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Inter- and Intraindividual Variability in Recognition Memory: Effects of Aging and Estrogen Use

Domonick J. Wegesin and Yaakov Stern
Columbia University

Traditionally, studies of cognitive aging have focused on comparing the average performance of younger and older adults, whereas variability around the mean has been attributed to task-irrelevant noise. The present study examined the hypothesis that variability in memory performance increases with age and that estrogen helps temper age-related increases in variability. Postmenopausal estrogen users, estrogen and progestin (est + prog) users, and nonusers, as well as younger women, completed 16 blocks of an item–source memory task. Older women showed greater variability than younger women on measures of dispersion and consistency. Estrogen users, but not est + prog users, performed more consistently than nonusers. Overall, age-related increases in variability differed with the type of variability measured, and estrogen use, but not est + prog use, appeared to reduce age-related increases in at least 1 form of variability.

Traditionally, studies of cognitive aging have focused on comparing average performance levels between younger and older adults, whereas variability around the mean has been attributed to task-irrelevant noise. More recently, intraindividual variability, reflecting variation in performance within a task on a single occasion or for the same task administered on multiple occasions, has become the focus of interest (Anstey, 1999; Li & Lindenberger, 1999; Shammi, Bosman, & Stuss, 1998). At least two different elements of intraindividual performance variability can be measured independently (Hale, Myerson, Smith, & Poon, 1988). *Dispersion* reflects within-individual variability within a single condition on a single occasion. *Consistency* measures within-individual fluctuations in performance over multiple test occasions over time. Intraindividual variability is thought not only to index measurement error but also to reflect a "robust phenomenon in which there are reliable individual differences that are manifested consistently across quite different RT tasks" (Jensen, 1992, p. 869). In addition to these measures of intraindividual variability, interindividual variability can also be examined. *Diversity* reflects between-participants variability, in which the spread of scores for the group is being measured. In general, high variability is thought to reflect a reduction in performance quality. For example, in certain sports, success is evaluated in relation to one's ability to perform consistently (e.g., consistently hitting a bull's-eye with a dart).

Domonick J. Wegesin and Yaakov Stern, Division of Cognitive Neuroscience, Gertrude H. Sergievsky Center and Taub Institute on Alzheimer's Disease and the Aging Brain, Columbia University.

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Correspondence concerning this article should be addressed to Domonick J. Wegesin, Division of Cognitive Neuroscience, Gertrude H. Sergievsky Center, Columbia University, 630 West 168th Street, New York, NY 10032. E-mail: wegesin@sergievsky.cpmc.columbia.edu

It has been suggested that increases in intraindividual variability in cognitive function reflect neuropathological changes associated with neurological insult, aging, and disease (Li & Lindenberger, 1999; Stuss, Pogue, Buckle, & Bondar, 1994; Stuss et al., 1989). Compared with control participants, patients with traumatic brain injury have shown increased group variability or diversity (Hetherington, Stuss, & Finlayson, 1996; Stuss et al., 1989), greater intraindividual dispersion on reaction time (RT) measures (Hetherington et al., 1996), and decreased consistency in RT over time (Baker, Maurissen, & Chrzan, 1986). Increased variability in patients with traumatic brain injury may reflect frontotemporal pathology frequently associated with head injury (Hetherington et al., 1996). Further evidence of frontal lobe involvement in variability comes from data indicating that patients with frontal lobe dementia show greater diversity and less consistency compared with patients who have dementia of the Alzheimer type and with healthy elderly control individuals (Murtha, Cismaru, Waechter, & Chertkow, 2002).

Studies examining the effects of aging on performance variability have generally focused on measures of interindividual variability. Increased heterogeneity among older adults has long been part of gerontological doctrine (Botwinick & Thompson, 1968). In an archival study of RT, memory, and intelligence measures published in *Psychology and Aging* and the *Journal of Gerontology* from 1986 to 1990, Morse (1993) reported greater diversity in older participants on measures of RT, memory, and fluid intelligence but not on measures of crystallized intelligence. Age-related increases in diversity have also been documented in large community-based samples (Christensen et al., 1994) and in longitudinal studies (for review, see Nelson & Dannefer, 1992).

Few studies are available examining the effects of aging on dispersion. Anstey (1999) recently reported a significant relationship between age and several measures of intraindividual RT variability in a group of older women aged 60–90. Of the performance parameters in the Anstey study, the dispersion measures were those most consistently related to age. Shammi and colleagues (Shammi et al., 1998) reported age-related increases for a finger-tapping task but not for a choice RT or time-estimation task. West (2001) suggested that performance variability is greater on

tasks that place more demands on executive processes. He argued that executive processes fluctuate over time and that these fluctuations are more pervasive in older than in younger adults. Support for this hypothesis comes from data comparing RT dispersion between a choice RT task and a 1-back working memory task (West, Murphy, Armilio, Craik, & Stuss, 2002). Aging effects were revealed only in the working memory condition, which presumably required more executive control than the simple RT task.

Even fewer studies have examined the relationship of age and consistency. Information about age-related changes in consistency is of practical importance in evaluating cognitive change over time (e.g., in the clinical assessment of memory in patients with mild cognitive impairment or dementia). In one longitudinal study, intraindividual change in text recall was evaluated in a group of 7 women tested weekly for up to 2 years (Hertzog, Dixon, & Hultsch, 1992). Performance was highly variable across the 2-year period, with intraindividual recall ranging from 14% to 64%. The authors concluded that 20% of the variability in performance was stable and not due to practice effects, stimulus effects, or other systematic changes related to the study. A more recent study examined consistency in both younger women (ages 20–35) and older women (ages 60–75) on choice RT, finger-tapping, and time-estimation tasks. Within-session consistency was measured by dividing test sessions into 40-s intervals and comparing performance across these time intervals. Across-sessions consistency was also measured between two testing sessions separated by approximately 1 week (Shammi et al., 1998). Age-related differences in consistency were obtained for the time-estimation task, but this interacted with task conditions, such that the older women were less consistent between the two sessions for time estimations when completing a word-reading distracter task during the time estimation but not when estimating time without the distracter task. This finding supports West's (2001) contention that variability may vary, in part, with the executive processing demands of the task.

In sum, extant data suggest that age-related changes in diversity exist (for review, see Morse, 1993). That is, as a group, older adults are more heterogeneous than younger adults. However, data examining age-related changes in measures of intraindividual variability, that is, dispersion and consistency, are scarce. The present study contributes to the investigation of variability in aging by examining variability in an item–source recognition task that was administered 16 times over the course of a single testing session. On the basis of previous findings, we hypothesized that younger women would show less inter- and intraindividual variability compared with older women. In addition to aging effects, the effects of hormone use on measures of variability were explored.

Several studies have revealed effects of estrogen use on tests of verbal memory (Caldwell & Watson, 1952; Hackman & Galbraith, 1977; Jacobs et al., 1998; Kampen & Sherwin, 1994; Maki, Zonderman, & Resnick, 2001; Phillips & Sherwin, 1992; Robinson, Friedman, Marcus, Tinklenberg, & Yesavage, 1994; Sherwin, 1988), but to our knowledge no studies have examined how performance variability is related to estrogen use. Keenan, Ezzat, Ginsburg, and Moore (2001) recently proposed the prefrontal cortex as the site of estrogen's effects on cognition. For instance, estrogen use has been shown to be related to better performance on neuropsychological measures associated with frontal lobe function (e.g.,the Wisconsin Card Sorting Task; Schmidt, Nieman, & Rubinow, 1996; verbal fluency; Szklo et al., 1996; working memory; Duff & Hampson, 2000; Keenan et al., 2001; abstract reasoning; Fedor-Freybergh, 1977; Jacobs et al., 1998; Schmidt et al., 1996; Sherwin, 1988). Further, brain imaging studies have revealed effects of estrogen use within the frontal cortex on cognitive activation tasks (Berman et al., 1997; Resnick, Maki, Golski, Kraut, & Zonderman, 1998), and postmortem studies of the brain show high concentrations of estradiol in the prefrontal cortex (Bixo, Backstrom, Winblad, & Andersson, 1995). In light of the associations between (a) frontal lobe pathology and increased performance variability (Murtha et al., 2002; Stuss et al., 1989) and (b) estrogen use and frontal lobe function, we hypothesized that women taking estrogen would show less performance variability compared with women not taking estrogen.

Only a few studies are available that have compared the effects of estrogen versus estrogen and progestin (est + prog) on cognitive function, and these findings are mixed. Whereas a few have demonstrated that progestins counter the cognitive benefits associated with estrogen use (Janowsky, Carello, & Orwoll, 1999; Ohkura et al., 1995; Rice et al., 2000), at least three other studies have failed to show this negative effect (Hogervorst, Boshuisen, Riedel, Willekien, & Jolles, 1999; Maki et al., 2001; Sherwin & Tulandi, 1996). However, animal studies have shown that progesterone counters the beneficial effects of estrogens in the brain, such as neurite outgrowth (Woolley & McEwen, 1993) and arterial circulation (Sarrel, 1990). Further, medroxyprogesterone acetate, the type of progestin commonly used in combination hormone therapy (e.g., Provera), has been shown to be more potent than progesterone in attenuating the estrogen potentiation of glutamate toxicity in hippocampal neurons (Nilsen & Brinton, 2002a, 2002b). In the present study, we investigated whether the addition of progestins to estrogen therapy might mitigate any benefits on performance variability associated with taking estrogen alone.

Method and Materials

Participants

Sixteen younger women (ages 18–28) and 48 postmenopausal women (ages 60–80) recruited by community flyers, newspaper advertisements, and word of mouth participated in the study. Postmenopausal participants were divided into three groups. Estrogen users were current users of estrogen only. Est + prog users were current users of a combination of estrogen and progestin. Nonusers were women who were not currently taking and had never taken estrogen or progestin. All participants were paid for their time. The institutional review boards of Columbia University and the New York State Psychiatric Institute (New York, NY) approved the project, and all participants provided written informed consent.

Demographic profiles of the four groups are included in Table 1. Younger women reported being of a lower socioeconomic status (SES) than the older women, $F(3, 62) = 6.8$, $p < .01$, on a two-factor measure (occupation and education) of SES (Watt, 1976). This is attributable to their occupational status as student and may not accurately reflect their true SES. The three older groups did not differ on the SES measure. Younger women were also more ethnically diverse than the older groups, $\chi^2(9, N = 63) = 31.2$, $p < .01$. Estrogen users completed more years of education, $F(3, 62) = 3.8$, $p < .05$, than did younger women ($p < .05$) and nonusers ($p < .05$).

Table 1
Means and Standard Deviations of Demographic and Screening Measures

Variable	Younger women (n = 16)		Estrogen users (n = 15)		Est + prog users (n = 16)		Nonusers (n = 16)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age (years)	21.50	2.71	68.69	6.05	67.63	5.10	70.94	5.04
Education (years)	15.56	1.63	17.56	1.82	16.81	2.40	15.59	2.18
Socioeconomic status (Watt, 1976)	58.56	15.91	31.63	16.65	40.31	21.32	43.63	16.65
White (%)	37.50		100.00		87.50		93.80	
Black (%)	25.00				6.30		6.30	
Hispanic (%)					6.30			
Asian (%)	37.50							
Modified MMSE (Mayeux et al., 1981)	55.31	1.62	54.94	1.91	4.56	1.90	54.31	2.09
Depression (Gurland et al., 1984)			2.13	1.45	2.47	1.64	2.56	2.03
Dementia (Gurland et al., 1984)			0.69	0.70	0.33	0.62	0.75	1.00
ADL (Gurland et al., 1984)			1.19	1.38	1.07	1.62	1.75	2.74

Note. Est + prog = estrogen and progestin; MMSE = Mini-Mental State Examination; ADL = activities of daily living.

Procedures

Participants completed an initial telephone screening, followed by a more detailed screening in the lab. A semistructured interview (Gurland, Golden, Teresi, & Challop, 1984) was administered to older participants to ensure that they were free from depression and dementia and that they were not limited in the activities of daily living (see Table 1). For younger women, the experimental testing was scheduled to correspond with the preovulatory phase of the menstrual cycle, when estrogen levels should be high and progestin levels relatively low. Because of scheduling limitations, menstrual cycle phase was not controlled for the screening visit.

Screening

In an initial telephone screening, participants reported themselves to be native English speakers, in good physical health, and free from medications known to affect the central nervous system. The younger women completed a menstrual cycle questionnaire (Schechter, Bachmann, Vaitukaitis, Phillips, & Saperstein, 1989). Women included in the study reported a history of regular menstrual cycles without any skipped cycles or intracycle bleeding and no use of any hormone medications (e.g., birth control pills) in the last 12 months. There were no differences between the groups on a test of general cognitive status, the Modified Mini-Mental State Examination (Mayeux, Stern, Rosen, & Levethal, 1981).

Blood Assays

Compliance to hormone therapy in the hormone users was confirmed by collecting blood samples in which estradiol, E1-sulfate, and follicle-stimulating hormone were measured in serum by a commercial solid-phase, chemiluminescent immunoassay (Diagnostic Systems Labs, Webster, TX). The polyclonal antibodies used are highly specific with low cross-reactivity to other steroids or hormones. To help confirm menstrual phase, we measured progesterone levels in the younger women. An assay for the type of synthetic progestin used in the est + prog group was not available.

Serum assays were not available for 5 participants (1 estrogen user, 3 est + prog users, and 1 younger woman) because of either inability to draw blood at testing (2 participants) or technical difficulties in the lab (3 blood samples). Assay results, shown in Table 2, confirmed that estrogen users and est + prog users had higher circulating levels of estradiol, $F(2, 41) = 10.2$, $p < .01$, and E1-sulfate, $F(2, 41) = 7.7$, $p < .01$, than did nonusers and that the two hormone-using groups did not differ in their

Table 2
Means and Standard Deviations for Hormonal Assays, Hormone Replacement Histories, and Menopausal Data

Variable	Younger women (n = 15)		Estrogen users (n = 14)		Est + prog users (n = 13)		Nonusers (n = 16)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Estradiol (pg/ml)	71.2	55.6	45.4	31.8	45.0	29.2	16.1	33.2
Estrone (ng/ml)	7.9	1.4	10.6	11.8	8.0	5.7	2.0	1.7
Progesterone (ng/ml)	2.0	3.8						
FSH (mIU/ml)	4.8	3.5	49.5	24.0	35.6	27.5	74.2	16.8
Age at menopause (years)			47.9	3.6	49.6	3.9	49.1	3.9
Years of HRT			11.5	10.9	8.0	5.0		
No. of pregnancies	0.0	0.0	1.9	1.7	2.3	1.4	2.6	2.1
No. never pregnant	15.0		7.0		7.0		4.0	

Note. Est + prog = estrogen and progestin; FSH = follicle-stimulating hormone; mIU = milli International Units; HRT = hormone replacement therapy.

estrogen levels. As anticipated, nonusers showed higher levels of follicle-stimulating hormone than did the two hormone-using groups, $F(2, 41) = 8.9$, $p < .01$. The results suggest coherence to the self-reported hormone therapies. Younger women had higher levels of estradiol than all three groups of older women. In addition, high estradiol and low progesterone levels in the younger women were consistent with levels typical of the preovulatory phase of the cycle.

History of Hormone Use

Table 2 reports menopausal and hormone-use data of the older women. Of the estrogen users, the majority (11 women) used Premarin (0.625 mg/QD), and the remainder used alternatives (Ogen, Eustace, or Estrace). Of the est + prog users, 15 used Premarin (0.625 mg/QD), and 1 used Ogen. Provera was the most common form of progestin used (15 women). Most est + prog users ($n = 13$) followed the monophasic combination therapy (Prempro), taking both estrogen and progestin throughout the month. Cycle phase was not available for the 3 women taking Provera biphasically. Both estrogen and est + prog groups had been following these hormone regimens consistently for a minimum of 1 year and did not differ in their duration of hormone use, $F(1, 29) = 1.36$, $p > .10$. The older groups did not differ in the number of pregnancies. Data on hysterectomies were collected from 36 of the 48 older women by phone after the study was completed. Only 3 nonusers, of 11 reached by phone, did not report a hysterectomy.

Experimental Testing

The design of the study was based on the paradigm originally published by McKoon and Ratcliff (1979), modified by Howard, Heisey, and Shaw (1986), and revised for event-related potential recording by Trott, Friedman, Ritter, and Fabiani (1999). The present study focused on performance variability. A more detailed analysis of the overall performance levels has been published in studies dealing with the event-related potential data resulting from this task for the younger women and nonusers (Wegesin, Friedman, Varughese, & Stern, 2002) and for the estrogen users (Wegesin & Stern, in press).

The item–source recognition memory test included 16 study–test blocks. During the study phase, participants studied two separate lists of sentences of the following type: Noun 1–Verb–Noun 2 (e.g., *The chef created a spread*). Each list contained four sentences, for a total of eight nouns per list. Participants were instructed to memorize the two nouns, as well as the list in which they occurred, for a subsequent memory test. To enhance elaborative encoding, we asked participants to make subjective judgments of the study sentences, indicating whether they liked the sentence. No group differences were revealed for these subjective judgments. All groups reported "liking" approximately 68% of the sentences. To enhance encoding, we gave participants unlimited time to study the sentences, and their "like it" or "don't like it" judgments prompted the display of the next sentence. Analyses of study timing failed to reveal any group differences; participants studied each sentence for approximately 6.3 s, on average. To aid encoding of the study nouns, we arranged each sentence to appear twice within the list in randomized order. At the end of List 1, a line drawing depicting a nonverbal cartoon appeared, which was used to demarcate the two lists.

Immediately following the final "like it" or "don't like it" judgment of the second study list, a prompt reading *TEST* was presented for 5,000 ms to prepare participants for the onset of the test phase. During the test phase, nouns were presented sequentially in pairs, each with a 300-ms duration separated by a 2,000-ms interstimulus interval. A total of 256 sentences was divided into two sets, balanced for word frequency and length, and these sentences served as either targets or foils (counterbalanced across participants). Participants made speeded and accurate studied or unstudied recognition judgments for each of the two nouns (responding hands counterbalanced across participants). If either noun was judged to have been studied, that noun was re-presented, and a nonspeeded source (i.e., list) judgment was made. Source judgments were cued by prompts that read *LIST 1* and *LIST 2*, which were presented on the left and right lower corners of the computer screen (counterbalanced across participants).

Variability was examined for dependent variables from the experimental task, including the number of correctly identified studied words (hits) and unstudied words (correct rejections) as well as RTs to studied and unstudied items. Source memory scores reflect the percentage of correctly identified studied words that were subsequently attributed to the correct list.

Data Analyses

One concern in evaluating age-related changes in variability is that a direct comparison of group standard deviations is likely affected by differences in group means (Hale et al., 1988). This potential problem can be controlled for by using a coefficient of variation (CV), in which the standard deviation is divided by the mean (Murtha et al., 2002). If the standard deviation increases proportional to the mean, the CV will not show an aging effect. We therefore examined variability using CV measures to control for differences in overall group means.

Analyses of covariance (ANCOVAs) were conducted for item recognition speed and accuracy and for source recognition accuracy (because the source judgments were nonspeeded). Only items correctly identified as studied or unstudied were entered into the RT analyses. Education was covaried in these analyses because estrogen users completed more years of education than did the younger women and nonusers. The heterogeneity test for slopes for the effect of education on group was conducted and found to be nonsignificant and was thus removed from subsequent analyses. Because variability is predicted to differ according to the complexity of the mental operation under analysis (Jensen, 1992), responses to studied and unstudied items were analyzed separately to evaluate whether variability varied across word type.

Group differences were examined with planned contrasts of the educated and adjusted means to evaluate a set of a priori hypotheses. First, aging effects were evaluated by comparing the younger women to the three groups of postmenopausal women. Second, estrogen effects were evaluated by comparing the estrogen users to the nonusers. Finally, est + prog effects were evaluated by comparing the est + prog users to the nonusers. One estrogen user, an outlier who scored below chance on the experimental paradigm, was dropped from the analyses (the complete data set, including this outlier, is available from the authors). For repeated measures ANCOVAs, the Greenhouse–Geisser method was used to adjust the degrees of freedom for nonsphericity.

Results

A detailed analysis of the aging and estrogen effects on overall performance has been previously described (Wegesin & Stern, in press). For reference, overall task performance is reviewed in Table 3. Age-related declines were revealed on all experimental measures of the item–source memory task, including the number of correctly identified studied and unstudied words, the number of words attributed to the correct source, and RTs for identifying studied and unstudied words. Estrogen users outperformed nonusers at identifying studied and unstudied words and attributing studied words to the correct source. Est + prog users did not outperform nonusers on any of the experimental measures, but nonusers responded faster than est + prog users to correctly rejected unstudied items.

Diversity

Diversity, represented by the group's standard deviation, examined the spread of participants within each group. Both standard

Table 3
Means, Adjusted Means, and Standard Deviations for Experimental Measures

Measure	Younger women (n = 16)			Estrogen users (n = 15)			Est + prog users (n = 16)			Nonusers (n = 16)		
	M	M^a	SD^a	M	M^a	SD^a	M	M^a	SD^a	M	M^a	SD^a
Proportion of hits	92.73	92.78	6.88	89.51	89.39	7.33	86.56	86.58	6.44	83.11	83.16	6.86
Proportion of CRs	98.43	99.16	4.82	95.56	94.43	4.95	93.53	93.15	4.75	91.81	92.52	4.82
Source recognition	0.95	0.96	0.10	0.82	0.81	0.10	0.72	0.72	0.12	0.67	0.68	0.10
Hit RTs (ms)	794.81	804.08	150.07	968.54	949.22	160.06	1,059.48	1,055.38	115.95	973.28	982.12	149.77
CR RTs (ms)	798.54	798.96	131.18	976.17	975.31	139.92	1,040.94	1,041.88	101.75	952.83	953.22	130.92

Note. Est + prog = estrogen and progestin; CR = correct rejection; RTs = reaction times.
[a] Adjusted for education.

deviation and CV measures were analyzed to explore whether potential differences in variability could be attributable to differences in group means (Hale et al., 1988). Group differences in variability were examined using the ratio of the standard deviations and the ratio of the CVs in relation to the F distribution (Howell, 1987). Table 4 indicates significant aging effects in variability for correctly identifying unstudied words and attributing words to the correct source. However, these differences are due to ceiling performance in the younger women on both of these measures. Estrogen effects for diversity were noted in the standard deviation measures of unstudied item accuracy. However, in controlling for mean differences, the CV measure revealed no differences in diversity between estrogen users and nonusers. Finally, no differences in measures of diversity were revealed between est + prog users and nonusers.

Dispersion

Dispersion examined the spread of RT scores for an individual within a single condition and within a single testing block. To generate the individual CV measures, we divided the standard deviations of each individual's RT data for each block for each word condition by the individual's mean for that block and condition. The block (1–16) × word type (studied words vs. unstudied words) × group ANCOVA for intraindividual CVs revealed significant effects of word type and group. As shown in Figure 1, studied words were related to increased dispersion of RTs compared with unstudied words, $F(1, 58) = 8.2$, $p < .01$. Planned contrasts of group revealed aging effects, such that the younger women had lower CV scores compared with the older women, $F(1, 58) = 18.6$, $p < .01$. No hormone effects were obtained, as neither estrogen users nor est + prog users differed from the older nonusers.

Consistency

Across-blocks variation was measured as the standard deviation across the 16 blocks of each participant's mean score within each block. CV measures were calculated by dividing the resultant standard deviation by each participant's mean score. Lower CV scores reflect more consistent performance. Figure 2 illustrates CV scores of the participants for both accuracy and RT measures. The word type (studied words vs. unstudied words) × group ANCOVA for across-block consistency in performance accuracy revealed a main effect of group. Planned contrasts revealed that younger women performed more consistently across the 16 study–test blocks compared with all of the older women, $F(1, 58) = 21.5$, $p < .01$. Next, estrogen users performed more consistently across blocks compared with nonusers, $F(1, 58) = 6.73$, $p < .05$. No differences were revealed between est + prog users compared with nonusers. A similar analysis for the RT data revealed an aging effect, in which RTs for younger women were more consistent across blocks compared with RTs of older women, $F(1, 58) = 8.54$, $p < .01$. No effects of hormone use were revealed for RT consistency. Consistency did not vary by word type. Finally, the analysis of source recognition accuracy revealed that the younger women were more consistent than the older women in attributing words to the proper list, $F(1, 58) = 35.71$, $p < .01$, and

Table 4
F Values for Between-Groups Diversity for Accuracy and Reaction Time (RT) Measures

Measure	Younger vs. older women (dfs = 15, 46)		Estrogen vs. nonusers (dfs = 15, 14)		Est + prog users vs. nonusers (dfs = 15, 15)	
	SD	CV	*SD*	CV	*SD*	CV
Studied hits	2.25	1.60	2.02	1.54	1.73	1.37
Studied hit RTs	1.38	1.07	1.92	1.38	2.39	1.86
CRs	16.40*	4.42*	3.25*	1.88	0.67	0.83
CR RTs	1.46	1.03	1.38	1.20	2.06	1.70
Source recognition	7.51*	4.12*	1.08	1.28	1.18	1.13

Note. Est + prog = estrogen and progestin; CV = coefficient of variation; CR = correct rejection.
* $p < .05$.

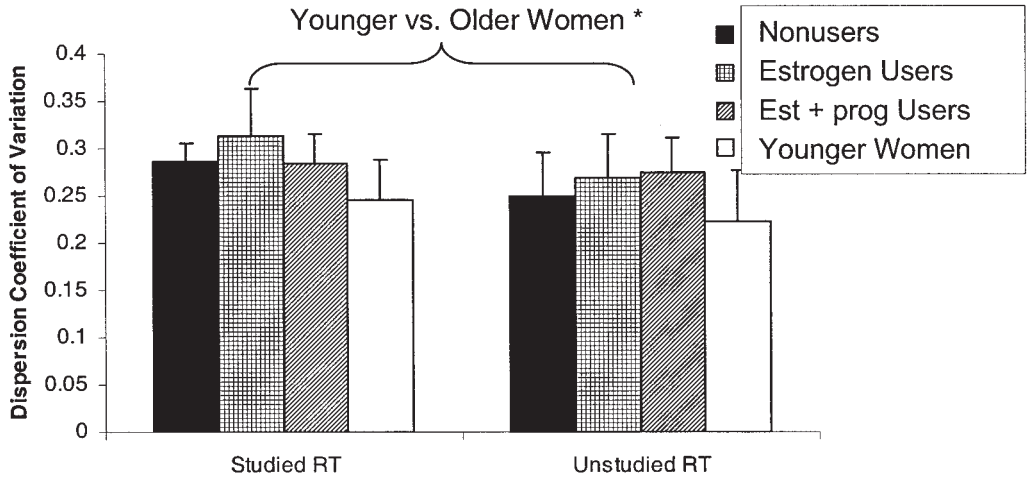

Figure 1. Mean reaction time (RT) dispersion for studied and unstudied words from the item recognition judgments averaged across the 16 blocks. Dispersion scores for older women were greater than those for younger women. Asterisks indicate significant group differences at $p < .05$. Error bars represent standard deviations. Est + prog = estrogen and progestin.

that estrogen users were more consistent than nonusers, $F(1, 58) = 7.81$, $p < .01$.

Relationship Between Variability and Accuracy Measures

A set of bivariate correlations, shown in Table 5, explored whether the CV measures of variability were related to overall performance among the full set of participants. Significance was evaluated with the use of a corrected p value to control for the number of bivariate correlations ($p = .05/35 = .01$). Note that lower scores reflect greater consistency. Thus, a negative relationship between consistency and accuracy indicates that more consistent performance is associated with greater accuracy. First, measures of RT dispersion were related to mean RTs, and this relationship was significant across both studied and unstudied words, though the significance of the relationship between hit RT

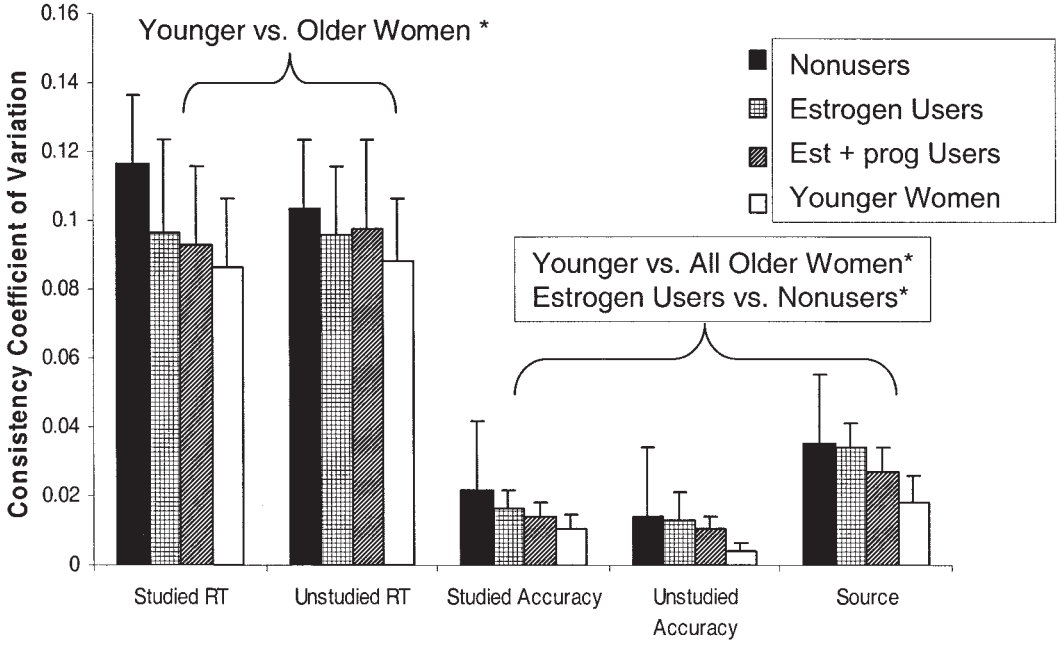

Figure 2. Mean across-blocks consistency for speed and accuracy measures on the item–source memory task. Asterisks indicate significant group differences at $p < .05$. Error bars represent standard deviations. RT = reaction time; est + prog = estrogen and progestin.

Table 5
Bivariate Correlation Matrix of Consistency, Dispersion, Accuracy, and Speed (Reaction Time) Measures With Corresponding p Values

	Accuracy			Speed	
Measure	Studied hits	Unstudied CRs	Source recognition	Studied hit RTs	CR RTs
			Consistency (CV)		
Studied hits	−0.638*	−0.179	−0.512*	0.470*	0.253
p	.000*	.161	.000*	.000*	.046
Unstudied CRs	−0.239	−0.746*	−0.445*	0.370	0.526*
p	.060	.000*	.000*	.003	.000*
Source recognition	−0.250	−0.175	−0.368	0.222	0.174
p	.048	.170	.003	.080	.172
Studied hit RTs	−0.342	−0.346	−0.520*	0.526*	0.494*
p	.006	.005	.000*	.000*	.000*
CR RTs	−0.091	−0.425*	−0.450*	0.531*	0.655*
p	.481	.001*	.000*	.000*	.000*
			Dispersion (CV)		
Studied hit RTs	−0.286	−0.326	−0.404*	0.356	0.445*
p	.023	.009	.001*	.004	.000*
CR RTs	−0.194	−0.183	−0.253	0.535*	0.502*
p	.127	.151	.046	.000*	.000*

Note. Asterisks indicate that values are significant ($p < .01$). CR = correct rejection; RT = reaction time; CV = coefficient of variation.

dispersion and hit RT was marginal. Second, measures of consistency for accuracy were related to overall accuracy within word type but not across word type. That is, across-block consistency in identifying studied words was positively related to overall accuracy for studied words but not to overall accuracy for unstudied words. Similarly, across-block consistency in correctly rejecting unstudied words was positively related to accuracy for unstudied words but not studied words. Measures of RT consistency showed significant relationships with overall speed across both word types. Finally, across-block consistency for source memory tended to show a relationship to overall source accuracy. Of interest is that source memory accuracy showed a strong relationship with nearly all measures of variability.

Because aging effects on both the performance and variability measures may have an impact on the above correlations, a second set of bivariate partial correlations (controlling for age) was conducted. Table 6 shows that measures of RT dispersion were related to mean RTs for new unstudied words but not old studied words. Again, measures of consistency for accuracy were related to overall accuracy within word type but not across word type. Measures of RT consistency for both correctly identified studied and unstudied nouns showed significant relationships with overall speed across both word types, though the relationship with speed to studied nouns was marginal. Source memory no longer showed a significant relationship with the variability measures.

Discussion

Our goal in the present study was to examine the effects of aging and, for the first time known to us, the effects of estrogen use on inter- and intraindividual variability. Our results support the assertion that variability is not a unitary construct, because measures of diversity, dispersion, and consistency bore different patterns of aging and estrogen effects on the item–source memory task. In addition, the pattern of results for performance variability differed from the results for mean group effects. Therefore, though correlated, performance mean and performance variability appear to reflect independent sources of variance, as has been demonstrated (Anstey, 1999; Jensen, 1992).

Variability and Aging

Past research on variability and aging has focused primarily on variability noted between participants. Reviews of gerontological research have reported age-related increases in diversity (Morse, 1993; Nelson & Dannefer, 1992). However, some researchers have argued that increases in diversity are simply an artifact of age-related differences in mean performance (Hale et al., 1988; Salthouse, 1993). For example, slower RTs noted in older adults are associated with larger standard deviations. In the present study, CV measures were used to control for mean group effects. However, ceiling effects in the younger women on some memory measures confounded a subset of the results for diversity. Specifically, age-related increases in diversity on both new word identification and source recognition were due to the reduced variability associated with the high performance in younger women. To overcome ceiling effects, researchers typically use RTs in place of accuracy measures (Lockhart, 2000). Use of RT measures in our study confirmed that diversity did not differ with age.

To further examine group diversity in item–source recognition memory, we examined the variance data reported by Trott and colleagues (Trott et al., 1999). Women in their study completed a version of the same item–source memory task described here. Because the list length was doubled in their study (16 study words per list), ceiling effects in the younger women were not observed. Nonetheless, analysis of standard deviation and CV data failed to

Table 6
Bivariate Partial Correlation Matrix of Consistency, Dispersion, Accuracy, and Speed (Reaction Time) Measures With Corresponding p Values Controlling for Age

	Accuracy			Speed	
Measure	Studied hits	Unstudied CRs	Source recognition	Studied hit RTs	CR RTs
			Consistency (CV)		
Studied hits	−0.71*	−0.03	−0.31	0.01	0.25
p	.000*	.815	.013	.954	.046
Unstudied CRs	−0.03	−0.72*	−0.04	0.21	0.36
p	.847	.000*	.737	.105	.008
Source recognition	−0.40*	−0.12	−0.14	0.26	0.27
p	.001*	.407	.279	.044	.036
Studied hits RTs	0.29	0.08	−0.01	0.33	0.41*
p	.021	.531	.964	.010	.001*
CR RTs	−0.01	0.30	−0.08	0.27	0.57*
p	.949	.018	.550	.033	.000*
			Dispersion (CV)		
Studied hit RTs	−0.11	−0.20	−0.12	0.12	0.24
p	.396	.124	.336	.355	.066
CR RTs	−0.05	−0.07	−0.01	0.43*	0.38*
p	.682	.598	.917	.001*	.002*

Note. Asterisks indicate that values are significant ($p < .01$). CR = correct rejection; RT = reaction time; CV = coefficient of variation.

reveal any significant aging effects. Together, our study and that of Trott et al. suggest that age-related increases in diversity are not pervasive across all types of memory tasks. However, the absence of a significant aging effect on measures of diversity may be due to the small sample size used in the present study. The aging effect size for diversity of memory measures ($d = 0.43$), calculated from Morse's (1993) meta-analysis, rendered an associated power of 0.42 for the current study. This analysis revealed that a sample size of 67 per group would be required to establish power at 0.80. Thus, the null effects for diversity may be due, in part, to inadequate power to detect the aging effect.

A related statistical concern in the aging data is the unequal sample size used to compare younger and older adults. Variance of the sampling distribution of the mean decreases as the *N* increases. Thus, the variance of the older group may have been attenuated due to the larger *N* in that group. To address this question, we compared the younger adults to a random sample of 16 of our older adults on measures of diversity. Results replicated those obtained from the full sample of older adults, in which significant aging effects for diversity were obtained for total correct rejections and source memory. Again, these aging effects were due to the reduced variability in the younger adults because of ceiling performance on those measures. RT measures failed to indicate aging effects for diversity. Thus, we conclude that the unequal sample size did not contribute to our null findings on diversity between younger and older adults. The issue of unequal *N*s does not apply to measures of dispersion and consistency, because these measures reflect intraindividual variability rather than group variability.

Measures of intraindividual RT variability within condition and session (dispersion) revealed significant effects of aging. Specifically, younger women showed decreased CVs for RT measures across both studied and unstudied words. Two other recent studies reported age-related increases on dispersion measures (Anstey, 1999; Shammi et al., 1998), though Shammi et al. (1998) found that the aging effect on dispersion for their choice RT task was not significant after controlling for differences in mean RTs. However, significant aging effects remained for a finger-tapping task. Further, West et al. (2002) reported an Age × Task interaction in which aging effects for dispersion were greater in an *n*-back working memory task than in an immediate choice RT task. These data suggest that aging effects for dispersion may be more conspicuous on tasks that tax executive control processes. Given the executive demands inherent in the item–source memory task (e.g., task switching and source monitoring), the present age-related increases in dispersion CV support this possibility.

The present data set provides an excellent means of exploring consistency, with 16 study–test blocks included for each participant. Previous studies have measured consistency by dividing a single experimental block into intervals or by using only two experimental blocks (Shammi et al., 1998). Thus, although the total number of participants in the present study is low, the large amount of data represented by each participant affords a stable measure of performance variability. These data revealed aging effects for across-block consistency. Younger women were more consistent across the 16 test blocks than were older women for item–source recognition accuracy. Note that performance approaching ceiling among a subset of the young women for item–source recognition also confounded measures of consistency, because near-ceiling performance translates into consistent high scores across blocks. However, measures of RT consistency also revealed aging effects. These findings support previous research showing inconsistent performance in older adults across time (Hertzog et al., 1992). Consistency has also been shown to be reduced when executive demands are high (e.g., when a distracter task must be carried out simultaneously with a target task; Shammi et al., 1998). For the present task, participants were required to

make speeded item judgments and, for items judged old, nonspeeded source judgments. Older participants reported difficulty in rapidly switching back and forth between these two judgment types. Task switching is a metacognitive executive process that declines with age and is thought to rely upon frontal lobe function (Fernandez-Duque, Baird, & Posner, 2000; McDowd, Joan, & Shaw, 2000; West, 1996). Therefore, the present findings support the proposal that age-related declines in consistency are evident on complex tasks that place demands on executive processes (West, 2001).

Mechanisms of Age-Related Changes in Variability

Though the mechanisms underlying performance variability remain largely unknown, studies of patients with frontal lobe damage suggest that the frontal lobes are likely involved in modulating performance variability (Baker et al., 1986; Murtha et al., 2002). The present correlational analyses provide support for this association, as source memory accuracy was significantly related to nearly all measures of variability (see Table 5). Data reflecting the dependence of source memory on frontal lobe function are abundant (Dywan & Jacoby, 1990; Janowsky, Shimamura, & Squire, 1989). For example, patients with frontal lobe damage are impaired in making source memory judgments (Butters, Kaszniak, Glisky, Eslinger, & Schacter, 1994; Mangels, 1997; Milner, Corsi, & Leonard, 1991), as are nonhuman primates with discrete middorsal–frontal lesions (Petrides, 1991). Further, imaging studies have revealed clear frontal lobe activation on source memory tasks with functional MRI (Henson, Shallice, & Dolan, 1999; Rugg, Fletcher, Chua, & Dolan, 1999), positron emission tomography (Cabeza et al., 1997; Nyberg et al., 1996), and event-related potentials (Trott et al., 1999; Wegesin et al., 2002). It is interesting to note that when the effects of aging were partialed out of the present correlations, the relationship between source memory accuracy and variability was no longer significant. However, the relationship between item memory and variability remained (see Tables 5 and 6). This pattern suggests that the factor driving the influence of aging on these associations is more closely related to frontal (source memory) compared with hippocampal (item memory) systems. As such, the present findings support the frontal lobe deficit hypothesis of aging (Dempster, 1992; West, 1996), which suggests that age-related cognitive decline is due, at least in part, to age-related changes in the frontal lobes.

Variability and Estrogen Use

Effects of estrogen use on variability were manifest on measures of consistency but not on measures of diversity and dispersion. Specifically, estrogen users performed more consistently than nonusers on both item and source recognition accuracy. We hypothesized that variability effects may be larger on tests imposing greater executive demands and thus would be larger for source memory than item memory. The estrogen findings on consistency of item and source performance do not support this hypothesis, because the estrogen effect was similar across the two types of memory. This may be due, in part, to the executive demands inherent in the task overall. As mentioned above, older participants reported difficulty in rapidly switching back and forth between these two judgment types and monitoring whether they needed to make a speeded or nonspeeded judgment. Further, making speeded item judgments is thought to involve greater executive demands than making nonspeeded judgments and has been shown to activate a frontoparietal network (Zysset et al., 2001). In this regard, the item decisions involved more executive processes than the source decisions. Overall, task switching and the differences in the speed of response required for item versus source judgments confounded the distinction between item memory and source memory in the present paradigm. Future studies may adopt a design that would include separate blocks for item and source memory to better address the hypothesis that performance variability for source memory is greater than performance variability for item memory.

Given the association between variability and frontal lobe function discussed above, the present findings provide support for the hypothesis that the cognitive effects associated with estrogen may be mediated by changes in frontal lobe function (Keenan et al., 2001). Brain imaging studies have revealed effects of estrogen within the frontal cortex on cognitive activation tasks (Berman et al., 1997; Resnick et al., 1998), and neuropsychological tests thought to tap frontal lobe function have shown effects of estrogen use (Fedor-Freybergh, 1977; Jacobs et al., 1998; Kimura, 1995; Schmidt et al., 1996; Sherwin, 1988; Szklo et al., 1996). The effects of estrogen on performance variability reported in our study add to a growing body of evidence of estrogen's role in the frontal lobe.

The addition of progestin to estrogen therapy appears to diminish the benefits of taking estrogen alone, as est + prog users did not show the same advantage over nonusers on measures of consistency as did estrogen users. This finding supports other studies that have reported detrimental effects on cognitive abilities when adding progestin to estrogen therapy (Ohkura et al., 1995; Rice et al., 2000; Sherwin, 1991), although at least two studies have failed to find such negative effects (Hogervorst et al., 1999; Maki et al., 2001). Recent data from the Women's Health Initiative have revealed a negative impact of est + prog on cognitive performance (Rapp et al., 2003) and the incidence of dementia (Shumaker et al., 2003) in postmenopausal women. Additional data consistent with the present findings show that progestogens are suspected to decrease activity of excitatory neurotransmitters (Backstrom, Bixo, & Hammerback, 1985). Certain metabolites of progesterone, such as allopregnanolone, are known to bind to $GABA^A$ receptors and produce sedative-like effects (Purdy et al., 1990). Basic neurobiological studies have also shown that most of the beneficial effects of estrogen on the brain (e.g., affecting neurotransmitter synthesis; McEwen, Gerlach, Luine, & Leinberburg, 1977; altering neuronal morphology; Woolley et al., 1993; enhancing cerebral perfusion; Funk, Mortel, & Meyer, 1991) are opposed by progesterone (Sarrel, 1990).

The observational nature of the design limits the conclusions that may be drawn from our study. Because older women were not randomly assigned to a treatment group, the effects of hormone use are confounded with participant variables that may differentiate women who choose to use hormones after menopause from those who do not. Previous research has shown that hormone users tend to be healthier and better educated than nonhormone users (Egeland et al., 1991; Matthews, Kuller, Wing, Meilahn, & Plantinga, 1996). Clinical trials represent the strongest design for assessing estrogen's impact on cognitive function and variability. Thus, measures of variability should be analyzed in a clinical trial setting

to confirm preliminary results obtained from observational studies like this one.

Summary

The results of our study support the assertion that variability is not a unitary construct. Furthermore, our results suggest that the effects of aging on variability are not universal but rather appear to fluctuate with the type of variability being measured, as well as with the cognitive task being evaluated. Estrogen use, but not est + prog use, appears to attenuate age-related decreases in performance consistency. Finally, the strong association between source memory performance and several measures of variability provides support for the hypothesis that the frontal lobes are involved in mediating performance variability. Overall, these findings highlight the need for further study of measures of variability, because exploration of performance variability may provide unique insights into neurocognitive changes associated with aging and estrogen use.

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New Editors Appointed, 2006–2011

The Publications and Communications Board of the American Psychological Association announces the appointment of seven new editors for 6-year terms beginning in 2006. As of January 1, 2005, manuscripts should be directed as follows:

- *Experimental and Clinical Psychopharmacology* (www.apa.org/journals/pha.html), **Nancy K. Mello, PhD,** McLean Hospital, Massachusetts General Hospital, Harvard Medical School, 115 Mill Street, Belmont, MA 02478-9106.
- *Journal of Abnormal Psychology* (www.apa.org/journals/abn.html), **David Watson, PhD,** Department of Psychology, University of Iowa, Iowa City, IA 52242-1407.
- *Journal of Comparative Psychology* (www.apa.org/journals/com.html), **Gordon M. Burghardt, PhD,** Department of Psychology or Department of Ecology & Evolutionary Biology, University of Tennessee, Knoxville, TN 37996.
- *Journal of Counseling Psychology* (www.apa.org/journals/cou.html), **Brent S. Mallinckrodt, PhD,** Department of Educational, School, and Counseling Psychology, 16 Hill Hall, University of Missouri, Columbia, MO 65211.
- *Journal of Experimental Psychology: Human Perception and Performance* (www.apa.org/journals/xhp.html), **Glyn W. Humphreys, PhD,** Behavioural Brain Sciences Centre, School of Psychology, University of Birmingham, Edgbaston, Birmingham B15 2TT, United Kingdom.
- *Journal of Personality and Social Psychology: Attitudes and Social Cognition* section (www.apa.org/journals/psp.html), **Charles M. Judd, PhD,** Department of Psychology, University of Colorado, Boulder, CO 80309-0345.
- *Rehabilitation Psychology* (www.apa.org/journals/rep.html), **Timothy R. Elliott, PhD,** Department of Psychology, 415 Campbell Hall, 1300 University Boulevard, University of Alabama, Birmingham, AL 35294-1170.

Electronic submission: As of January 1, 2005, authors are expected to submit manuscripts electronically through the journal's Manuscript Submission Portal (see the Web site listed above with each journal title).

Manuscript submission patterns make the precise date of completion of the 2005 volumes uncertain. Current editors, Warren K. Bickel, PhD, Timothy B. Baker, PhD, Meredith J. West, PhD, Jo-Ida C. Hansen, PhD, David A. Rosenbaum, PhD, Patricia G. Devine, PhD, and Bruce Caplan, PhD, respectively, will receive and consider manuscripts through December 31, 2004. Should 2005 volumes be completed before that date, manuscripts will be redirected to the new editors for consideration in 2006 volumes.