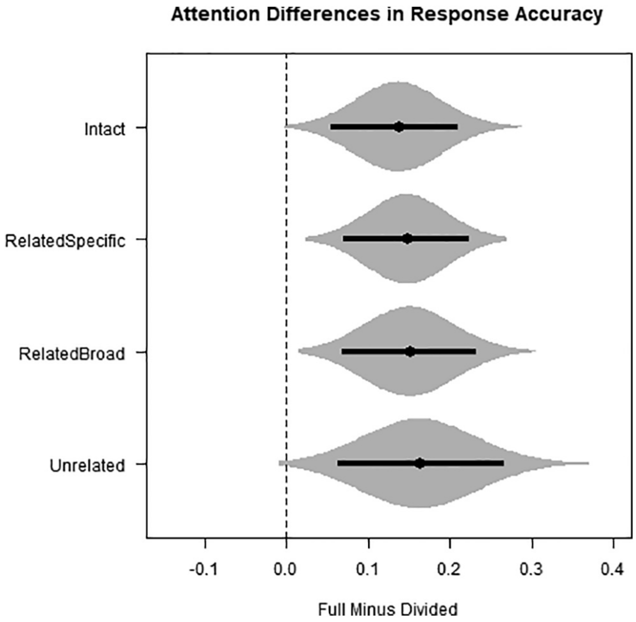
Results

Memory Accuracy Results

Divided Attention Disrupts Memory Across Levels of Specificity. Proportion correct for each probe for participants under the full and divided attention conditions of Experiment 2 is depicted in Figure 2b. Whereas older adults in Experiment 1 were only significantly worse than young adults at correctly classifying related-specific probes and to a lesser extent related-broad probes, young adults under divided attention in Experiment 2 appeared to be worse than young adults under full attention at correctly classifying all probes. In support of this, the results of the logistic regression analysis provided credible evidence for an effect of attention, $\beta_{\text{Attention}}$ = .45, 95% HDI [.28, .59], but no credible evidence for attention by probe interactions (as all 95% HDIs encompassed 0), indicating that accuracy was higher for the participants in the full attention at encoding condition. This is shown in Figure 6, where there is clear evidence that the 95% HDIs for each attention contrast on the probability scale credibly differed from 0. Indeed, the magnitude of the attention effect was about equivalent

Figure 6

Violin Plots of Posterior Density (Gray Distributions), Posterior Mean (Black Points), and 95% HDIs (Horizontal Black Lines) for Attention Contrasts (Full Minus Divided) for Each Probe in Experiment 2



Note. Ninety-five-percent HDIs that overlap with the dashed line at 0.0 indicate no credible evidence for a difference in response accuracy between young and older adults.

for all probes, with a mean difference and 95% HDI in accuracy on the proportion scale of (full minus divided) .14 [.06, .21] for intact probes, .15 [.08, .22] for related-specific probes, .15 [.07, .23] for related-broad probes, and .16 [.07, .26] for unrelated probes. These results suggest that divided attention at encoding had a generally disruptive effect on associative episodic memory, in contrast to our results in Experiment 1, which suggested that age-related deficits scaled with the amount of specificity needed to be retrieved.

We also assessed whether these effects of divided attention held when we excluded responses for which participants expressed low confidence in their decisions as many of these responses were likely random guesses. There were about twice as many low-confidence trials in the divided attention condition (*n* = 626 out of 5,520 trials) than in the full attention condition (*n* = 320 out of 5,280 trials). However, excluding these trials did not change the effects reported above. Difference scores and 95% HDIs, obtained by subtracting the posterior estimated proportion correct of the divided attention group from the full attention group, were the following: for intact probes, .12 [.04, .19], for related-specific probes, .15 [.06, .23], for related-broad probes, .15 [.07, .24], and for unrelated probes, .13 [.03, .23].

Errors to Recombined Probes Support Levels of Specificity in Associative Episodic Memory Under Full Attention but Less so Under Divided Attention in Young Adults. The proportion of errors (erroneous "intact" responses) to each type of recombined probe for the full and divided attention conditions of Experiment 2 is depicted in Figure 3b. As depicted, accuracy appeared to improve in the full attention group as a function of decreasing similarity of the recombined probes to studied pairs, whereas in the divided attention group, response accuracy initially improved (from related-specific to related-broad probes) but remained constant from related-broad to unrelated probes. The model-implied differences and 95% HDIs in response accuracy (related-broad minus related-specific probes) were .13 [.08, .18] for the full attention group and .13 [.07, .19] for the divided attention group, while for differences in response accuracy for unrelated minus related-broad probes, there was credible evidence for a difference for the full attention group, .05 [.02, .09], but not the divided attention group, .04 [−.01, .10]. These results show that under either full or divided attention at encoding, young adults had a higher tendency to mistakenly endorse highly similar probes (related-specific probes) than less similar probes (related-broad probes) as intact, but only young adults under full attention had a higher tendency to endorse related-broad probes, which maintain a fuzzier degree of representation to originally studied pairs, rather than unrelated probes as intact.

Confidence-Accuracy Results

Confidence-accuracy curves for Experiment 2 are depicted in Figure 5b. The results of a 2 (Attention) × 4 (Probe) mixed-effects Bayesian ANOVA model on proportion correct accompanied by "high" confidence responses revealed decisive evidence for an effect of probe ($BF_{10} = 6.47 \times 10^7$) and positive evidence for an effect of attention ($BF_{10} = 8.54$), but the evidence for the interaction favored the null ($BF_{10} = .32$). Thus, there was a general effect of divided attention on the proportion of correct responses at high confidence, in contrast to the aging effects from Experiment 1, which were most pronounced for related-specific probes and were only anecdotally present for unrelated probes. Post hoc tests for the main effect of probe demonstrated that high-confidence proportion correct credibly differed between related-specific and all other probes (all $BF_{10} \geq 168.99$), indicating lower accuracy for the related-specific probes, but all other probes did not credibly differ from each other.

Importantly, a control analysis on low-confidence responses showed substantial evidence in favor of the null for the effects of probe ($BF_{10} = .15$), attention ($BF_{10} = .16$), and the interaction ($BF_{10} = .01$). Therefore, the above-mentioned results showing an effect of divided attention at encoding on response accuracy at high confidence cannot be explained by a general propensity for divided attention young adults to be more error-prone, regardless of their rated confidence.

Discussion

Compared to young adults who studied face-scene pairs under full attention, young adults who studied those pairs while simultaneously completing an auditory CRT had deficits in associative recognition performance for all probes. This is in contrast to the findings from Experiment 1, in which older adults were deficient in response accuracy for related-specific probes and to a lesser extent related-broad probes. These differences between aging and divided attention in the patterns of effects on accuracy suggest that divided attention at encoding may affect not only highly specific but also less specific information about associative memory to comparable extents, whereas age-related effects on associative memory are less pronounced as less specific information needs to be remembered.

Regarding their ability to gauge the likely accuracy of their memories, young adults under divided attention were prone to the same high-confidence errors to related-specific probes that older adults were. However, young adults in the divided attention at encoding condition of Experiment 2 were also less accurate than full attention young adults on intact, related-broad, and unrelated probes when endorsing high confidence in these decisions, whereas older adults' high-confidence errors were most pronounced for related-specific probes.

General Discussion

Greene and Naveh-Benjamin (2020b) suggested a levels of episodic memory specificity framework and demonstrated empirically that associations in episodic memory can be retrieved from multiple levels of specificity. This notion of levels of specificity has clear antecedents in earlier work, such as Craik's (2002) proposal that memory exists on a continuum, with no categorical break between episodic and semantic memory "systems." But Greene and Naveh-Benjamin's (2020b) framework has provided perhaps more concrete evidence for levels of specificity in episodic memory as they measured the specificity of associations between components of an event, which are proposed to lie at the core of episodic memory (e.g., Tulving, 1983). Here, we have expanded on this framework by using a somewhat different paradigm and providing more concrete evidence for a specificity gradient that includes remembering highly specific information about an episode (e.g., "This old man was in this park"), somewhat less specific information (e.g., "This old man was in some park"), and even less specific information (e.g., "This old man was outside"). We have also examined how the specificity with which associations are remembered may be affected by age-related changes and by disruptions of attention during encoding. Finally, we examined how capable individuals with impaired memories for highly specific details were at gauging the accuracies of their memories.

The principal findings of the present study were as follows. First, older adults' deficits in associative memory (e.g., Naveh-Benjamin, 2000) scaled with how much specific information needed to be remembered, being greatest for discriminating highly similar recombined pairs but virtually disappearing when discriminating completely dissimilar recombined pairs. These findings replicate and extend the central claims of Greene and Naveh-Benjamin (2020b) that aging is associated with deficits in specific memory for associations, using a different research paradigm. Second, dividing attention at encoding in young adults resulted in a more general deficit in associative memory, regardless of the amount of specificity that needed to be retrieved. Third, older adults were liable to making high-confidence errors when gauging the accuracy of their responses to highly similar distractor pairs (related-specific pairs) and, to a lesser extent, to less similar pairs (related-broad pairs), while divided attention young adults were more susceptible to errors when rating their memory judgments with high confidence for all probes. In the following sections, we discuss how these new findings relate to and expand upon several lines of research on memory, metamemory, aging, and attention.

Levels of Specificity in Episodic Memory

Our findings have important implications for theories of memory that suggest that episodic memory may be accessed on a continuum (e.g., Craik, 2002; Greene & Naveh-Benjamin, 2020b). Importantly, remembering complex episodic memories at highly specific levels of representation appears to be most liable to forgetting, in line with Surprenant and Neath's (2009) specificity principle of memory. Indeed, this was true of all participants in our experiments as the rates of erroneous "intact" responses to recombined face-scene pairs were highest for pairs that were highly similar to original pairs (e.g., from old man-Park 1 to old man-Park 2), were intermediate for pairs that maintained a fuzzier degree of representation (e.g., old man-forest), and were lowest for pairs that were completely dissimilar (e.g., old man-kitchen). However, older adults made more errors than young adults to related-specific probes, and to a lesser degree to related-broad ones, whereas younger adults under divided attention made more errors across all probe types. Thus, the ability to access or remember highly specific details of associations in memory appears to be more impaired for older adults than younger adults (under full attention). Also, this ability is impaired for young adults under divided attention, and dividing attention at encoding appears to impair the ability to later remember associations at even reduced levels of specificity.

Age Differences in Memory Specificity

Several studies have shown that older adults are impaired at discriminating highly similar foils from studied items (e.g., Koutstaal et al., 1999; Koutstaal & Schacter, 1997; Luo & Craik, 2009; Stark et al., 2013), which may be related to age-related failures of hippocampal pattern separation (Yassa et al., 2011) and a tendency to use a gist-based processing strategy (Tun et al., 1998). Our findings are in line with these studies but may speak more directly to age-related deficits in episodic memory (e.g., Zacks et al., 2000) as we measured memory for associations between items. Episodic memories are representations of past events in which items are bound in specific spatiotemporal contexts (Tulving, 1983). One leading hypothesis that attempts to explain older adults' episodic memory failures is an associative deficit hypothesis (Naveh-Benjamin, 2000), which attributes these failures to age-related impairments in binding different components of an episode into a holistic unit. The evidence from the present study, coupled with that from Greene and Naveh-Benjamin (2020b), suggests that older adults may fail to bind or retrieve these bound representations at highly specific levels of representation but have smaller deficits at retrieving less specific information about associations.

Our findings are not entirely in line with those of an earlier study by Simons et al. (2004), who found that older adults were impaired at remembering both specific- and partial-source memory for spoken sentences. According to those results, we should have expected to observe age-related differences even for unrelated pairs. This is an interesting discrepancy that we hope will motivate continued research on this topic, but we can tentatively suggest some plausible reasons for this discrepancy. In the Simons et al. (2004) study, the items (sentences) were presented visually and auditorily simultaneously, whereas all of our stimuli were presented visually. Older adults in our study had normal or corrected-to-normal vision, but no assessments of hearing capabilities were reported by Simons et al. (2004). It is possible that older adults with hearing problems may have tried harder to focus on the specific sentence, perhaps allocating less resources to focusing on specifically which voice uttered the sentence (for a similar sensory-based mechanism within the associative memory paradigm, see Naveh-Benjamin & Kilb, 2014). It is also documented that older adults have a more severely limited working memory capacity than younger adults, and their ability to encode information from multiple sensory modalities is especially limited (Greene et al., 2020). Also, the voices in their study were all young adults, and some research suggests that older adults may perform better on associative recognition tasks when trying to remember characteristics of people their own age (e.g., Peterson et al., 2017).

Our results cannot definitively speak to whether age-related deficits in highly specific associative memory result from encoding or retrieval failures. However, some related work suggests that older adults' specificity deficits may be related to retrieval processes (e.g., Jacoby et al., 2005; Luo & Craik, 2009). For instance, Jacoby et al. (2005) showed that older adults were less likely than younger adults to engage in deep processing during retrieval in a memory-for-foils paradigm, in which new items were better recognized among young adults in a final recognition test when those new items were foils to targets from a deep-encoding condition compared to a foils to targets from a shallow-encoding condition, whereas older adults' memory for foils did not differ between the deep and shallow conditions. Jacoby et al. (2005) argued that older adults are less likely to engage in deep processing at retrieval, which could underlie older adults' specificity deficits observed in the present study. However, it is also possible that deficits at encoding, such as limited working memory capacity (e.g., Greene et al., 2020), which may constrain the amount of information that becomes available in long-term memory (Forsberg et al., 2020; Fukuda & Vogel, 2019), may also play a role in older adults' specificity deficits.

Divided Attention Effects on Memory Specificity

Our finding that divided attention at encoding disrupted performance across all probes, including those that were least similar to original pairs, suggests that disruptions in attention may have more general effects on the representational quality of episodic memories than those effects observed with aging. The present set of results suggests that divided attention at encoding impairs young adults' ability to remember highly specific details of associations (e.g., "The old man was with Park 1 not Park 2") as well as less specific details (e.g., such as "The old man was with a park, not a forest") and also impairs their ability to correctly discriminate dissimilar pairs (e.g., old man-kitchen). One possibility is that, when attention is divided at encoding, the memory representations that are formed are less detailed or complete. As such, our results are in line with other studies using divided attention paradigms that suggest that attention is necessary for encoding information into memory (e.g., Craik et al., 1996; Naveh-Benjamin et al., 1998, 2003). However, our results go beyond earlier studies by probing precisely how much specific associative information about studied pairs participants who studied those pairs under divided attention could remember.

Diminished attentional resources have also been proposed to underlie age-related deficits in memory (Craik & Byrd, 1982). There were some notable similarities between the divided attention group and the older adults in terms of task performance. Specifically, both groups performed worse, relative to the baseline young adults under full attention, at correctly classifying related-specific and related-broad probes as recombined. However, there were also some notable differences. In particular, the divided attention group performed less accurately on all memory probes compared to the full attention young adults, in contrast to the effects of aging, which were observed for the most highly similar and somewhat less for less similar recombined pairs. Also, the rates of erroneous "intact" responses to related-broad and unrelated pairs were relatively similar in the divided attention group, but older adults made fewer "intact" responses to unrelated than related-broad pairs, in line with expectations from a levels of specificity framework, in which fewer "intact" responses should be given to those probes that are least similar to original pairs. Overall, these results suggest that the effects of dividing attention at encoding may extend to less detailed representations in episodic memory. As such, diminished attentional resources among older adults may be a plausible explanation for their deficits in specific associative memory but cannot as adequately explain why older adults, but not younger adults under divided attention, had preserved memory for associations at less specific levels of representation.

We have chosen to focus on the effects of divided attention at encoding, rather than effects of divided attention at retrieval, as the former is known to produce more marked deficits in memory performance (e.g., Craik et al., 1996; Greene et al., in press). Therefore, a major aim of the present study was to assess whether the pervasive effects of divided attention at encoding would manifest only as disruptions in highly specific information in associative memory or if these effects would extend to less specific information about associations in memory. In a previous study, Dodson et al. (1998) showed that divided attention at retrieval impaired specific- but not partial-source memory for spoken sentences, whereas here, we have shown that divided attention at encoding impacted highly specific and less specific associative memory. These divergent findings could speak to the ideas of Jacoby et al. (2005) showing that older adults engage in less elaborate processing during retrieval, which may underscore their deficits in specific associative memory.

Aging, Divided Attention, and Metamemory for Different Levels of Specificity

We also probed whether participants could calibrate their subjective confidence in their memory judgments with their observed memory performance. The confidence-accuracy curves depicted in Figure 5 show that accuracy generally increased, for all participants, as a function of confidence, especially for those probes for which participants did not need to retrieve many specific details (e.g., unrelated probes) or for which the probe was a perfect match with an originally studied pair (intact probes). The slopes were somewhat shallower for probes maintaining a fuzzy degree of representation to original pairs (related-broad probes) and shallowest for those probes that were highly similar to original pairs (related-specific probes). These findings suggest that there is a relationship between confidence and accuracy that depends on the amount of specificity that needs to be retrieved such that individuals are more susceptible to making errors even when rating their memory judgments with high confidence when more specific information needs to be remembered.

Importantly, older adults were most prone to making high-confidence errors for related-specific probes. This finding is in line with the misrecollection account (Dodson et al., 2007) by showing that older adults were most prone to making high-confidence errors on probes that require the greatest amount of specific memory retrieval in order to be correctly classified. Other studies have also shown that older adults are prone to high-confidence errors on associative recognition tasks (e.g., Fandakova et al., 2013). Our results extend on these studies by showing that the magnitude of these errors is greatest at higher levels of specificity (e.g., when participants need to remember specific details to classify related-specific probes as recombined) but smaller as less specific information is needed in order to classify an association as intact or recombined. Young adults under divided attention at encoding were more prone than full attention young adults to making errors at high confidence for all probes, regardless of the amount of specificity needed to be retrieved.

Conclusions

Overall, the current results indicate that episodic memory can be accessed on a continuum of specificity, providing empirical support for a levels of specificity framework (Greene & Naveh-Benjamin, 2020b) and in line with a specificity principle of memory (Surprenant & Neath, 2009). Results from the present study show that, along this continuum of specificity, the ability to remember information at the highest levels of specificity is markedly affected by aging, whereas access to information at lower levels of specificity is less affected by age-related changes. Somewhat in contrast to these age-related findings, dividing attention at encoding in young adults results in deficits in the ability to retrieve associations across levels of specificity, including at less detailed levels of representation. Older adults were also most prone to high-confidence errors when they failed to remember highly specific information in memory, whereas young adults under divided attention at encoding were susceptible to high-confidence errors regardless of the amount of specificity that needed to be retrieved.

Context

Our interest in understanding the nature of episodic memory representations evolved from Surprenant and Neath's (2009) proposal of universal principles of memory. In earlier work (Greene & Naveh-Benjamin, 2020b), we tested whether their proposed specificity principle could shed insight into the nature of older adults' associative memory deficits. Our finding that older adults could remember the associations at less detailed levels of representation, and more generally our preliminary evidence for a levels of specificity framework, motivated this additional research, in which we sought to assess whether individuals could gauge how accurate their memories were when retrieving less-detailed representations. As interest in the qualitative nature of memory grows in the field, we believe it is important to assess how the specificity of representations differs across age cohorts and whether individuals are aware of deficiencies in their memories when trying to retrieve specific information.

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