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Dementia: Continuum or Distinct Entity?

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Abstract

The latent structure of dementia was examined in a group of 10,775 older adults with indicators derived from a neuropsychological test battery. Subjecting these data to taxometric analysis using mean above minus below a cut (MAMBAC), maximum covariance (MAXCOV), and latent mode factor analysis (L-Mode) produced results more consistent with dementia as a dimensional (lying along a continuum) than categorical (representing a distinct entity) construct. A second study conducted on a group of 2375 21-to-64-year olds produced similar results. These findings denote that dementia, as measured by deficits in episodic memory, attention/concentration, executive function, and language, differs quantitatively rather than qualitatively from the cognitive status of non-demented adults. The implications of these results for classification, assessment, etiology, and prevention are discussed.

Keywords

Taxometrics; Latent Structure; Dementia; Neuropsychological

The social, personal, and economic impact of Alzheimer's disease and other dementias on society is profound and growing. Alzheimer's disease is the sixth leading cause of death in the United States and carries with it an annual price tag of \$148 billion (Alzheimer's Association, 2009). The burden that dementias of the Alzheimer's type and non-Alzheimer's type impose on caregivers reverberates through every community, leaving no neighborhood untouched (Gaugler, Mendiondo, Smith, & Schmidt, 2003). Advances in medical science have extended the lifespan, one consequence of which has been an increase in the elderly population. Also, in the United States, as in many other countries, the baby boom generation is beginning to reach retirement age. Consequently the number of people over the age of 65 continues to climb and along with it the number of people affected by dementia. Currently about 5.3 million Americans suffer from Alzheimer's disease, with several million more diagnosed with vascular dementia, frontotemporal dementia, or dementia with Lewy bodies. These numbers are expected to double or triple in the next forty years (Alzheimer's Association, 2009). Although dementia may be more common in industrialized nations (Hendrie et al., 1995) it is a serious problem that affects all areas of the world. Consequently, it is vital that we understand the nature of this disorder, to include its underlying or latent structure.

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There are several different options available to researchers interested in investigating the latent structure of a theoretical construct: cluster analysis, finite mixture modeling, and taxometrics, among others. Because clustering techniques like cluster analysis and finite mixture modeling tend to overidentify the number of groups or components in a sample or mixture, some researchers prefer taxometrics (Ruscio, Haslam, & Rusio, 2006). In the course of developing the taxometric method, Meehl (1995, 2004) introduced several statistical algorithms, to include mean above minus below a cut (MAMBAC: Meehl & Yonce, 1994), maximum covariance (MAXCOV: Meehl & Yonce, 1996)/maximum eigenvalue (MAXEIG: Waller & Meehl, 1998), and latent mode factor analysis (L-Mode: Waller & Meehl, 1998). Each algorithm is designed to ascertain whether a discontinuity exists in a distribution of scores. A discontinuity indicates the presence of a taxonic or categorical latent structure, whereas continuity signals the presence of a dimension. Taxometric research on the latent structure of Diagnostic and Statistical Manual of Mental Disorders (DSM-IV: APA, 2000) diagnoses has produced both taxonic (Goedeker & Tiffany, 2008; Ingram, Takahasi, & Miles, 2008; Ruscio, Zimmerman, McGlinchey, Chalmers, & Young, 2007; Walters, 2008) and dimensional (Broman-Fulks et al., 2006; Broman-Fulks et al., 2008; Frazier, Youngstrom, & Naugle, 2007; Olatunji, Williams, Haslam, Abramowitz, & Tolin, 2008) results for Axis I (clinical) disorders like age-related dementia and mostly dimensional results for Axis II (personality) disorders (Edens, Marcus, & Ruiz, 2008; Foster & Campbell, 2007; Marcus, Lilienfeld, Edens, & Poythress, 2006; Rawlings, Williams, Haslam, & Claridge, 2008; Walters, Diamond, Magaletta, Geyer, & Duncan, 2007).

An exhaustive review of the taxometric literature revealed only one prior taxometric study on dementia. In that study Golden (1982) took 20 dichotomous item-indicators from a mental status questionnaire, classified 841 older individuals as either demented or not demented using Bayes' Theorem, and compared the taxometric classifications with the individual's actual clinical diagnosis. In observing a high degree of concordance between taxometric classification and clinical diagnosis Golden (1982) concluded that dementia was taxonic. There are at least two problems with this conclusion, however. First, demonstrating concordance with a fallible criterion is not a particularly powerful test of the taxometric hypothesis. A clinical diagnosis of dementia uncorroborated by postmortem results is a fallible criterion measure. The general absence of gold standard measures in psychology is precisely what led Meehl (1992, 1995) to develop multiple taxometric procedures (MAMBAC, MAXCOV/MAXEIG, L-Mode) as a means of bootstrapping a solution to the latent structure question. None of these procedures were included in the Golden (1982) study, although this was probably because they were not yet fully developed at the time Golden conducted his research. Second, the mental status questionnaire that Golden (1982) used to create indicators was composed of simple orientation questions and self-reported problems in everyday living. Validated performance measures of the memory, language, and executive function deficits currently considered diagnostic of dementia are required for an accurate assessment of latent structure.

Although only one prior taxometric study has been conducted on dementia there is a great deal of interest and debate among researchers as to whether dementia is a discrete category, qualitatively distinct from normal aging, or the upper end of a continuum that differs only quantitatively from normal aging. Non-taxometric research has generated support for both positions. In some research situations and with some measures the categorical position has been supported (Buckner, 2004; Johnson, Storandt, & Balota, 2003) and in other research situations and with other measures the continuum position has been supported (Imhof et al., 2007; Collette, Schmidt, Scherrer, Adam, & Salmon, 2009). Valid indicators are needed to properly implement the taxometric method and determine whether dementia represents a distinct entity or lies along a continuum. Pre-taxometric analyses are consequently performed to make sure the indicators we use are capable of distinguishing between the putative taxon (highest scoring participants) and the putative complement (remaining participants). These two

groups are formed by dividing the sample at the cutoff point where the upper portion of the sample (putative taxon) corresponds with the estimated population base rate of the construct being evaluated (dementia in the current study). Indicators are then selected based on the results of these pre-taxometric analyses.

In an effort to understand the latent structure of dementia-related disorders a taxometric analysis of a large sample of older Americans (age ≥ 65 years) was conducted using valid indicators from several well-established neuropsychological inventories, a full complement of taxometric procedures, and a methodology that compares the relative fit of the data to simulated taxonic and dimensional curves. Indicators were derived from performance measures of episodic memory, attention/concentration, executive function, and language and data were analyzed with three quasi-independent and nonredundant taxometric procedures (MAMBAC, MAXCOV, L-Mode), thus permitting consistency testing across procedures. Also, a methodology and inferential framework advanced by Ruscio (2007) in which the data curve is compared to simulated taxonic and dimensional curves was employed in this study to reduce the impact of subjective judgment on the determination of latent structure. Finally, because there is a belief on the part of some researchers that early-onset Alzheimer's disease is distinct from late-onset Alzheimer's disease (Campion et al., 1995), a second study was conducted on adults under the age of 65 using the same indicators, procedures, and criterion measures as those used in the 65 years of age and older sample.

Method

Participants

The initial visit packet of the Uniform Data Set (UDS) was the data source for this study. The UDS is a standardized protocol used by participating Alzheimer's Disease Centers (ADCs) to gather data on Alzheimer's disease and related disorders which is then made available to researchers. Data collection took place between 2005 and 2009 and was supported by a grant from the National Institute on Aging. The National Alzheimer's Coordinating Center (NACC) has served as a central repository for these data since 1999. NACC data sets, including the UDS, derive from data collected at 32 ADCs located throughout the United States. At the time of this study the UDS contained initial visit data for 16,470 subjects and 725 variables. ADCs enroll subjects through referrals from physicians, referrals from family members, referrals from community organizations, and self-referrals from potential patients and from volunteers who wish to contribute to research on dementia. Dementia diagnoses in the UDS are predominately of the Alzheimer's type and most were derived through consensus between several clinicians (76.8%), although about a quarter of the diagnoses (23.2%) were made by a single clinician.¹ The cognitive status (demented, non-demented) by referral (clinical evaluation, research volunteer) breakdown for the samples used in Studies 1 and 2 can be found in Table 1. For a full description of the sample the reader is referred to a paper by Morris et al. (2006).

Participants for the first study were the 10,775 UDS subjects who were 65 years of age or older at the time of their initial visit and who completed all ten neuropsychological measures routinely administered as part of the UDS. More than a quarter of the participants in this sample (28.0%) received a clinical diagnosis of dementia from an ADC neurologist. The average participant was 77.14 years of age ($SD = 7.00$, range = 65–117) with 14.94 years of education ($SD = 3.29$, range = 0–25). The sample comprised 4602 males (42.7%) and 6173 females

¹Dementia diagnoses were made by one or more experienced clinicians attached to an ADC. Each clinician was provided with a training video that showed how to construct a global dementia rating from a series of individual ratings. Clinicians had to demonstrate adequate reliability with videotaped case presentations before they could contribute data to the UDS. When the cases receiving a diagnosis from a single clinician were removed from the sample (leaving only cases diagnosed through consensus) the results did not differ meaningfully from the results obtained in the full sample. Consequently, only the full sample results are reported in this paper.

(57.3%) and the marital breakdown was 4.9% single/never married, 60.9% married, 10.1% divorced or separated, and 24.1% widowed. The majority of participants were white (78.4%), followed by 13.4% black, 5.8% Hispanic, and 2.4% other. At the time of the initial evaluation, 59.3% of the participants were living with a spouse or partner, 29.7% were living alone, 8.3% were living with a relative or friend, 1.0% were living in a group home or residence, and 1.6% had an unknown living situation. The majority of participants were living independently (70.5%) or required assistance only with complex activities (21.9%). Less than ten percent of the sample required assistance with basic activities (6.6%), were completely dependent (0.7%), or had an unknown level of independence (0.4%).

Participants for the second study were 2375 individuals from the UDS who had not participated in the first study because they were under the age of 65 at the time of the initial visit. Slightly less than a quarter of the sample (22.8%) received a clinical diagnosis of dementia by an ADC neurologist. These individuals ranged in age from 21 to 64 years ($M = 58.04$, $SD = 6.79$) with a mean educational level of 15.42 years ($SD = 3.08$, range = 0–25). The ethnic breakdown of the sample was 76.4% white, 13.8% black, 7.1% Hispanic, and 2.7% other, whereas the marital breakdown was 9.0% single/never married, 70.1% married, 16.5% divorced or separated, and 4.4% widowed. Like participants in Study 1, the majority of Study 2 participants were currently living with a spouse or partner (69.2%), with 19.4% reporting that they were living alone, 9.3% reporting that they were living with a friend or relative, and 0.5% reporting that they were living in a group home or residence. Over three-quarters of the participants from Study 2 were living independently (76.3%), although 18.7% required assistance with complex activities, 4.6% required assistance with basic activities, and 0.5% were completely dependent on others for their care.

Measures

There were ten neuropsychological measures administered as part of the ADC protocol. These included the Logical Memory immediate and delayed recall scores from the Wechsler Memory Scale-Revised (WMS-R: Wechsler, 1987), digits forward and digits backward from the WMS-R Digit Span subtest, category fluency in naming animals and vegetables from the Boston Diagnostic Aphasia Examination (Goodglass & Kaplan, 1983), Trails A and B of the Trailmaking Test (Armitage, 1945), the Digit Symbol subtest of the Wechsler Adult Intelligence Scale-Revised (WAIS-R: Wechsler, 1981), and the Boston Naming Test (Kaplan, Goodglass, & Weintraub, 1983). Preliminary analyses were conducted to ensure proper coverage of the major neuropsychological symptoms of dementia using an indicator set with sufficient validity and minimum nuisance covariance to conduct a proper taxometric analysis. These preliminary analyses produced an indicator set of four cognitive skills normally impacted by dementia: Logical Memory-delayed recall (episodic memory), Digits Backward (attention, concentration, working memory), Trails B (executive functioning), and the Boston Naming Test (language ability and aphasia).²

The Logical Memory task involves reading a story to the examinee (Story A in the case of the UDS) and asking the examinee to recall as many elements of the story as possible. The Logical Memory delayed recall score was the total number of story units recalled (out of a total of 25) after an average delay of 22.63 minutes ($SD = 8.30$). In the case of Digits Backward the examinee is presented with a series of digits (2 to 7 digits, two trials per length) and asked to repeat the digits in reverse order. Digits Backward was scored as the number of trials correctly

²Six of the 10 tests were not included as indicators in this study, either because they were deemed less adequate measures of the core features of dementia (Logical Memory immediate recall was discarded in favor of Logical Memory delayed recall as a measure of episodic memory, Digits Forward was discarded in favor of Digits Backward as a measure of attention/concentration/working memory, Trails A was discarded in favor of Trails B as a measure of executive functioning) or because they did not fare well in preliminary analyses with respect to nuisance covariance or indicator validity (i.e., category fluency-animals, category fluency-vegetables, Digit Symbol).

reversed prior to the commission of two consecutive errors at the same digit length. In Trails B of the Trailmaking Test the examinee must connect 25 numbered and lettered circles in ascending order, alternating between numbers and letters. The score on Trails B is the total amount of time (to a maximum of 300 seconds) it takes to connect all 25 circles. The Boston Naming Test consists of 60 line drawings the examinee is required to verbally label. For the purpose of the UDS only the 30 odd-numbered items were used, the score on this measure being the number of line drawings (out of 30) correctly identified by the individual.

Procedure

The UDS data were entered into Ruscio's (2009) taxometric software program for R language to determine whether they showed evidence of discontinuity on three of Meehl's taxometric procedures: mean above minus below a cut (MAMBAC: Meehl & Yonce, 1994), maximum covariance (MAXCOV: Meehl & Yonce, 1996), and latent mode factor analysis (L-Mode: Waller & Meehl, 1998). Using the default options in Ruscio's program, the MAMBAC procedure was implemented by ordering a composite input indicator along the *x*-axis and plotting, along the *y*-axis, the mean difference in scores on an output indicator falling above and below a series of evenly spaced cuts (50 in the present study), reserving 25 cases for the two most extreme cuts. A convex or peaked MAMBAC curve indicates the presence of a taxon, whereas a concave curve which bows upward at one or both ends signals a dimension (Meehl & Yonce, 1994). Summed input MAMBAC (combining the three indicators that were not the output indicator) was computed in all possible combinations to create four individual curves. These four curves were then averaged and compared to simulated taxonic and dimensional curves. Ten internal replications were performed in the calculation of the curves to minimize the obfuscating effect of tied scores. Cases were assigned to the taxon and complement groups using the base rate classification procedure.

Like MAMBAC, MAXCOV orders an input indicator along the *x*-axis, but instead of calculating mean differences in the output indicator, MAXCOV computes the covariance between two output indicators and plots the results on the *y*-axis. The equally spaced subgroups that form the *x*-axis can be divided into non-overlapping intervals or overlapping windows. Based on the results of a recent Monte Carlo study (Walters & Ruscio, 2009b), 25 sliding windows with 90% overlap were used to construct the input indicator. Similar to MAMBAC, a taxon is normally identified by a peak in the MAXCOV curve. The peak represents the subsample in which taxon and complement members are roughly equal. A flat or non-peaked curve, on the other hand, suggests the presence of a dimension (Meehl & Yonce, 1996). Because summed input MAXCOV is significantly less accurate than traditional MAXCOV (Walters & Ruscio, 2009a) the traditional approach was employed in this study. When implementing MAXCOV in the traditional manner all possible indicator triplets (one indicator serving as the input and two indicators serving as the output) are calculated. Tied scores on the input indicator were resorted ten times to stabilize the curves and cases were assigned to the taxon and complement groups using the base rate classification procedure.

Whereas MAMBAC and MAXCOV are examples of what Meehl (1995, 2004) called coherent cut kinetics, L-Mode derives from the factor analytic tradition. After calculating the first (and largest) principal factor of the indicators, L-Mode plots the distribution of participants' scores on this single latent factor. A bimodal curve normally denotes a taxon or discontinuity in the distribution, whereas a unimodal curve often signals the presence of a dimension. Just the same, taxa have been known to produce unimodal results and dimensions can sometimes give rise to bimodal patterns (Waller & Meehl, 1998). Given the fact that calculating base rates with L-Mode can be difficult, problematic, and time consuming, Ruscio and Walters (in press) recommend inputting taxon base rate estimates directly from MAMBAC and MAXCOV into L-Mode. The results of the L-Mode analyses at different base rates are then combined and

averaged to determine the extent to which they conform to taxonic or dimensional latent structure. In the current study the specific taxon base rates used to calculate L-Mode were derived from the average taxon base rates for MAMBAC and MAXCOV and scores on the four indicators were standardized before being factor analyzed.

In the current study latent structure was assessed solely on the basis of model fit. Using a bootstrapping technique, simulated taxonic and dimensional curves were created for MAMBAC, MAXCOV, and L-Mode based on the unique distributional and correlational characteristics of the data (Ruscio, Ruscio, & Meron, 2007). For the purpose of this study, 20 simulated data sets were calculated for taxonic structure and averaged and 20 simulated data sets for dimensional structure were calculated and averaged. Relative fit was operationalized using the comparison curve fit index (CCFI) which calculates the root mean square residual (RMSR) between the research data and simulated taxonic and dimensional curves. The computed RMSR figures are then entered into the following equation: $CCFI = \text{Fit}_{\text{RMSR-dim}} / (\text{Fit}_{\text{RMSR-dim}} + \text{Fit}_{\text{RMSR-taxon}})$. CCFI scores above .5 suggest that the measured construct is categorical, CCFI scores below .5 suggest that the measured construct is dimensional, and CCFI scores around .5 are indeterminate. A growing body of Monte Carlo research supports the accuracy of the CCFI (Ruscio, 2007; Ruscio & Marcus, 2007; Ruscio et al., 2007; Ruscio et al., 2008; Walters & Ruscio, 2009a, 2009b). In the largest of these studies, Ruscio et al. (2008) determined that a mean CCFI formed by averaging the individual MAMBAC, MAXCOV, and L-Mode CCFI values achieved 98.0% accuracy using a single threshold criterion ($< .500$ = dimensional; $\geq .500$ = taxonic) and 99.4% accuracy (with 5.2% ambiguous results) using a narrow dual thresholds criterion ($< .450$ = dimensional; $> .550$ = taxonic).

Results

Study 1

The indicators used in a taxometric study must be sufficiently valid and reasonably homogenous to produce interpretable taxometric results. A mean Cohen's d of 1.25 is considered the minimum threshold for valid indicators (Meehl, 1995). To assess indicator validity the four indicators were converted to standard scores and the scores summed. The sum was then divided into putative taxon and complement groups using a cutting score derived from the base rate of dementia diagnoses in this sample (28.0%).³ The results demonstrated adequate separation between the putative taxon and complement groups (mean $d = 1.86$). Table 2 lists the individual validity figures for each indicator along with basic descriptive statistics.

Effective implementation of the taxometric method requires that the mean correlation between indicators in the full sample (full sample covariance) exceeds .30 and the mean inter-indicator within-group (taxon and complement) correlations (nuisance covariance) fall below .30 (Meehl, 1995). The mean full sample correlation was .47, the mean within-group correlation for the putative taxon was $-.01$, and the mean within-group correlation for the putative complement was .20. The full sample correlation indicates that there was sufficient correlation between the indicators to perform a taxometric analysis and the within-group correlations indicate that nuisance covariance was not a major problem in this study.

The estimated base rates and CCFI values achieved when data from the full sample were subjected to MAMBAC, MAXCOV, and L-Mode analysis are reproduced in Table 3 and the actual curves are depicted in Figures 1 through 3, respectively. The individual MAMBAC,

³The base rate for Study 1 was calculated from the proportion of cases receiving a consensus or single clinician diagnosis of dementia. The sample was ordered according to the sum of the standardized scores (z) of the four indicators and the base rate of dementia diagnoses (28.0%) was used to divide the sample into a putative taxon group (the 3012 highest scoring cases) and a putative complement group (the 7763 lowest scoring cases).

MAXCOV, and L-Mode CCFIs and the mean CCFI (a particularly strong latent structure consistency measure) were all more congruent with dimensional latent structure than with categorical latent structure. The results of taxometric analyses conducted on subgroups of participants broken down by gender (male, female), ethnicity (white, black, Hispanic), education (< 12 years, ≥ 12 years), and age (young-old, old-old, and very old) were also more consistent with dimensional latent structure than with categorical latent structure (see Table 3).

Study 2

Descriptive statistics, including validity figures, for the four individual indicators included in Study 2 are listed in Table 4. Mean validity (d) when the four indicators were treated as a composite and the sum of the standardized indicator scores were used to divide the sample into putative taxon and complement groups using a cut score derived from the base rate of dementia diagnoses (22.8%) was 2.08.⁴ Analyses revealed that the mean full sample inter-indicator correlation was .47, the mean putative taxon inter-indicator correlation was .03, and the mean putative complement inter-indicator correlation was .21. Hence, there was ample correlation between indicators in the full sample and a sufficiently low degree of nuisance covariance to perform a meaningful taxometric analysis.

The estimated base rate for MAMBAC in this study was .38 with a standard deviation of .12. Curve shape showed a distinctive dimensional pattern with the ends of the curve bending upward, an observation supported by a CCFI score of .376. With MAXCOV, the base rate was .23 (SD = .11) and the CCFI was .373. Inserting base rates of .23, .26, .29, .32, .35, and .38 into L-Mode produced CCFI scores ranging from .440 to .496 ($M = .475$). Across the three taxometric procedures the mean CCFI was .408. Two of the three individual CCFI scores as well as the mean CCFI score were more consistent with dimensional latent structure than with categorical latent structure. The L-Mode results were indeterminate but leaned in a dimensional direction.

Discussion

The results of both studies support a dimensional interpretation of the latent structure of dementia and run counter to Golden's (1982) earlier conclusion that dementia has a categorical latent structure. Hence, differences in neuropsychological status between older individuals diagnosed with dementia and older individuals not diagnosed with dementia are quantitative (continuum) rather than qualitative (distinct entity). Consistency testing, being the sine qua non of taxometric research, is vital in determining the latent structure of a construct. Thirty six individual tests (3 procedures × 12 samples/subsamples) were computed in this study. Of this number, 34 fell below the threshold for dimensional latent structure and two were indeterminate. Even the two indeterminate CCFI scores (L-Mode for the Hispanic subsample in Study 1 and L-Mode in Study 2) fell below .50. There is growing consensus that the genetic factors underlying early-onset Alzheimer's disease differ from the genetic factors underlying late-onset Alzheimer's disease (Campion et al., 1995) and that early-onset Alzheimer's has a more rapid progression than late-onset Alzheimer's (Jacobs et al., 1994). Even with these obvious differences in etiology and course, early-onset and late-onset dementia both appear to possess dimensional latent structure such that individual differences on this trait (dementia) are a matter of degree rather than a difference in kind.

⁴The base rate for Study 2 was also calculated from the proportion of cases receiving a consensus or single clinician diagnosis of dementia. The sample was ordered according to the sum of the standardized scores (z) on the four indicators and the base rate of dementia diagnoses (22.8%) was used to divide the sample into a putative taxon group (the 541 highest scoring cases) and a putative complement group (the 1834 lowest scoring cases).

According to the results of the two studies described in this paper the neuropsychological functions and dysfunctions of demented and non-demented adults exist at opposite ends of the same continuum or dimension rather than bifurcating into conceptually distinct categories or classes of behavior. The view that dementia-related disorders like Alzheimer's disease are exaggerated or accelerated forms of normal age-related changes in cognitive function is not new (see Imhof et al., 2007). What may be new is the notion that there is no discontinuity between those who suffer from dementia and those who do not, even for early-onset cases. This preliminary hypothesis finds support in the fact that the rate of Alzheimer's disease grows rapidly when moving from the young-old age group to the very old age group. It is well known that the prevalence of dementia in people between the ages of 65 and 69 is only about one percent. However, the prevalence of dementia is almost six percent in people between the ages of 75 and 79 and in people over the age of 90 the prevalence rate of dementia can be as high as 40% (Fitzpatrick et al., 2004). Consequently, there may be less of a conceptual gap between dementia and non-dementia than has traditionally been assumed.

Taxometric findings have important scientific and practical applications. Chief among these are the application of taxometric research to classification and diagnosis. As preparations are being made to revise the nosological criteria for dementia and other mental disorders in anticipation of the upcoming release of the fifth edition of the diagnostic and statistical manual of mental disorders (DSM-V; Regier, 2007), the implications of taxometric research for classification become more salient. The fact that the latent structure of dementia appears to be dimensional rather than categorical means that there is no objective or taxonic boundary separating those who do and those who do not meet the criteria for dementia of the Alzheimer's type. Cutting scores on various classification and diagnostic instruments can still be developed and implemented but they do not represent a taxonic boundary between health and pathology. They could nonetheless be useful in a pragmatic sense by maximizing cost/benefit calculations (Swets, Dawes, & Monahan, 2000) or increasing the sensitivity and specificity of various diagnostic schemes (Kraemer, Noda, & O'Hara, 2004). Dimensional results suggest that severity quantifiers may be helpful in classifying individuals (Ruscio et al., 2006). In the case of dementia, this could be implemented by having a clinician complete a symptom severity rating scale.

Taxometric results can also have important implications for how a construct is assessed. Whereas the focus of assessment with a categorical or taxonic construct is finding items that maximally discriminate between the taxon and complement and reliably classify individuals into one of two groups, the focus of assessment in the case of a dimensional construct is finding items that make fine discriminations along a wider range of values for the purpose of locating an individual's position on the continuum (Ruscio et al., 2006). Mental status exams are often used to screen for dementia. Unfortunately, most of these measures focus on the severe memory and orientation problems found at the high end of the continuum. This is certainly true of the mental status questionnaire used in the Golden (1982) study where emphasis was placed on profound disorientation and long-term memory problems. To a certain extent it also applies to the Mini Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) administered as part of the standard UDS protocol. If the latent structure of dementia is dimensional then we must also assess the subtle memory, attention/concentration, executive function, and language deficits that are missed by the MMSE and other brief measures of cognitive impairment yet were detected in the present study by Logical Memory, Digits Backward, Trails B, and the Boston Naming Test, respectively. Measures like the Alzheimer's Disease Assessment Scale (Rosen, Mohs, & Davis, 1984) and Mattis Dementia Rating Scale (Mattis, 1976) may be helpful in assessing some of the cognitive functions missed by brief mental status questionnaires.

In addition to its implications for classification, diagnosis, and assessment, taxometric research also has a bearing on causal explanations. There is only modest consensus, at present, on the causes of Alzheimer's disease and other dementia-related disorders (Morris, 2008). Although findings from a taxometric study cannot be used to infer causal content they can be helpful in clarifying causal process. Meehl (1977, 1992) argued that a discontinuous or taxonic latent structure supports one of four major causal pathways: specific etiology, critical point or threshold effects, nonlinear interaction, and developmental bifurcation. The causal origins of a dimensional construct, on the other hand, ordinarily include many small influences that accumulate in what Meehl (1992) referred to as an additive effect. Many risk factors, both genetic and environmental, have been implicated in the development of dementia-related disorders, from the apoE4 gene (Holmes, 2002), to a history of head injury (Holsinger et al., 2002), to low educational attainment (Johnson et al., 1997). The accumulation of these and other risk factors—some weighted more heavily than others, with effects ranging from simple to interactive—is what gives rise to dementia in its various forms. An additive model also implies that there are no sufficient causes for dementia and no necessary causes other than perhaps age.

Taxometric researchers generally avoid drawing conclusions about the implications of taxometric research for therapy and intervention. However, the dimensional results obtained in this study may also be capable of informing dementia prevention. In situations where etiology is additive different combinations of risk factors can produce a comparable level of impairment. If no single risk factor other than age is a necessary causal condition for the development of Alzheimer's disease, eliminating these risk factors or finding compensatory protective factors may help prevent the onset of dementia by lowering the individual's position on the dementia continuum. Based on our understanding of risk factors, prevention in the form of physical exercise, a brain-healthy diet, new and challenging learning tasks, better sleep hygiene, improved stress management, and brain-protection strategies like wearing helmets and avoiding toxins should reduce the incidence or delay the onset of many dementia-related disorders (Fortanasce, 2008). More data are required, however. Uncontrolled clinical and cohort studies support the utility of physical activity (Lautenschlager & Almeida, 2006), dietary supplements (Gale, 2001), and anti-hypertension medication (Hanon & Forette, 2005) in reducing risk for future dementia, but there is a need for randomized clinical trials before such prevention strategies can be considered evidence-based.

The present study suffers from several limitations. First, a cross-sectional research design was implemented with this study. The neuropsychological evaluation took place when over 90% of the sample was under the age of 85 and we know that dementias of the Alzheimer's type increase markedly from young-old age to very old age (Fitzpatrick et al., 2004). Consequently, longitudinal research is required to determine whether the current dimensional results change as the age of the sample increases and the rate of new dementia cases accelerates. Second, the sample was more highly educated than the general population of the United States with a mean educational level of 15 years. Even so, restricting the analyses to individuals with less than a high school education did not change the overall conclusion that dementia has a dimensional latent structure. Third, because all of the indicators used in this study were based on neuropsychological test data, different results may have surfaced had mental status, neurological, or genetic indicators been employed. One advantage of using neuropsychological test results is that most forms of dementia show deficits in the areas of episodic memory, attention/concentration/working memory, executive functioning, and language, though the degree of deficit may vary between forms, with episodic memory deficits being more prominent in Alzheimer's disease and executive function deficits being more prominent in vascular dementia and frontotemporal dementia (Salmon & Bondi, 2009).

Another potential limitation of this study is that Ruscio's (2007, 2009) simulation approach is biased toward a dimensional solution which, in turn, may explain why dimensional results were obtained. This argument is not supported, however, by what we know about latent structure in general or Ruscio's approach in particular. In a posthumously published paper, Meehl (2004) acknowledged that true categories or taxa are relatively rare in human behavior. It accordingly makes perfect sense that the majority of taxometric findings would favor a dimensional interpretation of various psychological constructs and phenomena. This does not mean, however, that the simulation approach never yields categorical results. Recent studies using the simulated curve approach have produced taxonic results when examining the latent structure of unipolar depression (Ruscio et al., 2007), tobacco dependence (Goedeker & Tiffany, 2008), autism (Ingram et al., 2008), and alcohol dependence and abuse (Walters, 2008). Furthermore, the authors of several large-scale Monte Carlo studies report that the simulated curve approach is equally effective in identifying dimensional and categorical latent structure (Ruscio, 2007; Ruscio et al., 2007; Ruscio et al., 2008; Walters, McGrath, & Knight, in press; Walters & Ruscio, 2009a, 2009b). In fact, 11 out of 30 (36.7%) recently published studies using the simulated curve approach produced taxonic results, compared to 9 out of 11 (81.8%) studies for which the simulated curve approach was not used (Haslam, 2007). If there is bias in taxometric research it does not rest with Ruscio's simulated curve approach, where a concerted effort has been made to increase objectivity through development of the CCFI.

The current findings are inconsistent with the view that dementia, particularly dementia of the Alzheimer's type, is qualitatively distinct from non-dementia. Differences in neuropsychological test performance between adults diagnosed with dementia and comparably aged non-demented adults are quantitative rather than qualitative. A question that needs to be answered by future research is how well these quantitative differences in neuropsychological test performance generalize to differences in the neurophysiology and neuropathology of dementia-related disorders. Postmortem studies have found a large numbers of neurofibrillary tangles and amyloid plaques in the brains of people previously diagnosed with Alzheimer's disease. Neurofibrillary tangles and amyloid plaques are also found in the brains of elderly individuals without dementia, although the number is many times smaller than the magnitude found in the brains of Alzheimer's patients (Caselli, Beach, Yaari, & Reiman, 2006). One possibility is that the cognitive deficits observed in patients suffering from Alzheimer's disease and other forms of dementia are exaggerated or accelerated versions of normal aging. The current dimensional results are more congruent with this view and with the growing clinical practice of diagnosing mild cognitive impairment (MCI) in individuals who satisfy some but not all of the criteria for dementia (Roberts et al., 2009) than they are with Buckner's (2004) supposition that normal aging and Alzheimer's disease are distinct processes, with executive function deficits dominating the former and episodic memory problems characterizing the latter. A taxometric study using only episodic memory indicators might help resolve this issue.

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Figure 1. Average mean above minus below a cut (MAMBAC)-summed input data curve for the four dementia indicators (darker line) in comparison to simulated taxonic and dimensional data (lighter lines represent one standard deviation above and below the mean) in the full sample of Study 1.

Figure 2. Average maximum covariance (MAXCOV)-traditional data curve for the four dementia indicators (darker line) in comparison to simulated taxonic and dimensional data (lighter lines represent one standard deviation above and below the mean) in the full sample of Study 1.

Figure 3. Latent mode factor analysis (L-Mode) data curve for the four dementia indicators (dark solid line) in comparison to simulated taxonic (lighter solid line) and dimensional data (lighter dotted line) with the putative taxon base rate set at .37 in the full sample of Study 1.

Table 1

Referral by Diagnosis Breakdowns for the Two Samples

	Study 1	Study 2
	<i>N</i> = 10,775	<i>N</i> = 2,375
Clinical Evaluation	2555 (23.7%)	662 (27.9%)
Demented	1232 (48.2%)	234 (35.3%)
Alzheimer's Disease	1087 (88.2%)	145 (62.0%)
Other Dementia	145 (11.8%)	89 (38.0%)
Non-Demented	1323 (51.8%)	428 (64.7%)
Normal Cognition	408 (30.8%)	178 (41.6%)
Mild Cognitive Impairment	915 (69.2%)	250 (58.4%)
Research Volunteer	8220 (76.3%)	1713 (72.1%)
Demented	1781 (21.7%)	307 (17.9%)
Alzheimer's Disease	1525 (85.6%)	173 (56.4%)
Other Dementia	256 (14.4%)	134 (43.6%)
Non-Demented	6439 (78.3%)	1406 (82.1%)
Normal Cognition	4196 (65.2%)	1039 (73.9%)
Mild Cognitive Impairment	2243 (34.8%)	367 (26.1%)

Note. Other Dementia = Dementia with Lewy Bodies, Frontotemporal Dementia, Primary Progressive Aphasia, Vascular Dementia, Corticobasal Degeneration, and Parkinson's Disease; the first number in each column is the *n* and the second number, in parentheses, is the relevant proportion: Clinical Evaluation and Research Volunteer from the total sample; Demented and Non-Demented from the Clinical Evaluation and Research Volunteer subsamples; Alzheimer's Disease and Other Dementias from the two Demented subsamples; Normal Cognition and Mild Cognitive Impairment from the two Non-Demented subsamples; total breakdown across the two studies: 24.2% clinical evaluation vs. 75.8% research volunteer, 27.0% demented vs. 73.0% non-demented, 84.4% Alzheimer's Disease vs. 17.6% other dementia in the demented subsample, and 60.7% normal cognition vs. 39.3% mild cognitive impairment in the non-demented subsample.

Table 2
Descriptive Statistics and Indicator Validity Estimates for the Four Indicators: Study 1

Indicator	Range	M	SD	Skew ^a	Kurtosis ^b	Validity
1. Logical Memory-delayed	0–24	7.86	5.83	–0.20	–1.01	1.59
2. Digits Backwards	0–12	5.92	2.22	–0.36	–0.04	1.32
3. Trails B	0–300	147.21	87.91	0.71	–0.90	2.53
4. Boston Naming Test	0–30	24.14	5.78	1.46	1.80	2.01

Note. Validity = separation between putative taxon and complement groups as measured by Cohen's *d*; Range = minimum and maximum scores in the current sample; *M* = mean; *SD* = standard deviation; *N* = 10775.

^aThe standard error of measurement for skew in this sample was .02.

^bThe standard error of measurement for kurtosis in this sample was .05.

Table 3

Base Rate and Comparison Curve Fit Index Results for MAMBAC, MAXCOV, and L-Mode: Study 1

Sample	N	MAMBAC		MAXCOV		L-Mode		Mean	
		BR	CCFI	BR	CCFI	Range	M	CCFI	
Total	10775	.38(.12)	.332	.36(.18)	.152	.266–.271	.269	.251	
Male	4602	.45(.11)	.255	.38(.19)	.099	.246–.258	.254	.203	
Female	6173	.36(.09)	.359	.36(.18)	.189	.339–.349	.343	.297	
White	8448	.37(.12)	.331	.30(.12)	.204	.277–.306	.292	.276	
Black	1442	.50(.07)	.223	.47(.18)	.093	.342–.349	.346	.221	
Hispanic	628	.56(.06)	.113	.53(.23)	.228	.455–.483	.472	.271	
< 12 Yrs Ed	863	.56(.09)	.224	.64(.16)	.139	.334–.364	.350	.238	
≥ 12 Yrs Ed	9848	.38(.11)	.312	.34(.17)	.141	.236–.257	.247	.233	
Young-Old	4382	.38(.08)	.410	.30(.17)	.195	.324–.338	.331	.312	
Old-Old	4888	.39(.11)	.329	.37(.16)	.197	.282–.291	.288	.271	
Very Old	1505	.46(.09)	.209	.44(.19)	.182	.366–.380	.373	.255	

Note. Young-Old = ages 65–74; Old-Old = ages 75–84; Very Old = ages 85 and above; MAMBAC = mean above minus below a cut; MAXCOV = maximum covariance; L-Mode = latent mode factor analysis; Mean = mean of all three procedures; N = sample or subsample size; BR = base rate of the putative taxon with the standard deviation in parentheses; CCFI = comparison curve fit index; Range = range of CCFI scores; M = Mean CCFI score.

Table 4
Descriptive Statistics and Indicator Validity Estimates for the Four Indicators: Study 2

Indicator	Range	M	SD	Skew ^a	Kurtosis ^b	Validity
1. Logical Memory-delayed	0–24	9.81	5.75	0.14	–0.89	1.87
2. Digits Backwards	0–12	6.32	2.53	–0.23	–0.39	1.47
3. Trails B	0–300	111.84	83.05	1.37	0.54	3.19
4. Boston Naming Test	0–30	26.01	5.22	2.51	7.14	1.77

Note. Validity = separation between putative taxon and complement groups as measured by Cohen's *d*; Range = minimum and maximum scores in the current sample; *M* = mean; *SD* = standard deviation; *N* = 10775.

^aThe standard error of measurement for skew in this sample was .05.

^bThe standard error of measurement for kurtosis in this sample was .10.