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Recollection, not familiarity, decreases in healthy aging: Converging evidence from four estimation methods

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Abstract

Although it is generally accepted that aging is associated with recollection impairments, there is considerable disagreement surrounding how healthy aging influences familiarity-based recognition. One factor that might contribute to the mixed findings regarding age differences in familiarity is the estimation method used to quantify the two mnemonic processes. Here, this issue is examined by having a group of older adults (N = 39) between 40 and 81 years of age complete Remember/Know (RK), receiver operating characteristic (ROC), and process dissociation (PD) recognition tests. Estimates of recollection, but not familiarity, showed a significant negative correlation with chronological age. Inconsistent with previous findings, the estimation method did not moderate the relationship between age and estimations of recollection and familiarity. In a final analysis, recollection and familiarity were estimated as latent factors in a confirmatory factor analysis (CFA) that modeled the covariance between measures of free recall and recognition, and the results converged with the results from the RK, PD, and ROC tasks. These results are consistent with the hypothesis that episodic memory declines in older adults are primary driven by recollection deficits, and also suggest that the estimation method plays little to no role in age-related decreases in familiarity.

Keywords

Aging; Recollection; Familiarity; Episodic Memory; Dual-Process Theory

It is well established that healthy aging is associated with declines in episodic memory (Drag & Bieliauskas, 2010; Hoyer & Verhaeghen, 2006; Light, 1991), but there is debate regarding the specific mnemonic processes that are affected. For instance, healthy older adults show larger deficits on free recall and associative recognition tests compared to yes/no recognition tests (Craik & McDowd, 1987; Old & Naveh-Benjamin, 2008; Schonfield & Robertson, 1966; Spencer & Raz, 1995). From a dual-process perspective (Yonelinas, 2002), these findings suggest that aging leads to a relatively selective deficit in recollection – the ability to retrieve qualitative information about a prior study event – but leaves familiarity-based recognition unaffected. However, evidence from methods designed to estimate the contribution of recollection and familiarity have led to mixed findings; some

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have reported selective recollection declines associated with healthy aging (Cohn, Emrich, & Moscovitch, 2008; Jacoby, 1999; McCabe, Roediger, McDaniel, & Balota, 2009; Parkin & Walter, 1992; Wolk, Mancuso, Kliot, Arnold, & Dickerson, 2013), whereas others have found that aging is associated with decreases in both recollection and familiarity (Duarte, Ranganath, Trujillo, & Knight, 2006; Düzel, Schütze, Yonelinas, & Heinze, 2011; Parks, 2007; Wang, de Chastelaine, Minton, & Rugg, 2012). While there are many differences across studies that could contribute to the discrepancies in the extant literature, one factor that has been proposed to account for the mixed findings is the estimation method (Light, Prull, La Voie, & Healy, 2000; Prull, Dawes, Martin, Rosenberg, & Light, 2006)

The most commonly used methods to estimate recollection and familiarity are the RK procedure (Gardiner, 1988; Tulving, 1985), the examination of receiver-operating characteristic curves with the dual-process signal detection model (the ROC procedure; Yonelinas, 1999), and the Process Dissociation (PD) procedure (Jacoby, 1991). In the RK procedure, participants are asked to provide introspective reports about their memory judgments such that they respond “Remember” when recognition is accompanied by the retrieval of specific details about the study event, and respond “Know” when recognition is based on familiarity in the absence of recollection (Gardiner, 1988; Tulving, 1985). Recollection and familiarity are estimated directly from the “Remember” and “Know” judgments using the independence remember-know formulas (Yonelinas & Jacoby, 1995). In a typical ROC experiment, participants report subjective experiences of how confident they are in their memory decision, usually with a 6-point confidence scale (e.g., “6-sure old”, “5-maybe old”, “4-guess old”, “3-guess new”, “2-maybe new”, “1-sure new”). The confidence responses are used to plot an ROC that relates the hit rate to the false alarm rate across multiple levels of confidence, or response bias, in a cumulative fashion (Yonelinas & Parks, 2007), and estimates of recollection and familiarity are derived by fitting the dual-process signal detection model to the observed ROC (Yonelinas, 1999). The PD procedure estimates of recollection and familiarity by comparing performance in a condition where both processes act in concert (i.e., inclusion) to a condition where the two processes act in opposition (i.e., exclusion) (see Jacoby, 1991). Unlike the RK and ROC procedures, recollection is estimated objectively as the ability to remember a specific source detail from the initial episode (e.g., such as when or where an item was studied), whereas familiarity is measured as the ability to recognize an item as old in the absence of objective recollection (Jacoby, 1991; Yonelinas & Jacoby, 2012).

Although the three methods discussed above typically lead to similar conclusions regarding recollection and familiarity (e.g., Rosenbaum, Carson, Abraham, Bowles, Kwan, Kohler, et al., 2012; Serra, Bozzali, Cercignani, Perri, Fadda, Caltagirone, & Carlesimo, 2010; Yonelinas et al., 2002; for review see Yonelinas, 2001a; 2002), recent evidence suggests that the estimation methods lead to divergent conclusions when examining the influence of healthy aging on familiarity-based recognition. Results from a recent meta-analysis found significant age-related reductions in familiarity in studies using the RK procedure, whereas familiarity was age invariant in studies using the ROC and PD procedures (Koen & Yonelinas, in press). In contrast, a study by Prull and colleagues (2006) examined the RK, ROC, and PD procedures in a single sample of young and older adults, and reported that age differences in familiarity were significant in the RK and ROC procedures, but not in the PD procedure. However, it is difficult to draw firm conclusions based on the existing evidence for a number of reasons. First, the differences between the estimation methods reported by Koen and Yonelinas (in press) are based on comparing age differences in recollection and familiarity across different studies. It is possible that differences between the older adult samples in the different studies account for the findings reported in Koen and Yonelinas (in press) (also see Prull et al., 2006). Second, the conclusions from Prull and colleagues (2006) were based on separately evaluating the RK, ROC, and PD tasks for age differences in recollection and familiarity. However, determining whether or not the estimation method truly moderates differences in recollection and familiarity requires a direct comparison of age differences observed across the three methods.

The above discussion highlights that additional work is needed to determine if the estimation method does indeed moderate age differences in familiarity. The primary goal of the present experiment was to determine if recollection and familiarity decrease with age, and whether or not the estimation method (i.e., the RK, ROC, and PD tasks) moderates age differences in the two mnemonic processes. We addressed the two limitations mentioned previously by assessing recollection and familiarity in a group of 39 older adults using well controlled RK, ROC, and PD recognition tests, and directly compared the observed age differences in recollection and familiarity between the three estimation methods. Based on the meta-analysis by Koen and Yonelinas (in press), we expect that the relationship between age and recollection will be significantly larger than the relationship between age and familiarity. If the estimation method moderates age differences in recollection or familiarity, we expect that the relationship between age and one or both of the mnemonic processes will be significantly different in magnitude across the three tasks.

It is important to point out that the RK procedure is unique in that estimates recollection and familiarity are derived directly from a participant's introspective memory reports. For the RK procedure to accurately assess age differences in recollection and familiarity, one must assume that young and older adults base their decisions on similar mnemonic information. This assumption is difficult to validate, and it is possible that older adults might base "Remember" and "Know" responses on the different mnemonic signals than do young adults. This issue has also arisen in the amnesia literature. Amnesic patients with recollection deficits have been reported to have difficulties understanding RK instructions, and sometimes use "Remember" responses even for highly familiar items that are not recollected (Aggleton et al., 2005; Baddeley, Vargha-Khadem, & Mishkin, 2001; Yonelinas et al., 2002). In order to ensure that different groups are using the "Remember" responses only for recollected items, strict RK test instructions have been developed in which participants are told to only provide a "Remember" response if they can retrieve qualitative information about the study event that they can report to the experimenter (e.g., Koen & Yonelinas, 2010; Yonelinas, 2001b). Several studies that have used strict RK instructions found that estimates of recollection and familiarity converge with estimates from other methods, such as the ROC procedure (for caveats, see Rotello, Macmillan, Reeder, & Wong, 2005). However, very few of the existing aging studies have used strict RK instructions (Koen & Yonelinas, in press), and there is evidence that variations in the specific details of the RK instructions can influence familiarity estimates in older, but not young, adults (McCabe & Geraci, 2009). Thus, it is possible that age-related familiarity differences in the

RK task could arise because of group differences in interpreting the distinction between "Remember" and "Know" responses, and not due to actual age differences in familiarity. In the study reported below, we use strict RK instructions (Yonelinas, 2001b) to reduce any confound that might be caused by age differences in interpreting the RK instructions (cf. Koen & Yonelinas, in press).

An additional aim of this experiment was to examine whether age-related decreases in recollection and familiarity estimated using a confirmatory factor analysis (CFA) model converges with results from the more widely used RK, PD, and ROC methods. The CFA method adopted here is theoretically motivated by dual-process theory, and proposes that recall relies more heavily on recollection compared to familiarity whereas recognition memory can be supported by both recollection and familiarity (Yonelinas, 2002). The recollection latent variable loads onto both recall and recognition measures, whereas the familiarity latent variable loads only onto recognition measures (Quamme, Yonelinas, Widaman, Kroll, & Sauvé, 2004; Unsworth & Brewer, 2009; Yonelinas et al., 2002; 2007). To date, only one study has used the CFA method to examine age-related decreases in recollection and familiarity (Yonelinas et al., 2007) and, as far as we are aware, no study has examined how results from the CFA method converge with results from the "standard" estimation methods (i.e., RK, PD, and ROC) within the same sample of participants. Here, we take the first step of addressing this shortcoming in the literature by examining the covariance between recall measures from the neuropsychological test battery and the hit and false alarm rates from the RK, PD, and ROC estimation tasks.

It is important to point out that the CFA approach has an added benefit of being able address a long-standing debate in the memory literature. In particular, this approach can dissociate between single-process and dual-process accounts of episodic memory (Quamme et al., 2004; Unsworth & Brewer, 2009). Although we have adopted a dual-process interpretation of the RK, ROC, and PD tasks described above, there are critiques about whether or not data derived from these tasks support a dual-process model over a single-process model (e.g., Dunn, 2004; 2008). Using CFA, we are able to empirically assess whether a single-process or dual-process model provides a better fit to the data. To do this, we contrast the goodness of fit measures for the dual-process model just described with a single-process model that has single latent factor that loads onto all recall and recognition measures.

Methods

Participants

Forty adults between 40 to 81 years of age from the Davis, CA community volunteered for this experiment and were financially compensated for their time. All participants reported good health prior to the study, and were screened for cognitive impairment with a neuropsychological test battery described below. One participant was excluded because of low performance on some of the neuropsychological test measures (> 2 standard deviations below the age-adjusted mean). Data from the remaining 39 participants contributed to reported analyses.

Materials

The neuropsychological test battery comprised the Mini-Mental State Exam (MMSE; Folstein, Folstein, & McHugh, 1975), Shipley (Shipley, 1940), and the Logical Memory (LM) I and II, Verbal Pairs (VP) I and II, Visual Reproduction (VR) I and II, and Forward/Backward Digit Span of the WMS-r (Wechsler, 1987).

The materials for the RK, ROC, and PD experimental tasks comprised 1230 words between 2 and 9 letters long. One hundred and fifty words were assigned to the RK task, a set of 300 words was assigned to each PD session, and a set of 240 words was assigned to the ROC session. For each task, the words were randomly assigned to conditions for each participant.

Procedure

Overview—The experiment was completed over a series of six sessions. The neuropsychological battery was always administered in the first session. Of the remaining five sessions, one session was for the RK task, two sessions were for the ROC task, and two sessions were for the PD task. The order of the RK, ROC, and ROC sessions was randomized for each participant. However, the first and second sessions of the PD and ROC phases were tested sequentially and separated by approximately 2 weeks. The RK and ROC tasks discussed below were the same as those reported in Yonelinas et al. (2002). Additionally, each task included deep and shallow encoding conditions[1]. To increase the stability of the parameter estimates, performance was collapsed across deep and shallow encoding conditions and the multiple sessions for the PD and ROC.

RK Recognition Test—In the RK procedure, participants heard 100 aurally presented words read by the experimenter. Participants made a shallow judgment (i.e., count the number of syllables) for the first and last 25 words in the study list, and made a deep judgment (i.e., pleasantness) for the 50 words in the middle of the list. Responses were made verbally and recorded by the experimenter. The study phase was self-paced such that the next word was read after the shallow or deep judgment was given.

Following the study phase, a recognition memory test was administered that comprised the 100 studied words intermixed with 50 new words presented one at a time on a computer in a random order. Participants made their recognition judgments by pressing keys on the keyboard labeled “R” for a “Remember” response, “K” for a “Know” response, and “N” for a “New” response. The strict RK instructions from Yonelinas (2001b) were used in the present study. Participants were instructed to give a “Remember” response if they were able to recollect a specific detail about the words presentation during the study phase (e.g., the word that was presented before or after, what thoughts they had when the word was presented, or what judgment they made to the word during the study phase). Importantly, these instructions emphasized basing decisions on details from the study episode, and that a “Remember” response should only be given if they could communicate the retrieved detail to the experimenter if asked. Participants were further instructed to make a “Know”

[1]Typically, tests of recognition memory comprise an equal number of previously studied (i.e., old) and unstudied (i.e., new) items. In the tasks reported here, there were more old items than new items. This is typical of tasks with more than one class of old items, like the deep and shallow encoding tasks used here (e.g., Yonelinas et al., 2002), and is useful in increasing the number of critical trials.

response when they believed the word was previously studied but they were unable to retrieve specific details about a prior occurrence. A “New” response was to be given in the event that participants believed the word was not previously studied. There was a 500 ms inter-trial interval between each test trial.

ROC Recognition Test—The study phase of the two ROC sessions was nearly identical to the study phase for the RK test, with the exception that participants were presented 160 words read aloud by the experimenter in each session. Participants counted the number of syllables for the first and last 40 words of each study phase, and rated pleasantness for the 80 words in middle of the list. Afterwards, a recognition test comprised of the 160 studied words intermixed with 80 new words was completed. Words were presented one at a time on a computer in a random order, and participants made their memory decisions using a 6-point confidence scale (i.e., “6-sure old”, “5-maybe old”, “4-guess old”, “3-guess new”, “2-maybe new”, “1-sure new”), and were instructed to use the entire range of confidence responses. Participants entered their responses using keys labeled 1–6 on the keyboard.

PD Recognition Test—Each PD session comprised two study phases and one recognition test phase. The first study phase was identical to that described for the ROC procedure (i.e., auditory presentation with syllable and pleasantness judgments). In the second study phase, participants studied 60 words presented visually on a computer. Each visually presented word appeared for 3 s, and followed by a 500 ms inter-trial interval. Participants did not make any judgment for visually presented words, and were instructed to learn the visually presented words for a later memory test. The two studied phases occurred in the above-described order in both sessions for all participants in both sessions.

Following the second study phase, participants were administered a recognition test comprised of the 160 aurally presented words, the 60 visually presented words, and 80 new words. Words were presented one at a time on a computer and the different trials types randomly intermixed. Participants were instructed to identify studied words as “old” and words that did not appear in the study list as “new”. For words identified as “old”, participants were further instructed to determine the modality the word appeared in during the study phase (i.e., auditory or visual). If they were unable to do so, participants were instructed to respond ‘unsure’. Participants entered their responses using keys labeled “old” and “new” on the keyboard, in addition to keys labeled “auditory”, “visual”, and “unsure”.

Data Analysis

Missing Data—Four participants had missing data for the PD task because they did not complete either PD session. Five participants had missing data in the RK task because they did not complete the RK session. No participant with missing data in the PD task had missing data in the RK task and vice versa.

One participant did not complete the second ROC session and five participants did not complete the second PD session. For these participants, the analyses were conducted using the data from the one completed session.

Neuropsychological Tests—In addition to the raw scores, a percent correct recall measure was calculated for the LM, VP, and VR neuropsychological tests. For each test the raw number of correct responses on the immediate and delayed versions were summed and then divided by the number of possible correct recall responses. These proportions served as the recall measures in the CFA method.

RK Recognition Test—The hit and false alarm rates were determined as the proportion of the sum of "Remember" and "Know" judgments given to old and new words, respectively. Recollection and familiarity estimates were obtained from the RK test phase using the independent remember-know formulas (Yonelinas & Jacoby, 1995). Recollection was calculated by subtracting the proportion of "Remember" judgments to new items from the proportion of "Remember" judgments to old items (i.e., Recollection = $R_{Old} – R_{New}$). Familiarity for old items was estimated as the proportion of old items that received a "Know" response divided by the proportion of items that did not receive an "Remember" response (i.e., $F_{Old} = K_{Old}/[1\text{-}R_{Old}]$). A familiarity estimate for new items was calculated in the same way using the proportion of new items that received "Remember" and "Know" responses (i.e., $F_{New} = K_{New}/[1\text{-}R_{New}]$). Finally, a corrected familiarity estimate was calculated as the difference between the F_{old} and F_{new} values (i.e., Familiarity = F_{old} - F_{new}).

ROC Recognition Test—The hit and false alarm rates were calculated as the cumulative proportion of "6-sure old", "5-maybe old", and "4-guess old" responses to studied and new items, respectively. Recollection and familiarity estimates were obtained by fitting the dual-process signal detection model (Yonelinas, 1999) to the confidence ROCs by minimizing the sum of squared errors. The dual-process signal detection model estimates recollection as a probability and familiarity as the discrimination index d'. A Microsoft Excel spreadsheet with this ROC solver, as well as the one described below for the PD model, is available at http://psychology.ucdavis.edu/Labs/Yonelinas/PWT/index.cfm?Section=9. The familiarity d' estimate for each participant was converted to a probability estimate so that recollection and familiarity were estimated in identical units across the three tasks. The conversion was achieved using the following formula (Yonelinas, 2002):

$$F_{\text{Probability}} = \Phi(F_{d'} + \Phi^{-1}(\text{FAR})) - \text{FAR}$$

where Φ is the normal cumulative distribution function, Φ^{-1} is the inverse of the normal cumulative distribution function, $F_{d'}$ is the familiarity estimate derived from the dual-process signal detection model, and FAR is the false alarm rate described above.

PD Recognition Test—Only responses to aurally presented words and new words were considered in the memory analysis of the PD task. The hit rate was calculated as the proportion of "old" responses given to aurally studied words regardless of the subsequent source memory response, and the false alarm rate was calculated as the proportion of "old" responses made to new items. Inclusion and exclusion performance was defined as the proportion of "old – heard" and "old – visual" responses, respectively. These proportions, in addition to the false alarm rates to new items, were used to calculate recollection and familiarity using an estimation algorithm that accounts for response bias in the PD task using signal detection theory (Yonelinas & Jacoby, 1996). Recollection is calculated as a probability and familiarity is calculated as the discrimination index *d′*. The familiarity *d′* estimate was converted to a probability using the formula described above for the ROC task.

Group Analysis—The data analyses were performed with PASW 18.0 and AMOS 18.0. For all models that are described below, missing data for the RK and PD tasks, which included hit rates, false alarm rates, and estimates of recollection and familiarity, were estimated using full information maximum likelihood estimation implemented in AMOS 18.0 (Arbuckle, 2007). The goodness of fit measure used to examine the models was the χ^2 statistic.

Results

In all of the analyses reported below, an alpha level of .05 was used to determine significance. The demographic data for the older adult sample, along with average performance on the neuropsychological battery is reported in Table 1. In addition, we calculated discrimination (*d′*) and response bias (*c*) metrics for the RK, ROC, and PD tasks using the overall hit and false alarm rates described in the Methods section[2]. Age showed a significant negative correlation with LM II, VR II, Forward Digit Span, and the *d′* index for the PD task (see right column in Table 1).

Age-Related Decreases in RK, PD, and ROC Estimates of Recollection and Familiarity

A covariance matrix was defined in AMOS to examine the relationship between age and the estimates of recollection and familiarity obtained from the RK, ROC, and PD procedures. The standardized covariances (i.e., correlations) are reported in Table 2, and Figure 1 presents the scatter plots showing the relationship between age and estimates of the mnemonic processes. Age negatively covaried with estimates of recollection to a similar degree in all three methods (all p's $< .05$; top row of Figure 1). However, age did not significantly covary with any of the familiarity estimates derived from the RK, ROC, and PD tasks (all p's $> .40$; bottom row of Figure 1). These results are consistent with previous findings indicating that recollection, not familiarity, decreases with age.

The primary aim of this experiment was to directly compare the magnitude of age-related differences in recollection and familiarity across the RK, PD, and ROC procedures. This was accomplished in AMOS by placing equality constraints on the covariance between age and the recollection and familiarity estimates derived from the three methods. The logic behind this approach is that the equality constraints will produce a measurable amount of deviation from the observed pattern of covariances with no constraints. A significant amount of deviation, measured here as χ^2, would indicate that the estimation method moderates the magnitude of the covariance between age and estimates of recollection and familiarity.

[2]Missing data for the *d′* and *c* measures were not estimated. Also, note that two participants (one in the RK task and one for the PD task) did not false alarm to any new items. The *d′* and *c* metrics are undefined with a false alarm rate of 0. To estimate *d′* and *c* for these data points, we estimated the false alarm rate using the 1/2N correction described by Macmillan and Creelman (2005), where N is the number of trials (in this case, the number of new items).

Directly comparing the age-related decrease in recollection and familiarity between the RK, PD, and ROC procedures indicated that the observed aging effects were similar across the three methods. Specifically, an equality constraint on the covariance measures involving age and estimates of recollection (i.e., $Age \Leftrightarrow R_{PD} = Age \Leftrightarrow R_{RK} = Age \Leftrightarrow R_{ROC}$) did not produce a significant amount of deviation in the covariance matrix, $\chi^2(2) = .49$, $p = .78$. Moreover, an equality constraint placed on the covariance measures between age and estimates of familiarity (i.e., $Age \Leftrightarrow F_{PD} = Age \Leftrightarrow F_{RK} = Age \Leftrightarrow F_{ROC}$) did not produce a significant amount of deviation, $\chi^2(2) = .74$, $p = .69$. Importantly, a model that incorporated both of the equality constraints just described provided an acceptable fit to the data, $\chi^2(4) = 1.45$, $p = .84$. These results do not provide any evidence suggesting that age differences in familiarity differ between the RK, PD, and ROC methods.

A second aim was to determine if the magnitude of the age differences in recollection was significantly higher than age-related changes in familiarity. To examine this, a model was derived that placed an equality constraint on all covariances involving age with recollection and familiarity estimates (i.e., $Age \Leftrightarrow R_{PD} = Age \Leftrightarrow R_{RK} = Age \Leftrightarrow R_{ROC} = Age \Leftrightarrow F_{PD} = Age \Leftrightarrow F_{RK} = Age \Leftrightarrow F_{ROC}$). Importantly, this constraint is valid because the recollection and familiarity estimates are in identical units. The amount of deviation produced by the above equality constraint was determined by comparing this model to the model described previously that incorporated the equality constraints across the three methods. The equality constraint produced significant amount of deviation, $\chi^2(4) = 8.33$, $p < .01$. This finding suggests that aging is associated with a significantly larger decrease in recollection estimates compared to familiarity estimates. Together, these results demonstrate that (1) that chronological age has a significant negative relationship with estimates of recollection, but not estimates of familiarity, (2) that the covariance between age and recollection is significantly more negative than the covariance between age and familiarity, and (3) that there was no evidence the estimation method moderated age differences in familiarity.

Age-Related Decreases in CFA Estimates of Recollection and Familiarity

A third aim of the present investigation was to determine if estimating recollection and familiarity with CFA produced a similar pattern of results to those obtained from estimating the mnemonic processes with the RK, ROC, and PD approaches. The covariances between age, the recall measures, and the hit and false alarm rates from the recognition tests are shown in Table 3. Figure 2 depicts the structure of the model used to relate latent variable estimates of recollection and familiarity with chronological age, along with the best-fitting parameter estimates. Similar to previous studies (e.g., Quamme et al., 2004; Yonelinas et al., 2007), the recollection latent variable loaded onto the recall measures from the neuropsycholgical test battery (i.e., percent correct on LM, VP, and VR) and the hit rates from the RK, PD, and ROC recognition tests. The familiarity latent variable loaded onto both the hit and false alarm rates from the RK, ROC, and PD recognition tests.

The model in Figure 2 provided an acceptable fit to the data, $\chi^2(30) = 39.25$; $p = .12$. The covariances between CFA estimates of recollection and familiarity with chronological age were consistent with the results reported above for the RK, PD, and ROC estimates of recollection and familiarity. Specifically, the parameter estimates showed that age significantly covaried with recollection (p = .01), but not with familiarity (p = .36). Similar to the analyses reported in the previous section, a model that constrained the covariance between age and recollection to be equal to the covariance between age and familiarity resulted in a significant amount of deviation from the CFA model shown in Figure 2, $\chi^2(1)$ = 5.85, p = .02. This demonstrates that with the CFA model, age differences in recollection were significantly larger than age differences in familiarity.

As discussed in the Introduction, the CFA approach is also useful in dissociating between single-process and dual-process models of memory. Although the dual-process CFA model presented above fit the data at an acceptable level (i.e., it was not statistically rejected), it is possible that a single-process CFA model with one latent variable will provide a better fit, and thus a more parsimonious explanation of the current data. However, the model with a single latent variable that loaded onto the recall and recognition data was statistically rejected, $\chi^2(35) = 80.62$; $p < .001$. In our opinion, this finding rules out a single-process model interpretation of the data from the CFA method (see also Quamme et al., 2004). The results from the CFA models are in agreement with the results from the RK, PD, and ROC analysis in showing that recollection significantly decreases with chronological age to a larger degree than familiarity.

Discussion

The primary focus of this experiment was to determine how recollection and familiarity differ as a function of age and to examine if the RK, ROC, and PD estimation methods moderate age-related decreases in recollection and familiarity. To achieve this, we administered RK, ROC, and PD recognition memory tests to a group of healthy older adults between 40 and 81 years of age. The results showed that estimates of recollection, but not familiarity, had a significant negative covariance with chronological age. Importantly, this pattern of results, and in particular the covariance between familiarity and age, was statistically identical when recollection and familiarity were estimated from the RK, PD, and ROC methods. Additionally, the relationship between age and recollection was significantly more negative than the relationship between age and familiarity. A similar pattern of results was also observed when estimates of recollection and familiarity were estimated using a CFA model of the covariance between recall performance on the neuropsychological test and the hit and false alarm rates from the RK, PD, and ROC tasks. Thus, the converging results from the four estimation methods are consistent with previous findings indicating that healthy aging selectively affects recollection to a greater extent than familiarity (e.g., Anderson et al., 2008; Howard, Bessette-Symons, Zhang, & Hoyer, 2006; Jacoby, 1999; Jennings & Jacoby, 1993; 1997; Luo, Hendriks, & Craik, 2007).

One important limitation about the current data is that the sample size is relatively small. Our sample size was approximately half that used by Prull and colleagues (2006), who concluded that the estimation method moderated age differences in familiarity. This makes it difficult to conclude that the estimation method has absolutely no effect on familiarity differences, or that age has absolutely no effect on familiarity. It is possible that our null findings were due to a lack of power.

However, if our results happen to be an accurate in showing that the estimation method does not moderate age differences in familiarity, then how do we reconcile our results with those reported by Prull and colleagues (2006)? The hypothesis that the estimation method moderates age differences in familiarity predicts that age-related decreases in familiarity estimates will significantly differ in magnitude across the RK, ROC, and PD tasks. In other words, age should interact with the estimation method. The findings reported by Prull and colleagues do not fully support this hypothesis. As discussed in the Introduction, Prull and colleagues conclusion was based on considering young and older adults' memory performance in each task separately. The interaction between age and estimation method was not reported from what we can tell. In our opinion, the data reported by Prull and colleagues (2006) does not provide the strongest evidence that the estimation method moderates age-related decreases in familiarity for two reasons. First, although age-related familiarity impairments were only significant in the RK and ROC procedure, the same trend was also present in the PD task. This is evident from examining the effect sizes (i.e., Cohen's *d*; Cohen, 1988) calculated from the young and older adult estimates of familiarity. Although the effect sizes for the RK (d = .49), ROC (d = .64) and PD (d = .34) task differed numerically, all of the effect sizes were in the same direction. Second, and more importantly, when discussing the possibility of two separate familiarity processes, Prull and colleagues (2006) state:

> "If an age-sensitive familiarity process coexists with an age-invariant familiarity process, one might expect to see a main effect in such an analysis, such that the age difference in familiarity is reliably smaller for inclusion/exclusion relative to age difference in familiarity from any other method. However, we did not detect such an effect." (p. 115)

This statement suggests that age did not interact with the estimation method regarding familiarity estimates. However, this cannot be stated with certainty because the statistics for this comparison were not reported. Although at face value our results and those reported by Prull and colleagues (2006) seem to be inconsistent with one another, we believe the two sets of results actually converge for the reasons discussed above.

A recent meta-analysis by Koen and Yonelinas (in press) reported that age-related familiarity impairments were significant in studies using the RK procedure, but not in studies using the ROC and PD procedures. What can account for these apparent methodological differences? As we argued in the meta-analysis, it is possible that the ROC and PD procedures are biased in some fashion that makes it unlikely that age differences in familiarity will be observed. For instance, the ROC procedure might fail to detect familiarity differences because estimates of the two mnemonic processes are less reliable in one group than in the other group. The available evidence suggests, however, that this is not the case because the dual-process signal detection model provides similar quantitative fits to the data in both young and older adults (e.g., Healy et al., 2005; Parks, 2007; for further discussion, see Koen & Yonelinas, in press). We feel a more plausible scenario is that the RK procedure was biased in previous studies because of age differences in interpreting RK instructions. As discussed in the Introduction, familiarity differences could arise if older adults interpret the RK instructions differently than young adults, and incorrectly use "Remember" responses for items that are highly familiar. Indeed, familiarity estimates in older adults, but not young adults, can be influenced by varying some aspects of the RK instructions (McCabe & Geraci, 2009). To reduce this issue in the current study, we used strict RK instructions to help ensure that "Remember" responses were only given when the participant retrieved a qualitative aspect of the study event. While we contend that the nature of the RK instructions (i.e., strict versus standard) can account for the existing RK results, the findings presented here provide only weak evidence for this proposal. It is possible that testing a cross-sectional sample of older adults minimized age differences in interpreting the RK instructions by focusing exclusively on adults older than 40 years of age in the present study. Future research is needed that examines the impact of RK instructions, particularly comparing strict versus standard RK instructions, on age-related decreases in recollection and familiarity.

Although we found no evidence that the estimation method influenced our findings, it is important to point out that dissociations between different methods that are thought to index the same underlying mnemonic process might be useful diagnostic markers in other populations (Moulin, Souchay, & Morris, 2013). For instance, individuals diagnosed with autistic spectrum disorder have deficits subjectively reporting recollection experiences, but do not show impairments in source recognition, which is believed to be heavily dependent on recollection (Souchay, Wojcik, Williams, Crathern, & Clarke, 2013). Future work is needed to determine if dissociations between group differences in RK, ROC, and PD estimates of recollection and familiarity are useful in other populations. However, the current results and our above discussion suggest that differences between the RK, ROC, and PD procedures are not very robust in studies of recollection and familiarity in healthy older adults.

The results from the CFA model replicated prior research using a similar method (Yonelinas et al., 2007), and converged with the results from the RK, PD, and ROC tasks reported here. Additionally, the results from the CFA analysis ruled out a single-process model interpretation of the covariance between performance on recall and recognition tests (see also, Quamme et al., 2004). Although previous work with amnesic patients suggests that results from the CFA approach converge with the more widely used RK, PD, and ROC methods (Yonelinas et al., 2002), this is the first study we are aware of that has examined all four methods with the same sample of participants. Note that the CFA method was not directly compared to the RK, PD, and ROC methods because some of the data was shared between the estimation methods. Thus, it is unclear if results from the CFA method lead to a similar estimate of the magnitude of age-related decreases in recollection and familiarity or just a similar pattern of age-related decreases. Future work is needed to directly compare results obtained from this method with results from the RK, PD, and ROC methods using non-overlapping data.

The CFA approach of measuring recollection and familiarity has not been widely used to date. However, the results from the studies that have used this method are consistent with predictions generated from dual-process theory. For example, the duration of a hypoxic episode, which presumably positively correlates with the amount of hippocampal damage, shows a negative covariance with a latent variable estimate of recollection, but not with familiarity (Quamme et al., 2004). The success of the CFA method in measuring recollection and familiarity has important implications for aging research. Specifically, this approach could be used with existing data sets that have obtained numerous measures of recall and recognition from different neuropsychological tests (e.g., the Alzheimer's Disease Neuroimaging Initiative; Mueller et al., 2005) to examine recollection and familiarity-based episodic memory in memory impaired populations. Using the CFA method in such datasets might help resolve other debates in the literature, such as recollection and familiarity impairments in amnestic Mild Cognitive Impairment (Algarabel et al., 2012; Anderson et al., 2008; Wolk et al., 2013; Wolk, Signoff, & Dekosky, 2008), without having to recruit and test new patient samples.

In conclusion, the results observed across four separate estimation methods converged in showing that healthy aging is associated with a reduction in recollection, but not familiarity. Moreover, a direct comparison indicated that the aging effects were statistically comparable across the RK, ROC and PD methods. Lastly, we demonstrated that age-related differences in recollection were significantly larger than age-related decreases in familiarity. These findings help to resolve the ongoing debate regarding the fate of recollection and familiarity in healthy aging by suggesting that healthy aging is associated primarily with declines in recollection.

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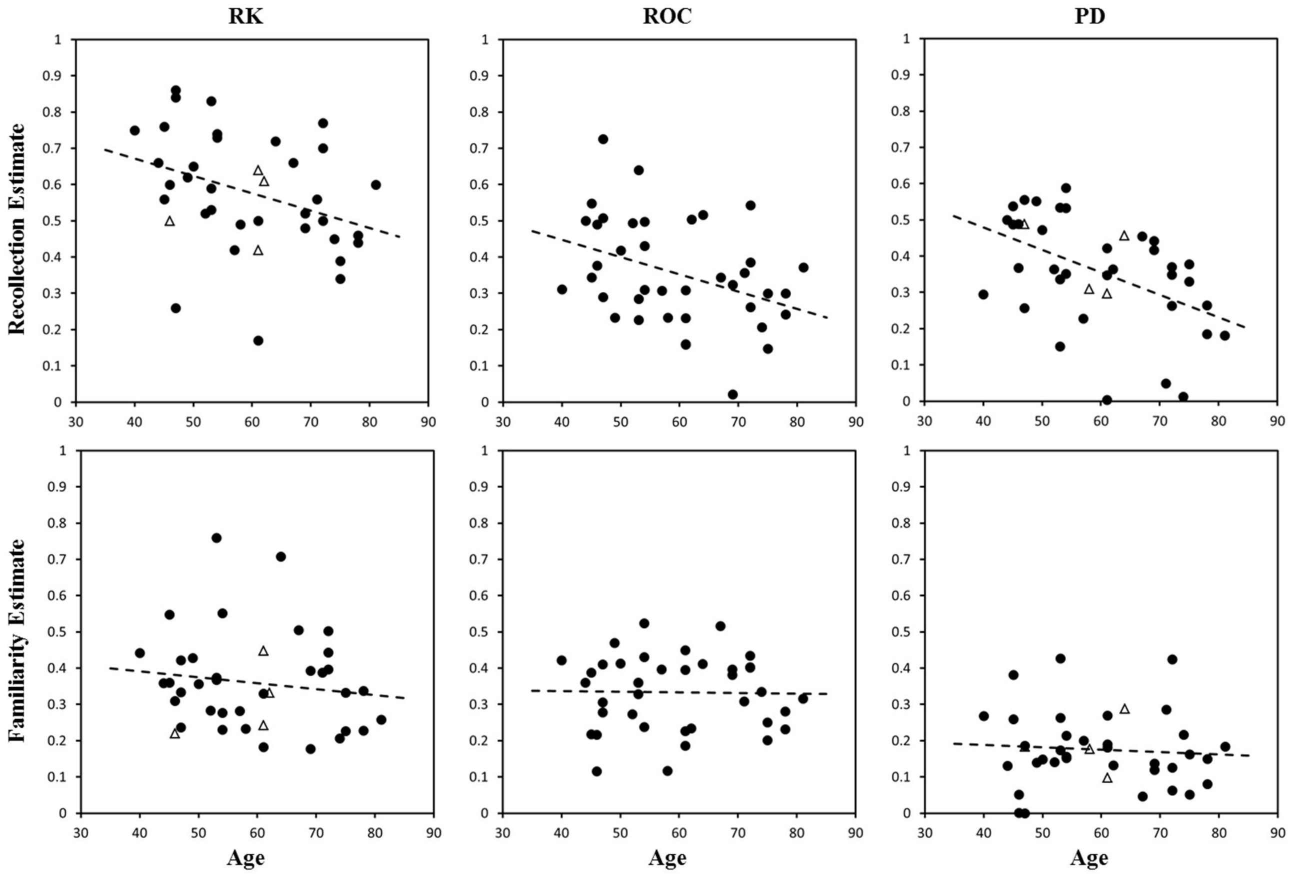

Figure 1.
Scatter plots showing the relationship between age and the probability estimates of recollection (top row) and familiarity (bottom row) for the remember/know (RK; left column), receiver-operating characteristic (ROC; middle column), and process-dissociation (PD; right column), andestimation methods. Note that solid circles represent observed data whereas open triangles represent imputed values for missing data calculated with AMOS (see Methods).

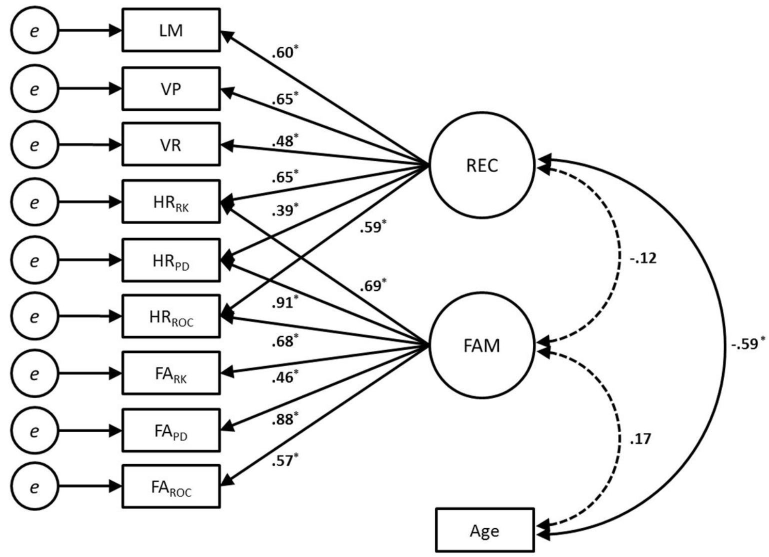

Figure 2.

A visual depiction of the confirmatory factor analysis (CFA) model used to examine the relationship between chronological age (a manifest variable), and the latent variables for recollection (REC) and familiarity (FAM) latent variables. REC showed a significant negative covariance with age, whereas FAM did not. The values shown in the figure are the standardized parameter estimates that provided the best fit to the data. LM = Logical Memory; VP = Verbal Pairs; VR = Visual Reproduction; HR = Hit Rate; FA = False Alarm Rate; RK = Remember/Know; ROC = Receiver Operating Characteristic; PD = Process-Dissociation; REC = Recollection Latent Variable; FAM = Familiarity Latent Variable. $^*p < .05$

Table 1

Sample demographics, raw scores on the neuropsychological test battery, and accuracy (d′) and response bias measures (c) on the RK, PD, and ROC tasks.

	Score	Correlation with Age
Age	59.41 (11.40)	-
Gender (M/F)	7/32	-
Years of Education	15.03 (1.66)	−0.18
MMSE	29.34 (.91)	−0.06
Shipley IQ	111.67 (7.94)	0.19
Logical Memory I	26.97 (7.94)	−0.21
Logical Memory II	23.08 (7.32)	−0.35*
Verbal Pairs I	19.13 (2.86)	−0.27
Verbal Pairs II	7.49 (.94)	−0.23
Visual Reproduction I	34.51 (3.42)	−0.17
Visual Reproduction II	31.72 (6.30)	−0.43**
Digit Span – Forward	8.85 (2.39)	−0.37*
Digit Span - Backwards	8.00 (2.27)	−0.09
d'_{RK} (N = 34)	1.93 (0.58)	−0.32†
d'_{ROC}	1.52 (0.32)	−0.27
d'_{PD} (N = 35)	1.25 (0.41)	−0.44**
c_{RK} (N = 34)	−0.06 (0.44)	0.12
c_{ROC}	0.23 (0.28)	0.18
c_{PD} (N = 35)	0.03 (0.45)	−0.09

Note. Standard deviations are provided in parentheses. The means, standard deviations, and correlations for the *d′* and *c* measures in the RK and PD tasks is based on subjects with the available data. Unless otherwise specified, the means, standard deviations, and correlations are based on N = 39.

† $p < 0.10$;

* $p < 0.05$;

** $p < 0.01$

Table 2

The standardized covariance matrix showing the relationship between age, and the estimates of recollection and familiarity derived from the RK, ROC, and PD methods.

	Age	R_{RK}	R_{ROC}	R_{PD}	F_{RK}	F_{ROC}	F_{PD}
Age	-						
R_{RK}	−.35*	-					
R_{ROC}	−.38*	.68**	-				
R_{PD}	−.47**	.55**	.43*	-			
F_{RK}	−.14	.55**	..47*	.37*	-		
F_{ROC}	−.02	.45*	.07	.27	.50**	-	
F_{PD}	−.07	.35†	.23	−.05	.46*	.13	-
M	59.41	.58	.36	.36	.36	.33	.18
SD	11.40	.16	.14	.15	.13	.10	.10

Note. The means, standard deviations, and standardized covariances (i.e., correlations) were obtained using AMOS 18.0 after estimating missing data. R = Recollection; F = Familiarity; RK = Remember/Know; ROC = Receiver Operating Characteristic; PD = Process Dissociation Procedure

† $p < 0.10$;

* $p < 0.05$;

** $p < 0.01$

Table 3

The standardized covariance matrix between age, the neuropsychological memory test scores, and the hit and false alarm rates from the RK, ROC, and PD tasks.

	Age	**LM**	**VP**	**VR**	**HR_{RK}**	**HR_{ROC}**	**HR_{PD}**	**FAR_{RK}**	**FAR_{ROC}**	**FAR_{PD}**
Age	-									
LM	$-.30^{\dagger}$	-								
VP	$-.31^{\dagger}$	$.55^{**}$	-							
VR	$-.38^{*}$	.25	.20	-						
HR_{RK}	−.22	$.30^{\dagger}$	$.40^{*}$	.22	-					
HR_{ROC}	$-.30^{\dagger}$	$.34^{*}$	$.37^{*}$	.11	$.75^{**}$	-				
HR_{PD}	−.09	.18	.24	−.03	$.79^{**}$	$.75^{**}$	-			
FAR_{RK}	.07	.12	.07	.09	$.49^{*}$	.18	$.37^{*}$	-		
FAR_{ROC}	−.04	−.01	.10	.00	$.38^{*}$	$.49^{**}$	$.50^{**}$	$.59^{**}$	-	
FAR_{PD}	.20	.02	−.01	$-.29^{\dagger}$	$.47^{*}$	$.58^{**}$	$.76^{**}$	$.36^{*}$	$.50^{**}$	-
M	59.41	.50	.87	.81	.81	.69	.71	.20	.17	.28
SD	11.40	.13	.09	.10	.12	.11	.14	.13	.08	.14

Note. The means, standard deviations, and standardized covariances (i.e., correlations) were obtained using AMOS 18.0 after estimating missing data.

LM = Logical Memory; VP = Visual Pairs; VR = Visual Reproduction; HR = Hit Rate; FAR = False Alarm Rate; RK = Remember/Know; ROC = Receiver Operating Characteristic; PD = Process Dissociation Procedure;

† $p < 0.10$;

* $p < 0.05$;

** $p < 0.01$