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Anxiety, Cognitive Performance, and Cognitive Decline in Normal Aging

Julie Loebach Wetherell,[1] Chandra A. Reynolds,[2] Margaret Gatz,[1,3] and Nancy L. Pedersen[1,3]

[1]Department of Psychology, University of Southern California, Los Angeles.
[2]Department of Psychology, University of California, Riverside.
[3]Department of Medical Epidemiology, The Karolinska Institute, Stockholm, Sweden.

A sample of 704 cognitively intact individuals (*M* age = 63.7 years) performed a battery of cognitive tests on as many as three occasions, at approximately 3-year intervals. The authors used random effects models to analyze cross-sectional relationships between cognitive performance and state anxiety and longitudinal relationships between cognitive change and neuroticism, after controlling for gender, age, and education. Cross-sectionally, higher state anxiety was associated with poorer performance on Wechsler Adult Intelligence Scale Synonyms, WIT III Analogies, Koh's Block Design, two measures of visual learning (Names and Faces and Thurstone's Picture Memory), and, for men, CVB-Scales Digit Span Test and Card Rotations. In longitudinal models, the main effects for neuroticism were significant for Block Design, Symbol Digit, and Names and Faces, but there were no significant interactions among neuroticism, gender, and time. These results provide some support for Eysenck's processing efficiency theory but none for neuroticism as a risk factor for cognitive decline in normal aging.

EYSENCK'S processing efficiency theory (Eysenck, 1992; Eysenck & Calvo, 1992) holds that anxiety interferes with cognitive performance by preempting some of the processing and storage resources of the working memory system. Working memory is hypothesized to consist of a phonological loop that is responsible for the brief storage and manipulation of verbal information, a visuospatial sketchpad that is responsible for manipulating visual images, and a central executive that performs attentional tasks and coordinates other subsystems (Baddeley, 1990). Storage and processing capacities of the subsystems are presumed to be limited. Thus, simultaneous performance of tasks that rely on the same component of working memory tends to result in greater interference than does performance of tasks that rely on different working memory components.

Eysenck's theory posits that anxiety produces worry and other intrusive thoughts that compete for resources in working memory (Eysenck, 1992). Because these thoughts are verbal, they are processed by the phonological loop and the central executive, but they do not affect the resources of the visuospatial sketchpad. Thus, the theory predicts that anxiety should interfere with verbal tasks and with tasks requiring complex attention and coordination, but should not interfere with simple visuospatial tasks whose demands on the central executive are relatively low.

Tasks that are heavily influenced by the phonological loop of working memory include Digit Span (particularly Digits Backward) and measures of verbal learning. Tasks influenced by the visuospatial sketchpad include Block Design, Card Rotations, Figure Logic, Matrix Reasoning, and Symbol Digit, which is also a measure of perceptual speed. Tasks influenced by the central executive include Analogies, Similarities, and other problem-solving tasks (including visual problem-solving tasks such as Block Design, Card Rotations, Figure Logic, and Matrix Reasoning). Other tasks assessing recall of well-learned verbal information or word meanings, such as Information, Synonyms, or Vocabulary, and simple visual pattern matching or perceptual speed (Figure Identification) are presumed not to rely as heavily on working memory.

Anxiety is often described as both a state and a trait phenomenon. State anxiety refers to an emotional condition characterized by feelings of tension, apprehension, nervousness, and worry, along with symptoms of increased physiological arousal (Spielberger, 1983). Trait anxiety, or anxiety proneness, is the tendency to perceive situations as threatening and to respond with more frequent and more intense elevations in state anxiety. Trait anxiety is considered a relatively stable variable showing individual differences. Neuroticism, a personality trait that predisposes individuals to experience negative affect, is sometimes considered a proxy for trait anxiety, and correlations between measures of trait anxiety and neuroticism are typically quite high (e.g., Harrison & Whissell, 1980; Merckelbach, Muris, Nijman, & de Jong, 1996; Watson & Clark, 1984). The effects described in processing efficiency theory are likely due to state anxiety, because the proposed mechanism for adverse effects on working memory is the experience of worry or intrusive thoughts, which accompany state anxiety. A relationship between trait anxiety and working memory would be mediated by state anxiety, which is typically higher in individuals with high trait anxiety.

Relative to younger adults, older adults show deficits in working memory performance, particularly for processing rather than storage tasks (Salthouse & Babcock, 1991). These differences appear to be mediated by perceptual speed

(Hultsch, Hertzog, & Dixon, 1990). Age-related declines in perceptual speed may thus be responsible for not only decreases in the processing tasks of working memory but also age-related changes in cognitive performance in general (Salthouse, 1996).

Because of already-reduced working memory and processing resources, older adults may be more vulnerable than younger adults are to the effects of anxiety across multiple cognitive domains. In particular, older adults with higher levels of anxiety may show poorer performance on tasks involving processing of verbal information. Likewise, anxious older adults may perform less well on complex visuospatial-processing tasks involving the central executive. However, less complicated visuospatial tasks without a heavy processing component should be relatively unaffected by anxiety, although performance on tasks of perceptual speed should be poorer in older adults, regardless of anxiety. Recall of well-learned (verbal) knowledge such as general information or word meanings is typically preserved in late life.

Empirical data largely support the hypothesis that increased anxiety is associated with poorer performance on verbal working memory tasks involving the phonological loop and the central executive in later life. State anxiety has shown a negative effect on Digit Span (Rankin, Gilner, Gfeller, & Katz, 1994; West, Boatwright, & Schleser, 1984). Studies have found state and trait anxiety associated with significantly poorer performance on Similarities, Analogies, and practical problem-solving tests (Cohen, Eisdorfer, Vitaliano, & Bloom, 1980; LaRue & D'Elia, 1985). There is also some evidence that both state and trait anxiety are associated with poorer verbal learning in late life (Deptula, Singh, & Pomara, 1993; Paterniti, Dufouil, Bisserbe, & Alperovitch, 1999; Whitbourne, 1976). Trait anxiety is typically not associated with tasks such as Information or Vocabulary in older samples (Cohen et al., 1980; Costa, Fozard, McCrae, & Bossé, 1976; Schultz, Hoyer, & Kaye, 1980). Hence, the evidence suggests that verbal tasks that involve the processing capacities of the phonological loop and the central executive functions of working memory can be compromised by anxiety in older adults.

Findings for visuospatial tasks are much less consistent than for verbal tasks. Poorer performance on Digit Symbol was associated with trait anxiety in one very large investigation (Paterniti et al., 1999) but not with state anxiety in another (Schultz et al., 1980). The relationship between anxiety and performance on Raven's matrices has yielded mixed results for both state and trait anxiety in larger samples (*N*s ≥ 100; Cockburn & Smith, 1994; Paterniti et al., 1999; Schultz et al., 1980). A pattern of less consistent results on visuospatial tasks than on verbal tasks is generally consistent with the hypothesis that worry and other verbal intrusive thoughts are responsible for the effects of anxiety on working memory. For verbal tasks, anxiety potentially interferes with the processing capacity of both the phonological loop and the central executive. For visuospatial tasks, anxiety potentially compromises only the efficiency of the central executive. Hence, effects of anxiety on visuospatial tasks may depend on the complexity of the task and the demands it places on the central executive, and results may therefore be less consistent than for verbal tasks.

To date, the relationship between anxiety and simple visuospatial tasks that do not rely heavily on the processing capacity of the central executive (such as pattern matching) does not appear to have been adequately tested with older adults. The relationship between anxiety and visual learning has also not been investigated. The processing efficiency theory would predict no effect of anxiety on simple visuospatial tasks such as pattern matching, but would predict an effect on visual learning due to the involvement of the central executive.

Furthermore, all reports on anxiety and cognition published to date have been limited to cross-sectional data. There appear to be no published studies on the relationship between anxiety and normal age-related cognitive decline. Previous research on longitudinal cognitive change has found age-related declines in perceptual speed, complex visuospatial skills, and learning and memory but not in verbal knowledge (Reynolds, Gatz, & Pedersen, 2000; Schaie, 1995). There are clear parallels in lists of tasks that typically show age-related decline and tasks usually affected by anxiety. Therefore, the question arises of whether general anxiety proneness is related to accelerated rates of decline relative to those who are less anxious. Specifically, because anxiety is hypothesized to affect complex visual tasks and visual learning, but not simple visual tasks involving perceptual speed, it is expected that higher levels of anxiety will be associated with greater age-related declines in complex visuospatial performance and visual learning but not with declines in verbal knowledge or simple visual pattern matching.

Exploring the relationships between anxiety and cognitive performance and decline in older adults is important for several reasons. First, because neuropsychological tests are used in diagnosing dementia, there are serious consequences for failing to recognize which tests may be vulnerable to the effects of anxiety in older adults. Additionally, learning more about the effect of anxiety on cognition across the life span can lead to a better understanding of cognitive processes associated with anxiety and aging. To address these questions and further explore the relationships between anxiety and cognitive performance, this study tested the following hypotheses using data from a large, longitudinal, population-based panel of cognitively intact older adults: (a) Higher levels of state anxiety will be associated with poorer performance on tests of verbal reasoning and working memory, complex visuospatial skills, and visual learning but will not have an effect on verbal knowledge or simple visual pattern matching; and (b) Trait anxiety, assessed with a measure of neuroticism, will be associated with longitudinal declines in visual learning and complex visuospatial tasks but not with declines in other cognitive domains.

Methods

Sample

Data were collected as part of the Swedish Adoption/Twin Study of Aging (SATSA), a longitudinal study of personality, health, and aging among cognitively intact same-sex twins (Pedersen et al., 1991). SATSA is a subsample of the Swedish Twin Registry, which includes virtually all same-sex twin pairs born in Sweden between 1886 and 1958 (Cederlöf & Lorich, 1978). Evidence from the Swedish Twin Registry indicates that twins are representative of the broader Swedish population on environmental and sociological variables, suggesting that findings from this sample are generalizable (Cederlöf, Friberg, & Lundman, 1977). The sample was chosen because it is large, population-based, and longitudinal; the fact that respondents are twins is incidental, and neither family nor genetic similarity is addressed in these analyses.

SATSA includes all registry twins who were reared apart and a control sample of twins reared together matched on the basis of gender, age, and county of birth. Twins were not excluded from SATSA if their partner had died; thus, the sample includes both complete pairs and singletons. In general, the SATSA twins are representative of twins in the Swedish Twin Registry, except that they are older, because most of the reared-apart twins were born during the first 3 decades of the 20th century, when economic depression and epidemics increased the likelihood of separation. Furthermore, twins reared apart experienced on average a lower standard of living as children than twins reared together did. A prior report indicated that twins reared apart do not differ from registry twins reared together on personality variables, with the exception of neuroticism, on which twins reared apart score higher (Pedersen, Friberg, Floderus-Myrhed, McClearn, & Plomin, 1984).

The SATSA investigators collected data through surveys mailed in 1984, 1987, 1990, and 1993. All intact SATSA twin pairs who were at least 50 years of age or who turned 50 over the course of the study were invited to participate in a supplemental in-person testing program consisting of cognitive and medical assessments (Pedersen, Plomin, Nesselroade, & McClearn, 1992). Three waves of in-person testing were conducted between waves of the mailed surveys. Data were collected by registered nurses trained specifically to administer the measures in a standardized fashion. The twins were tested at locations close to their homes; for the most part, district nurses' offices, health care schools, and long-term care clinics were used. An average testing session took 4 hr.

A total of 755 individuals provided cognitive data on at least one occasion. To ensure that the sample was cognitively intact rather than in the early stages of a dementing process, we retrospectively excluded from the analyses data from participants who were diagnosed with dementia at any point ($n = 51$), yielding a final sample of 704. Of these, 568 completed at least two assessments, and 415 participated in all three waves of cognitive testing. Not all participants entered the study at the first wave of cognitive testing. Of those who entered the study at the first or second wave, attrition was 24.5%. Previous research with the SATSA data indicates that attriters score relatively more poorly than nonattriters on measures of perceptual speed and visuospatial skills, without controlling for age (Kasl-Godley, Pedersen, Berg, & Gatz, 1996). In the current sample, older age predicted attrition, but gender, education, rearing status, state anxiety, neuroticism, and performance on any cognitive test did not, after controlling for age.

The sample consisted of 288 men (40.9%) and 416 women (59.1%). Participants had an average age of 63.7 years ($SD = 8.6$) at their initial assessment, 66.5 years ($SD = 8.5$) at their second assessment, and 70.3 years ($SD = 7.5$) at their third assessment. Education level was assessed in four categories: elementary (61.0%), vocational (27.2%), academic secondary school (5.7%), and university (6.1%). The majority were married (70.8%), with 12.2% widowed, 8.9% divorced, and 8.1% single. Women were significantly older than men were at their second assessment, $t(252) = -2.07$, $p = .04$, but not at the first or third assessment. Men had significantly more education than women did, $t(317) = 2.72$, $p = .007$.

Measures

The cognitive battery was selected to provide representation of the domains of verbal reasoning and knowledge, visuospatial skills, perceptual speed and attention, and visual memory, but not verbal memory. All tests were taken from standard batteries, with alpha coefficients ranging from .82 to .96 in this sample (Pedersen et al., 1992). For every test except Block Design, answers were reported orally to the examiner to minimize the effect of motor speed on performance. All cognitive tests administered were used in the present analyses.

A Swedish version of the Wechsler Adult Intelligence Scale (WAIS) Information subtest (Jonsson & Molander, 1964) includes 22 items assessing general knowledge (e.g., "What is the population of Sweden?"). Respondents are allowed 20 s to answer each question.

Synonyms is a 30-item forced-choice vocabulary test (sample item: "Inform: divide, award, expire, distribute, announce") from the Swedish Dureman–Sälde Battery (Dureman, Kebbon, & Osterberg, 1971). Respondents are allowed 3.5 min to finish each 15-item section.

Analogies is a 27-item Swedish test of verbal reasoning (sample item: "Pen: Draw; Brush: Painting, Paint, Picture, Frame") in which respondents have 3.5 min to finish each of two sections (Westrin, 1969).

Figure Logic is a 30-item visual reasoning test in which respondents choose which one of five figures differs from the other four (Dureman et al., 1971). Respondents have 4 min to complete each 15-item section.

Koh's Block Design is a visuospatial test, similar to the WAIS Block Design subtest, in which respondents create designs using colored blocks (Dureman et al., 1971). Each of its seven items is scored from 0 to 6 on the basis of the amount of time the respondent takes to correctly complete the design.

Card Rotations is a mental rotation task in which respondents report whether each of four items is a rotated form of a target design (Ekstrom, French, & Harman, 1976). Possible scores range from 0 to 112, and respondents have 2 min to complete each of two sections.

Figure Identification is a 60-item pattern-matching test assessing perceptual speed and attention (Dureman et al., 1971). Respondents report which of five options matches a target item. They have 2 min to complete each 30-item section.

In Symbol Digit, respondents verbally report digits that correspond to symbols. They have 45 s to complete each of 10 groups of 10 items.

CVB-Scales Digit Span was scored as the sum of the highest number of digits the respondent was able to repeat correctly in each direction, ranging from 3–9 forward and 2–8 backward (Jonsson & Molander, 1964). Respondents were given two trials of different strings of digits for each length span; correct performance on either string was counted toward their final score.

In Names and Faces, respondents pair names with 16 pictures of faces after viewing them for 1 min (DeFries, Plomin, Vandenberg, & Kuse, 1981). Immediate and 30-min delayed recall performance are summed to create a total score.

Thurstone's Picture Memory tests recognition memory of 28 drawings of common items such as a truck and a table (Dureman et al., 1971). Respondents are shown each picture for 5 s; their response is not timed.

Anxiety was assessed using the 10-item State Anxiety subscale of the State–Trait Personality Inventory (STPI; Spielberger, 1979). This is a general state anxiety measure that is not specific to cognitive performance or testing situations. The STPI contains a subset of the 20 items from the State–Trait Anxiety Inventory, Form Y-1 (Spielberger, 1983). In the present study, each item was scored on a 5-point scale representing how the respondent was feeling "right now, at this moment" from 1 (fits exactly) to 5 (does not fit at all); this response format differs slightly from the 4-point scale usually used with the STPI. The response format was modified to be consistent with other personality scales administered in the same battery.

The STPI was mailed to SATSA participants 10 days before their appointment for the second and third wave of in-person testing sessions. The state anxiety questionnaire was not completed immediately prior to the first wave of assessments, so cross-sectional analyses of state anxiety and cognitive performance could not be performed using the first wave of cognitive data.

For longitudinal analyses, neuroticism was used as a proxy for trait anxiety. Participants completed a nine-item short form of the Eysenck Personality Inventory Neuroticism scale as part of the mailed surveys (Pedersen et al., 1984). Neuroticism data from the first measurement occasion, typically the 1984 mailed SATSA survey, were used in the present analyses.

State anxiety data were considered missing if the participant failed to answer two or more items; if only one anxiety item was left blank, it was replaced with the average item score for the individual. Respondents who answered at least six of the nine neuroticism items received a valid score on this measure. Two participants were missing neuroticism data. Of the 558 who participated in the second wave of cognitive testing, 15 were missing state anxiety data, and of the 537 who participated in the third wave of cognitive testing, 46 were missing state anxiety data. Average anxiety scores were 17.7 (SD = 7.3, range = 10–49) at the second wave and 17.4 (SD = 7.1, range = 10–46) at the third wave; the average neuroticism score was 2.68 (SD = 2.31, range = 0–9). State anxiety scores were at approximately the 59th to 65th percentile for women and the 53rd to 58th percentile for men, compared with a sample of working adults aged 33 or older (Spielberger, 1979). The correlation between state anxiety scores at the second and third waves was .57. Correlations between neuroticism and state anxiety scores were .38 at the second wave and .39 at the third wave. Age showed no significant correlations with state anxiety but was negatively correlated with neuroticism, $r = -.08$, $p = .04$. There were no significant relationships between education and state anxiety, but the relationship between education and neuroticism was significant, $r = -.07$, $p = .05$. Women reported higher levels of neuroticism and state anxiety at both time periods than men did, $t(318) = -2.98$, $p = .003$, $t(236) = -3.32$, $p = .001$, $t(203) = -2.12$, $p = .04$.

Because prior investigations have found an effect of psychotropic medications on cognitive performance in older adults (e.g., Paterniti et al., 1999), we compared test scores between those who did and those who did not report use of such medications, including tranquilizers and sleeping aids, within 30 days prior to the second and third wave of assessments. Prevalence of medication use was 11% to 12% at each period. Although medication users scored significantly higher on state anxiety and neuroticism than nonusers did, 22.7 versus 17.1, $t(62.3) = -4.21$, $p < .001$ (unequal variance; first time point), 22.2 versus 16.7, $t(74.6) = -4.92$, $p < .001$ (unequal variance; second time point), and 4.6 versus 2.5, $t(65.9) = -5.69$, $p < .001$ (unequal variance; first time point), we found no significant differences between recent medication users and nonusers on any cognitive test at either time point, so medication use was not included as a covariate in these analyses.

Statistical Analyses

Cognitive performance was analyzed using a random effects model (SAS PROC MIXED; SAS Institute, 2000). The random effects model is a multilevel model that allows estimation of overall fixed effects (the average model for the entire group) and also allows for individual variation from the group model (i.e., the random effects; Campbell, 1999; Laird & Ware, 1982; Teri, Hughes, & Larson, 1990). Thus, there is a model for the group and a model for each individual. It is possible to explain individual deviations from the fixed model in terms of other covariates, such as anxiety. Furthermore, this method of analyzing data allows for dependent observations, such as members of twin pairs in these analyses. In longitudinal analyses, correlations among scores across time are accounted for and all available data can be used, regardless of attrition. The maximum likelihood approach was used to estimate parameters. The estimation of the variances/covariances among the random coefficients was set to the unstructured option.

For the cross-sectional analyses, we used data from each participant at the first measurement period in which the participant completed both cognitive testing and a state anxiety questionnaire (for most participants, this was the second wave of cognitive testing). Gender, age, education, state anxiety, and the Gender × State Anxiety interaction were entered into a PROC MIXED model as predictor variables for each cognitive test score. Age and education were included in the models because they consistently correlated with most of the cognitive tests in univariate analyses. Gender was included because gender differences are often found in some areas of cognitive performance. Age, education, and state anxiety were mean-centered for these analyses. A twin-pair identifier was entered into a random statement to take into account nonindependence between twin partners. We tested the significance of model fits by comparing the difference between the −2 log likelihood ratio [−2 Log (L)] for nested models; this value has a chi-square distribution and can be evaluated for statistical significance accordingly. Lastly, we present parameter estimates for each predictor in the final model.

The longitudinal models contained the variables gender, education, age, neuroticism, time, and several interactions: Neuroticism × Gender, Neuroticism × Time, and Neuroticism × Time × Gender. The goal was to analyze the effects of neuroticism on cognitive change (the Neuroticism × Time interaction and the Neuroticism × Time × Gender interaction), after controlling for other potentially confounding effects. Age and education were mean-centered for these analyses. Participants were included regardless of the number of assessments they completed. A variable denoted *time* was created whereby an individual's age at each time of measurement was centered on that individual's first age at testing so that the individual intercepts reflect the percent correct for each cognitive test at the first measurement occasion; essentially the group or fixed effect intercept would then reflect the average intercept at the first occasion. We included a random statement for the pair as well as a random statement for the individual to model correlations between twin partners and correlations across time for each individual. The random effect for time tested the significance of individual variation in change over time. Again, we tested the significance of model fits by comparing the difference between the −2 log likelihood ratio for nested models.

Results

Descriptive Statistics

Mean percent correct on the cognitive tests at each assessment period is presented in Table 1. Gender was a significant predictor of performance on a number of cognitive tests, including Information, Figure Logic, Card Rotations, Figure Identification, Names and Faces, and Thurstone's Picture Memory, after controlling for education and age. Men were advantaged in knowledge, visual reasoning, and mental rotation; women, in visual memory and perceptual speed.

Table 2 displays correlations among cognitive tests at Time 2, between cognitive tests and predictor variables such as age, education, state anxiety, and neuroticism at Time 2, and autocorrelations between cognitive tests at different time points. In general, higher level of education is associated with better performance on cognitive tests, whereas older age is associated with poorer performance. State anxiety and neuroticism are generally associated with poorer performance on cognitive tests, although the magnitude of the correlations is small and not typically significant.

State Anxiety and Cognitive Performance

Table 3 displays model fitting statistics ($\Delta\chi^2$ between −2 log likelihood values) for cross-sectional nested models and the intercept and parameter estimates for each cognitive test. Model 1 includes as fixed effects gender, age, education, state anxiety, the State Anxiety × Gender interaction, and an intercept term. Model 2 includes all variables except the State Anxiety × Gender interaction. Model 3 drops both the interaction and the main effect of state anxiety. The comparison between Models 1 and 2 tests the significance of the State Anxiety × Gender interaction. The comparison between Models 2 and 3 tests the significance of the main effect of state anxiety. Models 1 and 2 were significantly different for Card Rotations and for Digit Span, indicating that the State Anxiety × Gender interaction was a significant predictor of performance on these tests. Models 2 and 3 were significantly different for Synonyms, Analogies, Block Design, Names and Faces, and Thurstone's Picture Memory, indicating that state anxiety was a significant predictor of performance on these tests. We also tested a quadratic state anxiety term to explore a curvilinear relationship between anxiety and cognitive performance; this term was not significant for any cognitive test (results not shown).

Table 1. Cognitive Test Performance at Three Measurement Periods: Average Percentage Correct and Standard Deviations for Men and Women

	First		Second		Third	
Cognitive Test (Domain)	Men	Women	Men	Women	Men	Women
Information (verbal knowledge)	77.7 (16.4)	67.1 (18.0)***	77.9 (15.8)	69.0 (17.2)***	79.4 (15.5)	69.0 (16.9)***
Synonyms (vocabulary)	63.3 (19.7)	63.0 (18.0)	64.6 (18.8)	64.3 (16.7)	65.1 (19.0)	64.2 (17.6)
Analogies (verbal reasoning)	57.4 (15.9)	53.2 (13.9)	57.9 (14.5)	55.2 (13.6)	57.9 (16.2)	54.1 (13.7)
Figure Logic (visual reasoning)	63.3 (12.4)	58.6 (13.1)**	63.5 (13.4)	59.0 (13.1)*	63.6 (14.0)	58.6 (12.6)**
Block Design (visuospatial)	48.2 (18.1)	44.7 (18.0)	46.6 (17.2)	45.0 (17.0)	46.0 (17.7)	43.9 (17.2)
Card Rotations (visuospatial)	50.7 (17.8)	41.1 (16.5)***	51.7 (17.2)	42.3 (16.0)***	48.2 (19.1)	39.5 (16.8)***
Figure Identification (attention, speed)	48.6 (12.0)	50.1 (13.3)**	48.6 (12.5)	50.9 (13.3)***	47.1 (13.8)	50.2 (13.5)***
Symbol Digit (speed, working memory)	40.2 (11.7)	39.9 (11.7)	38.7 (11.8)	38.4 (11.8)	36.8 (13.0)	37.9 (12.0)*
Digit Span (attention, working memory)	58.9 (12.9)	57.4 (12.4)	58.9 (12.5)	58.4 (12.8)	58.5 (13.7)	57.7 (13.1)
Names and Faces (visual memory)	10.9 (10.8)	13.3 (12.1)***	12.1 (11.9)	14.3 (11.7)***	9.9 (10.2)	14.0 (12.3)***
Thurstone's Picture Memory (visual memory)	72.6 (16.5)	76.6 (15.3)***	72.4 (17.6)	77.2 (15.4)***	72.3 (18.5)	79.0 (15.3)***
n	288	416	238	330	173	242
M age	62.8 (8.0)	64.4 (9.0)	65.5 (7.7)	67.2 (8.9)*	69.5 (6.5)	70.8 (8.2)

$^*p < .05$; $^{**}p < .01$; $^{***}p < .001$, after controlling for age and education.

Table 2. Correlation Matrix

Variable	1	2	3	4	5	6	7	8	9	10	11
1. Information	—										
2. Synonyms	.68	—									
3. Analogies	.48	.59	—								
4. Figure Logic	.40	.43	.46	—							
5. Block Design	.42	.49	.50	.57	—						
6. Card Rotations	.24	.27	.40	.47	.60	—					
7. Figure Identification	.26	.37	.34	.43	.59	.53	—				
8. Symbol Digit	.43	.52	.51	.52	.68	.58	.69	—			
9. Digit Span	.29	.43	.40	.30	.39	.30	.31	.43	—		
10. Names and Faces	.27	.36	.29	.28	.41	.23	.36	.44	.29	—	
11. Thurstone's Picture Memory	.30	.43	.35	.34	.46	.27	.37	.44	.27	.39	—
Age	−.15	−.18	−.31	−.32	−.41	−.41	−.46	−.53	−.20	−.36	−.26
Education	.37	.39	.44	.29	.33	.21	.21	.33	.27	.24	.23
State Anxiety	−.08	−.11	−.14	−.06	−.12	−.09	−.00	−.05	−.04	−.08	−.10
Neuroticism	−.06	−.07	−.06	−.06	−.10	−.03	−.01	−.05	−.03	−.09	−.11
Autocorrelations											
IPT 1–IPT 2	.88	.87	.67	.55	.82	.71	.73	.80	.69	.65	.67
IPT 2–IPT 3	.87	.88	.70	.58	.82	.81	.79	.84	.66	.68	.69

Notes: IPT = in-person testing. Correlation matrix depicts data from IPT 2, except for autocorrelations. Correlations above approximately .09 are significant at $p < .05$.

Table 3 also shows the intercept and parameter estimates associated with each covariate as well as with state anxiety and the State Anxiety × Gender interaction (from Model 1). The intercept reflects the average percent correct on each cognitive test. The value of each parameter reflects the difference in percent correct on each cognitive test for each point above the mean on the relevant variable (e.g., age, education, state anxiety). Women were considered the default gender in these analyses, so parameter estimates for gender were used to adjust scores for men. The random effects intercepts are variance components and may be interpreted as the variances of the participant-specific intercepts.

Overall, state anxiety appears to have a significant effect on visual learning (Names and Faces and Thurstone's Picture Memory), even after controlling for covariates. Parameter estimates indicate that for each point above the mean on state anxiety, individuals score 0.20 and 0.25 below the mean on Names and Faces and Thurstone's Picture Memory, respectively. State anxiety was also associated with significantly poorer performance on Synonyms, Analogies, and

Table 3. Model Fit Statistics and Fixed and Random Effect Parameters for Cross-Sectional Models With State Anxiety

			Fixed Effects[c]						Random Effects	
Cognitive Test	Model 1 vs. 2 $\Delta\chi^2(1)$[a]	Model 2 vs. 3 $\Delta\chi^2(1)$[b]	Intercept	Gender	Age	Education	State Anxiety	State Anxiety × Gender	Intercept	Residual
Information	0.5	0.7	69.86	6.59	−0.16	6.10	−0.03	−0.13	118.93	114.16
Synonyms	0.1	6.4*	65.22	−2.23	−0.26	6.77	−0.26	0.06	104.54	148.38
Analogies	2.3	9.0*	55.76	0.37	−0.43	5.64	−0.15	−0.25	28.51	115.72
Figure Logic	1.6	0.9	59.81	2.65	−0.41	3.22	−0.01	−0.21	26.71	116.45
Block Design	0.2	12.0*	46.57	−1.63	−0.77	4.88	−0.26	−0.08	88.88	115.53
Card Rotations	5.5*	2.1	42.88	7.29	−0.80	1.73	0.01	−0.49	75.67	154.06
Figure Identification	2.8	0.3	51.93	−4.53	−0.69	1.83	0.04	−0.25	26.88	94.87
Symbol Digit	0.0	3.4	39.17	−1.75	−0.67	2.77	−0.10	−0.01	32.84	50.81
Digit Span	8.5*	0.1	58.67	−0.26	−0.23	3.23	0.11	−0.45	42.38	101.84
Names and Faces	2.1	4.8*	15.35	−4.16	−0.49	2.39	−0.20	0.21	33.34	79.75
Thurstone's Picture Memory	0.1	8.5*	77.88	−6.61	−0.47	3.52	−0.25	−0.07	50.06	169.80

[a]The chi-square values in this column represent the difference between the −2 Log (L) values associated with two nested models: Model 1 contains a random intercept term and fixed intercept, gender, age, education, state anxiety, and State Anxiety × Gender terms. Model 2 contains a random intercept term and fixed intercept, gender, age, education, and state anxiety terms. The chi-square difference between these values tests the significance of the State Anxiety × Gender interaction.

[b]The chi-square values in this column represent the difference between the −2 Log (L) values associated with two nested models: Model 2 contains a random intercept term and fixed intercept, gender, age, education, and state anxiety terms. Model 3 contains a random intercept term and fixed intercept, gender, age, and education terms. The chi-square difference between these values tests the significance of the main effect of state anxiety.

[c]Because the State Anxiety × Gender interaction was significant for two cognitive tests, Card Rotations and Digit Span, parameter estimates are presented for Model 1.

$*p < .05$.

Block Design in this sample. No significant effects of state anxiety were observed for Figure Identification, Symbol Digit, Figure Logic, and Information. Men were more adversely affected than women on Card Rotations and Digit Span.

Neuroticism, Cognitive Performance, and Cognitive Decline

Model fitting statistics for longitudinal models ($\Delta\chi^2$) are presented in Table 4. Model 1 includes as fixed effects the main effects of time, gender, age, education, and neuroticism, and the interactions between neuroticism and gender, neuroticism and time, and Neuroticism × Gender × Time, as well as an intercept term. Random effects include an intercept term and time. Model 2 includes the same set of fixed effects but drops the random effect of time. The comparison between Models 1 and 2 tests whether there is significant individual variation in change over time on each cognitive test. Model 3 includes the random effects intercept term and time and drops the fixed effects interaction terms Neuroticism × Time, Neuroticism × Gender, and Neuroticism × Gender × Time. The comparison between Models 1 and 3 tests the significance of the interaction terms, including interactions with time, in the fixed effects model. Model 4 is the same as Model 3 after dropping the main effect of neuroticism, and Model 5 is the same as Model 3 after dropping the main effect of time. The comparison between Models 3 and 4 tests the significance of the main effects of neuroticism. Finally, the comparison between Models 3 and 5 tests whether, on average, scores decline over time for each cognitive test.

After controlling for all other effects, significant individual variation for time (random effects) was found for Information, Block Design, Card Rotations, Symbol Digit, Figure Identification, Digit Span, and both memory tests. Results indicate no significant interactions with neuroticism over time on cognitive abilities. The main effect of neuroticism on cognitive function was significant for Block Design, Symbol Digit, and Names and Faces. The main effect for neuroticism is not entirely consistent with results for state anxiety reported above: Both state anxiety and neuroticism were associated with poorer performance on one visuospatial test (Block Design) and on a visual learning measure (Names and Faces). State anxiety but not neuroticism was associated with poorer performance on Synonyms, Analogies, and Thurstone's Picture Memory, and neuroticism but not state anxiety was associated with poorer performance on Symbol Digit. Only speeded and spatial tasks (Block Design, Card Rotations, Symbol Digit, and Figure Identification) evidenced a significant average effect of time.

Table 4 also presents the intercepts and parameter esti-

Table 4. Model Fit Statistics and Fixed and Random Effect Parameters for Longitudinal Models With Neuroticism

Cognitive Test	Model 1 vs. 2 $\Delta\chi^2(2)$[a]	Model 1 vs. 3 $\Delta\chi^2(4)$[b]	Model 3 vs. 4 $\Delta\chi^2(1)$[c]	Model 3 vs. 5 $\Delta\chi^2(1)$[d]	Fixed Effects[e]						Random Effects[f]			
					Intercept	Gender	Age	Education	Neuroticism	Time	Intercept	Time	$r_{INT,TIME}$	Residual
Information	13.6*	1.2	1.0	2.4	68.97	8.11	−0.34	6.70	−0.24	0.11	219.11	0.41	−0.41	36.50
Synonyms	0.8	4.7	2.1	0.0	65.22	−2.11	−0.35	7.91	−0.38	0.01	238.57	0.15	−0.16	40.98
Analogies	1.4	1.2	3.3	0.0	55.05	1.54	−0.54	5.95	−0.22	0.00	96.59	0.16	−0.26	63.97
Figure Logic	1.6	0.4	1.4	0.0	59.86	2.94	−0.48	3.55	−0.21	0.00	68.86	0.24	−0.20	74.50
Block Design	20.5*	4.0	9.4*	16.2*	48.39	−0.54	−0.87	4.92	−0.71	−0.36	203.90	1.15	−0.42	47.97
Card Rotations	10.4*	1.7	2.1	24.5*	43.10	7.56	−0.76	2.24	−0.35	−0.50	168.12	0.52	0.04	69.50
Figure Identification	9.0*	1.9	2.0	9.3*	51.68	−3.43	−0.75	2.07	−0.24	−0.24	87.25	0.38	−0.06	38.05
Symbol Digit	17.3*	1.3	4.0*	79.4*	41.39	−1.77	−0.74	3.26	−0.30	−0.62	62.58	0.30	0.12	23.53
Digit Span	6.4*	3.1	0.1	3.5	58.59	0.14	−0.24	3.53	−0.04	−0.15	80.15	0.17	0.35	51.37
Names and Faces	6.3*	2.4	6.5*	0.1	15.32	−4.36	−0.53	2.38	−0.40	0.03	70.78	0.57	−0.27	41.76
Thurstone's Picture Memory	17.9*	4.0	2.1	1.0	78.23	−6.28	−0.53	3.43	−0.32	0.11	150.21	1.89	−0.25	76.25

[a]The chi-square values in this column represent the difference between the −2 Log (L) values associated with two nested models: Model 1 contains random time and intercept terms and fixed intercept, time, gender, age, education, neuroticism, and Neuroticism × Gender, Neuroticism × Time, and Neuroticism × Gender × Time terms. Model 2 contains a random intercept term and fixed intercept, time, gender, age, education, neuroticism, and Neuroticism × Gender, Neuroticism × Time, and Neuroticism × Gender × Time terms. The chi-square difference between these values tests the significance of individual variations in change over time.

[b]The chi-square values in this column represent the difference between the −2 Log (L) values associated with two nested models: Model 1 contains random time and intercept terms and fixed intercept, time, gender, age, education, neuroticism, and Neuroticism × Gender, Neuroticism × Time, and Neuroticism × Gender × Time terms. Model 3 contains random time and intercept terms and fixed intercept, time, gender, age, education, and neuroticism terms. The chi-square difference between these values tests the significance of interactions between neuroticism and gender, neuroticism and time, and Neuroticism × Gender × Time.

[c]The chi-square values in this column represent the difference between the −2 Log (L) values associated with two nested models: Model 3 contains random time and intercept terms and fixed intercept, time, gender, age, education, and neuroticism terms. Model 4 contains random time and intercept terms and fixed intercept, time, gender, age, and education terms. The chi-square difference between these values tests the significance of the main effect of neuroticism.

[d]The chi-square values in this column represent the difference between the −2 Log (L) values associated with two nested models: Model 3 contains random time and intercept terms and fixed intercept, time, gender, age, education, and neuroticism terms. Model 4 contains random time and intercept terms and fixed intercept, gender, age, education, and neuroticism terms. The chi-square difference between these values tests the significance of the main effect of time.

[e]Parameter estimates are presented for Model 3.

[f]The random variance parameters are the sum of within-pair and between-pair systematic variance components calculated from factor analytic loadings. The correlation between intercept and slope, denoted $r_{INT,TIME}$, is the correlation calculated on the basis of the systematic variance/covariance matrix (the sum of within-pair and between-pair variance/covariance components calculated from factor analytic loadings).

*$p < .05$.

mates for Model 3, including the main fixed effects for neuroticism and time but not including any interaction terms with neuroticism. In these analyses, the main effect of variables such as age, education, and neuroticism reflects the difference in percent correct on each cognitive test for each point above the mean on the score for that variable. The fixed effect for time quantifies the rate of change in percent correct on each cognitive test per year. The parameter estimate for gender is used to adjust scores for men. The random effects intercept and time may be interpreted as the variances of the participant-specific intercepts and slopes, respectively. The correlation between the participant-specific (random effects) intercept and time indicates that, for example, individuals with higher initial scores on Information and Block Design have steeper rates of decline, whereas individuals with higher initial scores on Digit Span have slower rates of decline (flatter slopes).

As a measure of effect size, we calculated the proportion of variance explained by the growth model (variance explained by intercept and slope as a percent of total variance). Results ranged from .48 for Figure Logic to .85 for Information and Synonyms, with a median of .71.

Discussion

We hypothesized that higher levels of state anxiety would be associated with poorer performance on tests that tap the phonological loop or central executive functions of working memory, namely Analogies, Block Design, Card Rotations, Digit Span, Figure Logic, Names and Faces, Symbol Digit, and Thurstone's Picture Memory, but not on tests of verbal knowledge such as Information and Synonyms or simple visual pattern matching as in Figure Identification. This hypothesis was partially supported: Significant effects of state anxiety were found for visual learning and complex visuospatial skills, as expected, and were not found for Information or Figure Identification. Additionally, significant interactions between state anxiety and gender were found for two tests, Card Rotations and Digit Span. For both of these tests, men with higher levels of state anxiety performed more poorly than less anxious men did. However, contrary to expectations, the association between state anxiety and cognitive performance was not significant for Figure Logic or Symbol Digit and was significant for Synonyms.

We failed to support our second hypothesis that neuroticism, a proxy for trait anxiety, would be associated with declines in memory and complex visuospatial skills but not with declines in other cognitive domains. We found no support for neuroticism as a predictor of age-associated decline on any test in this cognitively intact older sample. Neuroticism was associated with poorer average performance across time on one measure of visuospatial skills, one measure of visual memory, and a test of perceptual speed and processing. We found decline over time on average on speeded and spatial tasks and individual differences in decline on speeded, spatial, and memory tasks, as well as on Information. These findings suggest that higher levels of neuroticism are not generally associated with longitudinal cognitive decline in normal aging.

The failure to find an effect of state anxiety on Symbol Digit suggests that this test may assess perceptual speed more than working memory. As appears to be the case with Figure Identification, anxiety-related differences on Symbol Digit performance may be negligible compared with the effect of age on processing speed in this older sample. Failure to find an effect of state anxiety on Figure Logic, while finding such effects for Block Design and, for men, Card Rotations, may be explained by the fact that Figure Logic was easier than the other visuospatial tasks (Table 1). Figure Logic may have been insufficiently difficult to call on the resources of the central executive enough to be vulnerable to the effects of state anxiety on working memory. The main effect of state anxiety on Synonyms performance cross-sectionally was unexpected because Synonyms is often considered a test of well-learned knowledge. In this sample, Synonyms correlated most highly with Information, another test that is considered a measure of verbal knowledge (Table 2). However, Eysenck (1992) cited evidence from younger samples that high neuroticism is associated with long-term basic deficits such as poorer vocabulary and with behaviors that could interfere with learning, such as poorer study habits. Although we did not find an association between neuroticism and Synonyms performance, these mechanisms may account for state-anxiety–based deficits in verbal knowledge in this sample.

Limitations and Advantages

One limitation of this study involves the measurement of anxiety. Ideally, the state anxiety measure should have been given within minutes, rather than days, of cognitive testing. Furthermore, the state anxiety measure was completed in a more familiar environmental setting (the person's home) than the cognitive testing was. A scale administered at the same time and place as the cognitive battery would probably have produced higher and more variable state anxiety scores than were observed in the present study, because vulnerable individuals would likely experience greater anxiety in a novel setting when about to undergo cognitive testing. Increased variability of state anxiety scores would provide greater power to discover relationships between anxiety and cognitive performance. Hence, our methodology likely underestimated the effects of state anxiety on cognitive performance.

Additionally, neuroticism was used as a proxy for trait anxiety. Although these constructs are related, they are not identical. Neuroticism may capture additional elements (such as vulnerability to other negative emotions like depression or anger) that are not inherently part of trait anxiety. Use of a true trait anxiety scale may have increased power to detect significant longitudinal relationships between anxiety and cognition.

Other investigators have found that the way anxiety is measured can influence results. Domain-specific measures assessing anxiety about cognitive abilities tend to be more sensitive predictors of memory performance than general state anxiety measures are (Cavanaugh & Murphy, 1986; Davidson, Dixon, & Hultsch, 1991; Lachman, Baltes, Nesselroade, & Willis, 1982). The present study used a very commonly employed general state anxiety measure, not a measure of test anxiety. If anything, this approach may have minimized the effects of anxiety on cognitive performance.

The sample was composed of racially and culturally homogeneous Swedish twins; findings may differ in a more diverse sample. Twins may differ from single-birth individuals in ways that affect cognition or anxiety in later life, although evidence suggests that registry-based twin samples are representative, and findings from twin samples are commonly considered generalizable to a broader population. Previous investigations have used twin samples such as the National Heart, Lung, and Blood Institute Twin Study and the Australian Twin Registry for longitudinal analyses, treating participants as genetically unrelated individuals (Dunne, Martin, Pangan, & Heath, 1997; Swan et al., 1998). In this study, we used random effects models to allow for the analysis of dependent observations, in effect controlling for correlations between twin partners, to test hypotheses about the relationship between anxiety and cognitive performance across individuals. A related study could use these models to explore individual differences by comparing predicted values to actual performance, but this was not the focus of the present investigation. A further limitation is that approximately half of the sample were separated from their twin partner in early life. This unusual feature may limit generalizability, although age and education level, on which differences were found between twins reared apart and those reared together, were included as covariates in these analyses.

Both memory measures in this battery tested visual, as opposed to verbal, memory. Tests of nonverbal memory have typically been overlooked in studies of anxiety in older samples, an important reason for using them here. However, because verbal memory tasks draw on resources from both the phonological loop and the central executive of working memory, they may be more vulnerable to the effects of anxiety than visual memory tests are.

The main advantage of this large longitudinal study is the ability to test hypotheses about the relationship between anxiety and normal age-related cognitive decline, which has apparently not been reported previously. The study included a comprehensive test battery, including visuospatial and visual-memory measures that have not been as frequently investigated among older adults as verbal memory or attentional tasks in relation to anxiety. The sample is population-based, eliminating the potential for bias from sources such as memory clinics or senior centers. Furthermore, longitudinal follow-up of the sample allowed us to limit analyses to those participants who were cognitively intact, rather than in the early stages of dementia.

Conclusion

Overall, results provide some support for Eysenck's processing efficiency theory. State anxiety did result in poorer performance, at least for men, on a task that draws heavily on the phonological loop of working memory (Digit Span). Likewise, performance on tasks involving the central executive, such as Analogies, Block Design, Names and Faces, Thurstone's Picture Memory, and—for men—Card Rotations, was poorer for those reporting higher levels of state anxiety. Performance on tasks that draw more on retrieval of knowledge from long-term storage (Information) and perceptual speed and pattern matching (Symbol Digit and Figure Identification) than on working memory was not related to state anxiety.

The pattern of results further suggests that cognitive performance is more sensitive to state anxiety than to neuroticism, a proxy for trait anxiety. This would also be consistent with processing efficiency theory's emphasis on verbal processes such as worry interfering with cognitive performance. These processes are a state phenomenon, although they may occur more frequently in individuals with high trait anxiety.

Finally, this study provides no support for neuroticism as a risk factor for cognitive decline. Although tasks that typically show age-related decline may be affected by anxiety, general anxiety proneness does not appear to be related to accelerated rates of decline. Of course, neuroticism is not synonymous with trait anxiety. Future research should revisit the relationship between anxiety and cognitive decline using a better measure of trait anxiety than neuroticism.

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Julie Loebach Wetherell is now with the Department of Psychiatry, University of California, San Diego and the VA San Diego Healthcare System.

Address correspondence to Julie Loebach Wetherell, Department of Psychiatry, University of California at San Diego, VA San Diego Healthcare System (116A-1), 3350 La Jolla Village Drive, San Diego, CA 92161. E-mail: jwetherell@ucsd.edu

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