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Monitoring Cognitive Functioning: Psychometric Properties of the Brief Test of Adult Cognition by Telephone

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Abstract

Assessment of cognitive functioning is an important component of telephone surveys of health. Previous cognitive telephone batteries have been limited in scope with a primary focus on dementia screening. The Brief Test of Adult Cognition by Telephone (BTACT) assesses multiple dimensions central for effective functioning across adulthood: episodic memory, working memory, reasoning, verbal fluency, and executive function. The BTACT is the first instrument that includes measures of processing speed, reaction time, and task-switching/inhibitory control for use over the telephone. We administered the battery to a national sample (*N* = 4,268), age 32 to 84 years, from the study of Midlife in the United States (MIDUS) and examined age, education, and sex differences; reliability; and factor structure. We found good evidence for construct validity with a subsample tested in person. Implications of the findings are considered for efficient neuropsychological assessment and monitoring changes in cognitive aging, for clinical and research applications by telephone or in person.

Keywords

cognitive functioning, testing by telephone, neuropsychological assessment

There is a growing recognition of the importance of assessing cognitive abilities in large interdisciplinary studies of psychological, physical, and economic health in adulthood (Deary, Allerhand, & Der, 2009; Hofer & Alwin, 2008; McArdle, Fisher, & Kadlec, 2007). This is particularly urgent given the dramatic shifts in population aging and the accompanying projections about widespread cognitive deficits and impairments (Sheffield & Peek, 2011). However, many longitudinal and epidemiological surveys do not routinely include measures of cognition or only include basic measures of cognitive status (Breitling, Wolf, Müller, Raum, & Kliegel, 2010; Lachman & Tun, 2008). Cognitive tests are not typically included in surveys, in part because there is a widespread assumption that they are time-consuming and must be administered in the laboratory or clinic, with visual stimuli and special equipment, by highly trained testers. The Brief Test of Adult Cognition by Telephone (BTACT, Lachman & Tun, 2008; Tun & Lachman, 2006) was developed to address the need for reliable and valid testing of cognitive functioning in survey work with community-based samples varying in age, educational background, and level of cognitive functioning, who may not be available for in-person testing.

There are a number of available cognitive telephone batteries, with the majority designed for assessment of basic cognitive status and dementia (Lachman & Tun, 2008). These batteries, often derived from the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975), have been used successfully to test adults with a focus on screening for cognitive impairment. Such instruments, including the Brief Screen for Cognition Impairment (Hill et al., 2005), the Memory and Aging Telephone Screen (Rabin et al., 2007), and the Telephone Cognitive Assessment Battery (Debanne et al., 1997), do not typically provide a comprehensive assessment of cognitive domains (see Lachman & Tun, 2008; Martin-Khan, Wootton, & Gray, 2010; Soubelet & Salthouse, 2011; Wolfson et al., 2009, for reviews) and are not sensitive enough to variations in cognitive abilities across adulthood (Wolfson et al., 2009). Due to ceiling effects and limited variance they cannot typically discriminate among those with mild deficits or those in the normal range of functioning especially when comparing adults of different ages. It is desirable to tap into a broader range of cognitive functioning especially given the importance of early detection of cognitive declines and the need for

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identifying more nuanced levels of performance and subtle warning signs. There are some telephone batteries that focus on normal cognitive functioning (see Lachman & Tun, 2008, for a review). However, they typically do not cover a broad range of cognitive abilities, and they primarily have been used with small, nonrepresentative, or regional samples, with a limited age range.

In designing the BTACT, we included key dimensions identified as relevant in the cognitive aging literature (Salthouse, 2001) and that have been identified by the National Institutes of Health as important measures for assessment of cognitive functioning (Gershon et al., 2010). We selected well-validated tests where possible, especially if they had been successfully administered previously over the telephone. Some of the same cognitive tests (i.e., verbal fluency, word list recall) are also assessed by the standardized instruments developed by The Consortium to Establish a Registry for Alzheimer's Disease for the evaluation and diagnosis of patients with Alzheimer's disease (Fillenbaum et al., 2008). A significant advantage of the BTACT is that it includes measures of speed of processing and reaction time. We developed two new measures to operationalize these constructs via telephone: the 30 Seconds and Counting Task (30-SACT) and the Stop and Go Switch Task (SGST).

Telephone tests such as the BTACT offer a vehicle for measuring individual differences in cognitive functioning in large epidemiological studies as well as in smaller studies at relatively low cost. Previous studies that have looked at effects of mode of testing have found no significant differences between telephone and face-to-face testing (e.g., Cullum, Weiner, Gehrmann, & Hynan, 2006; Herzog & Rodgers, 1998; Herzog & Wallace, 1997; Kliegel, Martin, & Jäger, 2007; Wilson et al., 2010). Although the Internet is also a viable means for cognitive assessment (White et al., 2003), there are some limitations, and it is not ideal for use with a wide range of ages and socioeconomic backgrounds given some may have limited experience or access to computers (http://www.pewinternet.org/Commentary/2010/January/38-of-adults-age-65-go-online.aspx).

The goal of the present study was to provide information about the psychometric properties of BTACT and the variations in performance as a function of key demographic variables (age, sex, and education) in a large national sample of adults.

Method

Participants

We used data from a probability sample of participants in the second wave of Midlife in the United States (MIDUS) national longitudinal study, as well as a MIDUS subsample from the second occasion of the Boston Longitudinal Study (BOLOS). MIDUS participants were cognitively tested using the BTACT. BOLOS participants were tested using both the BTACT and a cognitive battery administered in person.

The initial MIDUS sample (N = 7,100) was generated in 1995-1996 through random digit dialing of U.S. households having at least one telephone in the contiguous 48 states, stratified by age with the greatest number of participants between 40 and 60 years old (Brim, Ryff, & Kessler, 2004). The participants ranged in age from 24 to 75 years (M = 46.40, SD = 13.00). The overall response rate was 70% for the telephone interview.

Nine years later on average (SD = 0.64), at the second occasion of measurement, 69.79% (N = 4,955) of the original sample was retested (75% retention rate when adjusted for mortality; Radler & Ryff, 2010). At Time 2, participants ranged in age from 32 to 84 years (M = 55.36, SD = 12.40) and had a mean education level of 14.24 years (SD = 2.60). Women made up 53.8% of the sample, and mean self-rated health on a 5-point scale (1 = *poor*, 5 = *excellent*) was 3.53 (SD = 1.02). As is typically found, those who participated at the second wave showed some differences on Time 1 variables compared with those who dropped out of the study. Compared to the dropouts, longitudinal participants were more highly educated, $t(6757) = 12.48$, $p < .001$, mean years of education 13.21 versus 14.06; were more likely to be women, 48.3% versus 53.8%, $\chi^2(1) = 17.49$, $p < .001$; and had higher self-rated health, $t(6759) = 10.42$, $p < .001$, 3.33 versus 3.61 on a 5-point scale where 1 = *poor*, 5 = *excellent*. Dropouts did not differ from longitudinal participants in age at Time 1, $t(6711) = .70$, $p = .48$, 46.14 versus 46.39 years old.

In MIDUS, the BTACT was administered in a separate telephone interview, with a completion rate of 86% (N = 4,268). At the same occasion, in BOLOS, a MIDUS subsample of 299 adults from the Boston area was also tested on an in-depth in-person cognitive battery. As a consequence, both cognitive data (i.e., BTACT and the in-person cognitive battery) were available for this subsample. The participants (N = 299) ranged in age from 34 to 85 (M = 58.53, SD = 12.92), with a mean education level of 15.36 years (SD = 2.63). Self-rated health on a 5-point scale was 3.70 (SD = 1.03), and 53.5% of the sample were women.

Measures

Demographics. Besides age and sex, information about education was also obtained in the telephone interview on a 12-point scale and then recoded into years of education.

Health. Participants rated their physical health on a five point scale ranging from 1 (*poor*) to 5 (*excellent*). A measure of functional health, based on the Physical Functioning subscale from the Short-Form–36 Health Survey (α reliability = .92; Ware & Sherbourne, 1992), was also used. Seven items, which capture the extent to which the participants' health level limits them in doing different activities (e.g., lifting or carrying groceries, climbing several flights of stairs), were averaged. The scores ranged from 1 (*a lot*) to 4 (*not at all*), with a higher score indicating better health.

Hearing. In addition to a brief hearing assessment given before the cognitive test (described in the Procedure section), participants rated their overall hearing, compared to others their age, on a 5-point scale ranging from 1 (*excellent*) to 5 (*poor*) in a mail questionnaire given in advance of the cognitive test. Participants in BOLOS completed the Hearing Screening Inventory (Coren & Hakstian, 1992), which includes 11 questions that provide an estimate of hearing ability. The inventory has been validated with audiometric tests. Higher scores indicate more hearing problems. The alpha reliability coefficient for the 11-item inventory was .86 ($N = 252$). The correlation between the single-item rating described above and the Hearing Inventory Score was $r(247) = .60$, $p < .001$. Only the single item will be used in the analyses, as it was the measure given to all MIDUS and BOLOS participants.

MIDUS (BTACT) Battery. The BTACT consisted of the following tests, administered in the following order: word list recall immediate, backward digit span, category fluency, SGST, number series, 30-SACT, and word list recall delayed.

Table 1 presents the description and the average duration of each test, the assessed cognitive constructs, the source from which each test was derived, as well as the differences between the two BTACT forms.[1]

For immediate and delayed episodic memory (Rey, 1964), the participants were instructed to listen carefully to a list of 15 words read aloud at a rate of one word per second, and then to recall as many words as possible in 1 minute. No feedback was given regarding correct responses, repetitions, or errors. Scores for both trials reflected the number of correct responses given out of a possible 15 words.

For the backward digit span task, the listener heard increasingly longer series of digits, ranging from two to eight digits, and attempted to repeat them in the reverse order from which they were heard. There were two chances to complete each level, and the score was the longest string that was repeated exactly in reverse order. The experimenter read aloud each set of digits in list intonation, at a rate of one per second, beginning with a set size of two digits. The test was discontinued when the participant missed both trials from a set. The score is the largest number of digits in a set that was correctly reproduced.

Verbal fluency and executive function were assessed with a test of category fluency, which required participants to rapidly generate new members of a class of words from the category animals. Scores indicate the number of correct, unique responses given in 1 minute.

The SGST was developed as a measure of choice reaction time, task switching, and executive functioning (Lachman & Tun, 2008; Tun & Lachman, 2008). The test included two single-task blocks (baselines) and a mixed-task task-switching test that required alternating between the two response modes. The baseline trials were separated into two conditions, representing two response modes: normal and reverse. In the normal condition, the experimenter spoke the stimulus words "RED" or "GREEN" and participants responded with "STOP" or "GO," respectively. The reverse condition required inhibiting the familiar response and giving the opposite, noncanonical response ("GO" to "RED" and "STOP" to "GREEN"). In a mixed-task section, participants switched back and forth between the normal and reverse conditions at random intervals of two to six trials after cues of "NORMAL" or "REVERSE." Latencies were measured, in milliseconds lapsed between the cue and the correct response. Switch trials were defined as those trials that occurred after the participant had to switch from one condition to the other ("NORMAL" to "REVERSE" or "REVERSE" to "NORMAL"). Trials that did not involve a cue change were referred to as nonswitch trials. Participants practiced each condition before test trials began. They received 20 normal and 20 reverse baseline trials, followed by a mixed-task block of 32 trials. Median latencies were used to eliminate the effects of outliers. Medians were computed for each baseline (normal and reverse), and a mean of these two baseline conditions was also computed. Median latencies were also computed for the normal and reverse conditions in both switch and nonswitch trials in the mixed condition (Cepeda, Kramer, & Gonzalez de Sather, 2001). In all analyses with the SGST, the mean latency of the mixed-task trials (switch and nonswitch) was used. A total of 262 participants (6.1%) were assigned missing values because they failed to meet an acceptable level of accuracy (below 75% correct in normal, reverse, or mixed trial blocks) or they had extreme median latencies (values greater than 2 seconds on single-task blocks or greater than 4 seconds on mixed-task blocks). Higher scores on the latency variables indicate slower response time. When combined with the other tests for the factor solution, the latency measures were multiplied by −1 so that higher scores indicate a faster speed of response time.

To measure inductive reasoning, we used a number series completion task (Salthouse & Prill, 1987; Schaie, 1996). Participants heard each number of a five-number series one at a time, and were able to indicate when they were ready for the next number in the series. After all numbers were presented, they were asked to respond with the next number that would best complete the sequence. Scores ranged from 0 to 5 and reflected the number of series completed correctly.

Table 1. Overview of the Brief Test of Adult Cognition by Telephone.

Test	Average duration	Theoretical construct(s) (and National Institutes of Health Toolbox cognitive function)	Test used/source	Content/sample items (Form A)	Alternate Form B
Word list recall (immediate and delayed)	1.5 minutes + 40 seconds	Episodic verbal memory (Episodic Memory)	Rey Auditory-Verbal Learning Test (RAVLT, Lezak, 1995; Rey, 1964)	Free recall of a list of 15 words (List A from the RAVLT) Examples: flower, truck, school	List B from the RAVLT
Backward digit span	2.5 minutes	Working memory span (Working Memory)	Wechsler Adult Intelligence Scale–III (Wechsler, 1997)	Highest span achieved in repeating strings of digits backward (spans from 2 to 8, each consisting of two levels) Example Level 3 7-1-3 (3-1-7) 2-8-6 (6-8-2)	The second level of each trial was administered first
Category verbal fluency	1.5 minutes	Executive function, semantic memory retrieval Verbal ability and speed of processing (Executive Function–Cognitive Flexibility and Language)	Borkowski, Benton, and Spreen (1967), Tombaugh, Kozak, and Rees (1999)	Number of animal names produced in 1 minute	Participants asked to name foods
Number series	2.5 minutes	Inductive reasoning Fluid intelligence (not included in toolbox)	New items based on number series tests (Salthouse & Prill, 1987; Schaie, 1996)	Complete the pattern in a series of five numbers with a final number (five problems include three types of patterns) Example 5, 7, 10, 14, 19 . . . (25)	Each item changed to conform to the same patterns as those in Form A using different numbers
30 Seconds and counting task	45 seconds.	Processing speed (Processing Speed)	New test	Maximum number of items produced counting backwards from 100 as quickly as possible in 30 seconds	The same instructions were given
Task-switching, stop and go switch task	3.5 minutes	Reaction time, attention, task switching, inhibitory control (Attention and Executive Function–Inhibitory Control)	New test	Speeded two-choice reaction time tests, either 1. Single-task baseline (blocked tests of Normal and Reverse response modes), or 2. Mixed-task task-switching test (requires switching response mode between Normal and Reverse when cued) Normal condition Every time I say RED you will say STOP, and every time I say GREEN you will say GO. Reverse condition Every time I say RED you will say GO, and every time I say GREEN you will say STOP.	Trials within each of the conditions were randomly reordered

The 30-SACT was used to measure speed of processing. Participants counted backward from 100 as quickly as they could in 30 seconds and were scored for the total number of digits correctly produced. The score was computed as 100 minus the number reached, with the result indicating how many numbers were counted. Errors due to skipping or repeating numbers were tallied and subtracted from the total score.

Boston Cognitive Battery. The Boston participants also completed the Boston cognitive battery, in person, in about 90 minutes, within 2 years (mean = 18 months) after the BTACT was administered. The Boston cognitive battery includes four factors based on a confirmatory factor analysis (Miller & Lachman, 2000) using the cognitive tests administered at both Time 1 and Time 2. The factors and their test markers are Short-Term Memory, measured with Forward Digit Span, Backward Digit Span (from Wechsler Adult Intelligence Scale [WAIS]; Wechsler, 1955), and Serial Sevens (Folstein et al., 1975); Verbal Ability (WAIS, Vocabulary, Wechsler, 1955); Reasoning, measured with Letter Series (Schaie, 1985) and Ravens Advanced Progressive Matrices (Raven, Raven, & Court, 1991); and Speed, measured with Letter Comparison (Salthouse, Kausler, & Saults, 1990) and Digit Symbol Substitution (Wechsler, 1955). Factor scores for each factor were computed as the mean of the *z* scores for the measures in that factor. Additional measures were given to a subset of the sample at Time 2: the "How Many, What Number" task switching (Cepeda et al., 2001), trail making A & B (Reitan, Wolfson, Wedding, Horton, & Webster, 1986), letter number sequencing (Wechsler, 1997), and logical memory (Wechsler, 1997).

Procedure

The BTACT cognitive battery was administered over the telephone by live interviewers at a large university survey center. Interviews were conducted at times chosen by the participants for convenience and to minimize distractions. The timing of stimuli during the cognitive tasks was controlled by computer (CATI system) and the sessions were recorded and saved as sound files for later analysis. Administration time was usually 20 minutes. Participants were asked to use their landline telephones to maximize the sound quality. We instructed participants not to write anything down during the testing and to close their eyes during the cognitive testing. There is evidence that eye closure improves recall by reducing cognitive load (Vredeveldt, Hitch, & Baddeley, 2011) and the instruction to close one's eyes is included in cognitive interviews, such as for eyewitness testimony or police reports (Fisher & Geiselman, 1992). Prior to the administration of the BTACT, interviewers gave a brief hearing test to participants to verify that the participant could hear the interviewer: "First, I would like to make sure you are able to hear me clearly. Please repeat these numbers after me: 2, 8, 3, 6, 9, given one at a time. Could you hear me clearly?" Changes in volume were made as needed. The interviewer made note of any hearing issues that may have interfered with testing. There were 192 cases (3.83%) that required adjustment of the volume due to hearing problems noted by the interviewers.

Results

Descriptive statistics for the BTACT measures and sociodemographic variables are shown in Table 2.

Factor Structure of the BTACT

An exploratory factor analysis was performed with all the BTACT measures. A principal axis factor analysis with oblique rotation yielded two factors with eigenvalues greater than 1 (Table 3). Based on the pattern of loadings, the factors were labeled episodic memory (immediate and delayed word recall) and executive functioning (the other cognitive measures). Factor scores were computed by averaging the standardized values of variables loading .30 and above on each factor, and then standardizing that mean score. The factors were correlated, $r(4{,}237) = .43$, $p < .001$, and accounted for 60% of the total variance.

We also conducted confirmatory factor analyses with the seven BTACT cognitive tests. Based on the exploratory factor analysis and the previous literature (Farias et al., 2013; Jurado & Rosselli, 2007; Royall et al., 2002), the seven tests were expected to measure two key intercorrelated factors: episodic memory and executive functioning. The goal was to test the expected two-factor solution with two independent samples and to compare the fit with a one-factor model. The results revealed that the proposed two-factor model provides a good fit. Results from the two randomly generated subsamples both support the two-factor solution over the one-factor solution (Table 4). The factor structure with standardized estimates is presented in Figure 1.

Concurrent Validity

Correlations of the individual BTACT tests (backward digit span, category fluency, number series, and 30-SACT) with the expected corresponding Boston cognitive factors (Short-Term Memory, Verbal Ability, Reasoning, and Speed, respectively) ranged from .42 to .54 and were all significant (ps $< .001$), demonstrating convergent validity of the BTACT tests (Table 5). Category fluency was correlated with the Verbal Ability factor, $r(288) = .42$, $p < .001$, as expected, and also with the Reasoning factor, $r(283) = .44$, $p < .001$, suggesting that this test covers not only crystallized ability but also fluid abilities.

Table 2. Means, Standard Deviations, and Correlations Between Sociodemographic Variables and All BTACT Cognitive Tests.

Variables	*M*	*SD*	Age	Education	Sex
Age	55.54	12.45	—		
	4,999	*4,999*	*4,999*		
Education	14.30	2.62	−.14	—	
	4,997	*4,997*	*4,991*		
Sex (1 = men, 2 = women)	1.54	.50	.01[a]	−.10	—
	5,005	*5,005*	*4,999*	*4,997*	
Word list immediate	6.74	2.28	−.32	.21	.21
	4,247	*4,247*	*4,242*	*4,240*	*4,247*
Word list delayed	4.44	2.61	−.32	.19	.21
	4,055	*4,055*	*4,050*	*4,048*	*4,055*
Backward digit span	5.01	1.50	−.17	.20	.02[a]
	4,251	*4,251*	*4,246*	*4,244*	*4,251*
Category fluency	18.84	6.18	−.31	.34	−.06
	4,251	*4,251*	*4,246*	*4,244*	*4,251*
Number series	2.28	1.51	−.26	.41	−.11
	4,224	*4,224*	*4,219*	*4,217*	*4,224*
30-SACT	37.32	11.42	−.43	.29	−.14
	4,234	*4,234*	*4,229*	*4,227*	*4,234*
SGST mixed-task trials	−1.07	.22	−.34	.18	−.09
	3,812	*3,812*	*3,807*	*3,805*	*3,812*
BTACT composite	−.01	.67	−.46	.40	.01[a]
	4,268	*4,268*	*4,263*	*4,261*	*4,268*
Episodic memory factor	0	1	−.34	.21	.22
	4,247	*4,247*	*4,242*	*4,240*	*4,247*
Executive functioning factor	0	1	−.43	.41	−.11
	4,260	*4,260*	*4,255*	*4,253*	*4,260*

Note. BTACT = Brief Test of Adult Cognition by Telephone; 30-SACT = 30 seconds and counting task; SGST = stop and go switch task. Italics represent sample sizes.
All are $p < .001$, two-tailed, except as noted.
[a] Correlation is not statistically significant.

Table 3. Exploratory Factor Analysis Solution for BTACT Tests.

	Factor weights		
	Executive functioning	Episodic memory	Communalities
Word list immediate	.021	**.881**	*.793*
Word list delayed	−.027	**.885**	*.763*
Backward digit span	**.308**	.249	*.222*
Category fluency	**.516**	.065	*.299*
Number series	**.580**	.052	*.365*
30-SACT	**.810**	−.072	*.612*
SGST mixed-task trials	**.566**	−.024	*.309*
Eigenvalue	2.914	1.284	
Total variance	41.63%	18.35%	

Note. BTACT = Brief Test of Adult Cognition by Telephone; 30-SACT = 30 seconds and counting task; SGST = stop and go switch task.
Tests with factor loadings in bold are included in the factor scores

In addition, the SGST mixed-task trials measure was significantly correlated with the BOLOS task-switching test, $r(87) = .52$, $p < .001$, and the Trails B, $r(234) = .41$, $p < .001$. The 30-SACT was correlated with the BOLOS Speed

Table 4. Fit Indices for the Two-Factor and One-Factor Solutions of BTACT.

		Fit indices					
Sample	Model	χ^2	*df*	CFI	GFI	AGFI	RMSEA
Full sample, *N* = 3,676	Two-factor solution	364.55	13	.95	.97	.94	.09
	One-factor solution	2316.87	14	.69	.81	.62	.21
Subsample 1, *N* = 1,835	Two-factor solution	159.59	13	.96	.98	.95	.08
	One-factor solution	1139.50	14	.69	.82	.63	.21
Subsample 2, *N* = 1,841	Two-factor solution	218.18	13	.95	.97	.93	.09
	One-factor solution	1165.34	14	.70	.81	.61	.21

Note. df = degrees of freedom; BTACT = Brief Test of Adult Cognition by Telephone; CFI = comparative fit index; GFI = goodness-of-fit index; AGFI = adjusted goodness-of-fit index; RMSEA = root mean square error of approximation.

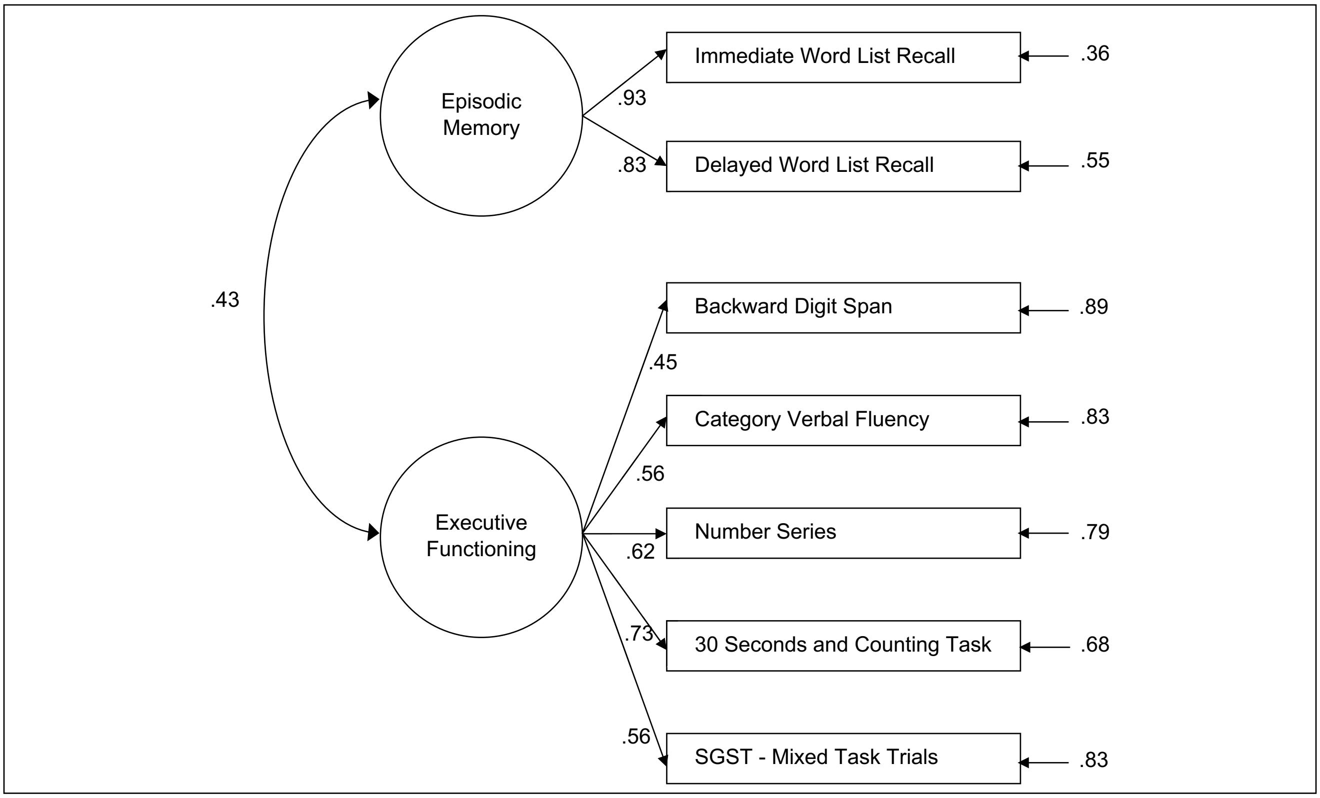

Figure 1. Two-factor solution with standardized factor loadings and error variances.
Note. Model fit: $\chi^2(13) = 364.55$, $p < .001$; comparative fit index = .95; goodness-of-fit index = .97; adjusted goodness-of-fit index = .94; root mean square error of approximation = .09; $N = 3{,}676$.

factor, $r(287) = .53$, $p < .001$, and individual speed tests, digit symbol substitution, $r(283) = .55$, $p < .001$ and letter comparison, $r(286) = .46$, $p < .001$.

Additionally, there was evidence of discriminant validity of the BTACT tests. The backward digit span, number series, and 30-SACT were more highly correlated with their corresponding BOLOS factors than with other BOLOS factors: $r(288) = .49$, $p < .001$, for backward digit span with Memory; $r(282) = .54$, $p < .001$, for number series with Reasoning; and $r(287) = .53$, $p < .001$, for 30-SACT with Speed.

Relationships of BTACT Tests and Boston Factors

A series of multiple linear regression models predicting the four Boston factors were computed using the BTACT tests (word list immediate, word list delayed, backward digit span, category fluency, number series, 30-SACT, and SGST) as predictor variables (Table 6). The overall model for each of these factors was significant, Short-term Memory: $R^2 = .40$, $F(7, 260) = 24.72$, $p < .001$; Verbal Ability: $R^2 = .33$, $F(7, 260) =$

Table 5. Correlations (Sample Sizes) Between the Tests and Factors From BTACT and BOLOS Cognitive Battery.

	BTACT									
BOLOS	Word list immediate	Word list delayed	Backward digit span	Category fluency	Number series	30-SACT	SGST mixed-task trials	BTACT composite	Episodic memory	Executive functioning
Backward digit span	.14* (286)	.19** (281)	.43*** (286)	.17** (287)	.36*** (286)	.34*** (287)	.22*** (270)	.40*** (288)	.18** (286)	.43*** (288)
Forward digit span	.14* (289)	.12* (283)	.39*** (289)	.15** (290)	.36*** (289)	.30*** (290)	.23*** (272)	.37*** (291)	.15* (289)	.41*** (291)
Serial sevens	.21*** (275)	.13* (269)	.33*** (276)	.29*** (276)	.47*** (275)	.45*** (276)	.31*** (259)	.48*** (276)	.19** (275)	.54*** (276)
Letter series	.40*** (279)	.28*** (274)	.31*** (280)	.40*** (280)	.48*** (279)	.47*** (280)	.46*** (263)	.61*** (281)	.38*** (279)	.61*** (281)
Ravens matrices	.27*** (278)	.22*** (274)	.31*** (279)	.41*** (279)	.52*** (278)	.37*** (279)	.34*** (262)	.53*** (280)	.27*** (278)	.56*** (280)
Digit symbol substitution	.38*** (284)	.37*** (278)	.30*** (284)	.42*** (285)	.42*** (284)	.55*** (285)	.48*** (268)	.64*** (286)	.41*** (284)	.63*** (286)
Letter comparison	.31*** (287)	.30*** (281)	.23*** (287)	.32*** (288)	.32*** (287)	.46*** (288)	.41*** (270)	.50*** (289)	.34*** (287)	.49*** (289)
Vocabulary factor	.22*** (289)	.15** (283)	.31*** (289)	.42*** (290)	.44*** (289)	.31*** (290)	.34*** (273)	.48*** (291)	.21*** (289)	.52*** (291)
Memory span factor	.21*** (290)	.18** (284)	.49*** (290)	.26*** (291)	.51*** (290)	.47*** (291)	.34*** (273)	.54*** (292)	.22*** (290)	.59*** (292)
Reasoning factor	.38*** (284)	.28*** (279)	.34*** (285)	.44*** (285)	.54*** (284)	.45*** (285)	.43*** (268)	.62*** (286)	.37*** (284)	.63*** (286)
Speed factor	.36*** (288)	.36*** (282)	.28*** (288)	.39*** (289)	.38*** (288)	.53*** (289)	.48*** (271)	.60*** (290)	.40*** (288)	.58*** (290)
BOLOS composite	.37*** (290)	.32*** (284)	.47*** (290)	.47*** (291)	.61*** (290)	.59*** (291)	.52*** (273)	.73*** (292)	.38*** (290)	.76*** (292)
Task switching (mixed-task all trials)	.28** (99)	.32** (95)	.28** (99)	.15 (99)	.28** (99)	.43*** (99)	.52 (89)	.51*** (99)	.33** (99)	.50*** (99)
Trails A	.20** (267)	.22*** (261)	.22*** (267)	.29*** (268)	.34*** (267)	.39*** (268)	.33*** (252)	.44*** (269)	.24*** (267)	.45*** (269)
Trails B	.27*** (251)	.25*** (245)	.33*** (251)	.34*** (252)	.43*** (251)	.44*** (252)	.41*** (236)	.53*** (253)	.29*** (251)	.55*** (253)
Letter–number sequencing	.23*** (256)	.16** (250)	.39*** (257)	.28*** (257)	.42*** (256)	.35*** (257)	.39*** (241)	.49*** (258)	.22*** (256)	.52*** (258)
Logical memory immediate	.23** (142)	.16 (137)	.01 (142)	.32*** (142)	.29*** (142)	.10 (142)	.16 (130)	.28** (142)	.22** (142)	.26** (142)
Logical memory delayed	.29** (143)	.31*** (138)	.11 (143)	.35*** (143)	.30*** (143)	.12 (143)	.19* (131)	.36*** (143)	.33*** (143)	.30*** (143)
Backward counting	.24** (142)	.20* (137)	.40*** (142)	.32*** (142)	.40*** (142)	.85*** (142)	.52*** (130)	.66*** (142)	.25** (142)	.73*** (142)

Note. BTACT = Brief Test of Adult Cognition by Telephone; BOLOS = Boston Longitudinal Study; 30-SACT = 30 seconds and counting task; SGST = stop and go switch task. For Trails A and B, the latency measures were multiplied by −1 so that higher scores indicate a faster speed of response time.
***$p < .001$. **$p < .01$. *$p < .05$.

17.96, $p < .001$; Reasoning: $R^2 = .42$, $F(7, 256) = 25.98$, $p < .001$; Speed: $R^2 = .44$; $F(7, 258) = 28.76$, $p < .001$. A Boston cognitive composite[2] score was also regressed on all of the BTACT tests (Table 6). The percentage of variance accounted for by the overall model was significant, $R^2 = .59$, $F(7, 260) = 52.88$, $p < .001$. Consistent with the zero-order correlations, all of the cognitive tasks significantly predicted the Boston composite, except for immediate and delayed word list recall (episodic memory). Although the BTACT Episodic Memory measures were not significantly related to the BOLOS short-term memory factor when the other BTACT tests were included in the model, the BTACT Backward Digit Span was related to the BOLOS short-term memory factor. This highlights the fact that episodic memory and memory span are different aspects of memory. The BTACT includes measures of both of these components of memory, but the BOLOS battery included only memory span.

Reliability

Although we were not able to assess the test–retest reliability of the BTACT in the MIDUS study, we conducted two other reliability studies using the two parallel forms of the BTACT (A and B). Both studies suggest good test–retest reliability and alternate forms reliability for the BTACT (Table 7).

The two forms of the BTACT were administered in randomly counterbalanced order, over the phone, 1 week apart in the first study (Whitbourne, Neupert, & Lachman, 2008) and within 4 weeks in the second. The participants from the first study ($N = 53$) ranged in age from 22 to 83 years ($M = 54.28$, $SD = 16.99$). There were 22 (41.5%) men and 31 (58.5%) women. The mean level of education in years was 15.46 ($SD = 2.15$). The age of the participants from the second study ($N = 56$) ranged between 18 and 88 years ($M = 47.84$, $SD = 26.24$) and the mean level of education was 15.73 years ($SD = 2.78$).

As shown in Table 7, the alternate forms reliability coefficients were all significant. They ranged from .59 to .93 in Study 1. In Study 2, the coefficients ranged from .54 to .84, with the exception of category fluency ($r = .30$). The test–retest correlation coefficients were also all significant and ranged in Study 1 from .55 and .94. The range in Study 2 was .52 to .85, with the exception of category fluency

Table 6. Multiple Regression Analysis Predicting BOLOS Composite and Factors With BTACT Tests.

	BOLOS composite (*N* = 268)			Short-term memory (*N* = 268)			Verbal ability (*N* = 268)			Reasoning (*N* = 264)			Speed (*N* = 266)		
Predictor	β	*t*	*p*	β	*t*	*p*	β	*t*	*p*	β	*t*	*p*	β	*t*	*p*
Word list immediate recall	.01	0.09	.931	−.08	−1.07	.286	.00	0.02	.982	.12	1.67	.096	.02	0.30	.765
Word list delayed recall	.07	1.14	.256	.02	0.24	.808	−.06	−0.76	.448	.01	0.16	.874	.18	2.62	.009
Backward digit span	.13	2.77	.006	**.28**	**4.87**	**<.001**	.13	2.18	.030	.02	0.32	.747	−.05	−0.86	.389
Category fluency	.17	3.69	<.001	.03	0.64	.526	**.30**	**5.26**	**<.001**	.20	3.63	<.001	.13	2.39	.018
Number series	.35	7.68	<.001	.30	5.49	<.001	.28	4.90	<.001	**.35**	**6.39**	**<.001**	.18	3.38	.001
30-SACT	.24	4.71	<.001	.23	3.68	<.001	.00	0.04	.969	.11	1.78	.077	**.32**	**5.24**	**<.001**
SGST mixed-task trials	.17	3.24	.001	.05	.88	.382	.12	1.82	.069	.14	2.31	.022	**.17**	**2.89**	**.004**
	R^2 = .59, *F*(7,260) = 52.88, *p* < .001			R^2 = .40, *F*(7,260) = 24.72, *p* < .001			R^2 = .33, *F*(7,260) = 17.96, *p* < .001			R^2 = .42, *F*(7,256) = 25.98, *p* < .001			R^2 = .44, *F*(7,258) = 28.76, *p* < .001		

Note. BOLOS = Boston Longitudinal Study; BTACT = Brief Test of Adult Cognition by Telephone. Items in bold indicate factors for which convergent validity is predicted.

(r = .28), suggesting differences as a function of category (animals vs. foods; Strauss, Sherman, & Spreen, 2006).

Administration Form

Many of the BTACT tests have been used previously in neuropsychological and laboratory applications. To confirm that our telephone measures yield results similar to the more standard in-person tests, we administered the BTACT with both an in-person and a telephone version counterbalanced in order of administration, and found no significant effect of mode of testing for any of the tests (see Lachman & Tun, 2008). The participants (N = 28; 64.3% women) were between 18 and 82 years old (M = 48.43, SD = 26.46). Correlations between telephone and in-person versions of the BTACT tests ranged from .55 to .95 (Table 8). They were reduced but still significant after adjusting for age and sex.

Hearing

In light of the auditory administration format by telephone, we examined hearing in relation to age and cognitive performance (Lin et al., 2011; Pachana, Alpass, Blakey, & Long, 2006; Wingfield, Tun, & McCoy, 2005). As indicated in the procedures section, only a small number of participants indicated difficulty in hearing the stimuli, and these cases were addressed by adjusting the volume. Self rated hearing was positively associated with age, $r(4{,}058) = .16$, $p < .001$; and negatively correlated with the Episodic Memory factor, $r(3{,}731) = -.18$, $p < .001$; and the Executive Functioning factor, $r(3{,}740) = -.14$ $p < .001$, indicating that poorer hearing was associated with older age and poorer performance. The performance correlations with hearing remained significant after controlling for age.

To examine whether the association between age and cognitive performance was related to hearing, we computed partial correlations. For the cognitive factors, the magnitude of the correlations between age and cognitive performance did not change significantly when controlling for hearing: $r(3{,}744) = -.45$ for the BTACT composite,[3] $r(3{,}730) = -.32$ for Episodic Memory, and $r(3{,}739) = -.42$ for Executive Functioning, all ps < .001. This shows that the age differences in cognitive performance were not due to greater difficulty in hearing the test stimuli among the older adults.

Health and BTACT

BTACT factors were significantly associated with physical health, suggesting that BTACT is sensitive to variations in health even in a relatively healthy community-residing sample. Better self-rated health was related to better cognitive performance, Episodic Memory: $r(4{,}245) = .19$, $p < .001$; Executive Functioning: $r(4{,}258) = .30$, $p < .001$. The same pattern of results was obtained with functional health, Episodic Memory: $r(3{,}740) = .19$, $p < .001$; Executive Functioning: $r(3{,}750) = .32$, $p < .001$. The correlations of the BTACT factors with the health variables remain significant when controlling for age, sex, and education.

Demographic Variations: Age, Sex, and Education Differences

To examine differences in BTACT cognitive performance by age, sex and education, we conducted a 6 (age decade) × 2 (sex) × 2 (education) multivariate analysis of variance on all seven BTACT cognitive tests. We created two education groups: less than a bachelor's degree (no college degree) and a bachelor's degree or higher (college degree). Bartlett's

Table 7. BTACT Reliability: Correlations (Sample Sizes) Between the Alternate Forms and Between the Times of Measurement.

	Forms A and B		Time 1 and Time 2	
	Study 1	Study 2	Study 1	Study 2
Word list immediate	.59*** (53)	.58*** (55)	.59*** (53)	.59*** (55)
Word list delayed	.61*** (53)	.58*** (50)	.61*** (53)	.59*** (50)
Backward digit span	.63*** (53)	.60*** (55)	.66*** (53)	.58*** (55)
Category fluency	.71*** (53)	.30* (55)	.55*** (53)	.28* (55)
Number series	.76*** (53)	.54*** (53)	.76*** (53)	.52*** (53)
30-SACT	.93*** (53)	.83*** (54)	.94*** (53)	.85*** (54)
SGST mixed-task trials	—	.82*** (46)	—	.83*** (46)
Episodic memory	.66*** (53)	.65*** (55)	.66*** (53)	.66*** (55)
Executive functioning	.88*** (53)	.80*** (55)	.86*** (53)	.80*** (55)
BTACT composite	.86*** (53)	.84*** (55)	.87*** (53)	.84*** (55)

Note. BTACT = Brief Test of Adult Cognition by Telephone; 30-SACT = 30 seconds and counting task; SGST = stop and go switch task.
***$p < .001$. **$p < .01$. *$p < .05$.

test of sphericity was significant, $\chi^2(27) = 47{,}816.56$, $p < .001$. We found main effects of age: Wilks's $\Lambda = .78$, $F(35, 15289.29) = 26.20$, $p < .001$; sex: Wilks's $\Lambda = .96$, $F(7, 3634) = 23.04$, $p < .001$; and education: Wilks's $\Lambda = .92$, $F(7, 3634) = 44.61$, $p < .001$. There were no statistically significant interactions. An examination of the univariate tests revealed statistically significant age and education differences on all cognitive tests. In general, higher levels of cognitive performance were obtained for younger participants than for older participants. On all tests, mean performance was higher for participants with a bachelor's degree than for those who did not have a bachelor's degree. Sex differences were obtained on several tests, but the direction of the effect varied by cognitive dimension. In the immediate and delayed recall tasks, women outperformed men. However, on the number series and backward-counting tasks, performance was higher for men than for women. In the SGST, there were no sex differences in the baseline latency measures; however, men's latencies were faster than women's in all three of the mixed-task measures.

In addition to the analyses on the individual cognitive tests, we conducted a 6 (age decade) × 2 (sex) × 2 (education) univariate analysis of variance on the BTACT composite and found main effects of age, $F(5,4232) = 181.74$, $p < .001$; and education, $F(1,4232) = 251.08$, $p < .001$. The main effect of sex was not significant, $F(1,4232) = 1.59$, $p = .208$; and there were no statistically significant interactions.

Table 8. Correlations (Sample Sizes) Between the Phone and In-Person BTACT Administration Forms.

Word list immediate	.75*** (29)
Word list delayed	.90*** (28)
Backward digit span	.55** (28)
Category fluency	.68*** (29)
Number series	.61*** (29)
30-SACT	.95*** (29)
SGST mixed-task trials	.71*** (30)
Episodic memory	.88*** (28)
Executive functioning	.76*** (28)
BTACT composite	.82*** (28)

Note. BTACT = Brief Test of Adult Cognition by Telephone; 30-SACT = 30 seconds and counting task; SGST = stop and go switch task.
***$p < .001$. **$p < .01$. *$p < .05$.

We also conducted a 6 (age decade) × 2 (sex) × 2 (education) multivariate analysis of variance on the two-factor scores. Bartlett's test of sphericity was significant, $\chi^2(2) = 1119.38$, $p < .001$. We found significant main effects of age, Wilks's $\Lambda = .82$, $F(10, 8404) = 86.96$, $p < .001$; sex, Wilks's $\Lambda = .96$, $F(2, 4204) = 93.78$, $p < .001$; and education, Wilks's $\Lambda = .94$, $F(2, 4202) = 135.94$, $p < .001$. There were no statistically significant interactions. An examination of the univariate effects revealed statistically significant age, sex, and education differences on both factors. The age patterns for episodic memory and executive functioning are presented in Figure 2. The means and standard deviations by age, education, and sex for all cognitive tests and factors/composites and the performance distribution by quartiles are available on request from the first author.

Discussion

There is increasing recognition of the importance of considering cognitive functioning in the context of overall health (Alwin & Hofer, 2011; Anstey, Low, Christensen, & Sachdev, 2009; Spiro & Brady, 2008). One factor limiting this work has been the lack of appropriate cognitive measures that can be used in large epidemiological surveys, allowing for brief yet comprehensive assessments in samples that can not necessarily be tested in person. The findings presented here provide psychometric data for a new cognitive test battery, the BTACT, which can be used as an efficient, reliable, and valid assessment of key adult cognitive dimensions in diverse samples, with a wide range of age and socioeconomic status.

The BTACT requires about 20 minutes to administer, and it shows convergent correlations with gold standard cognitive tests administered in person. Confirmatory factor

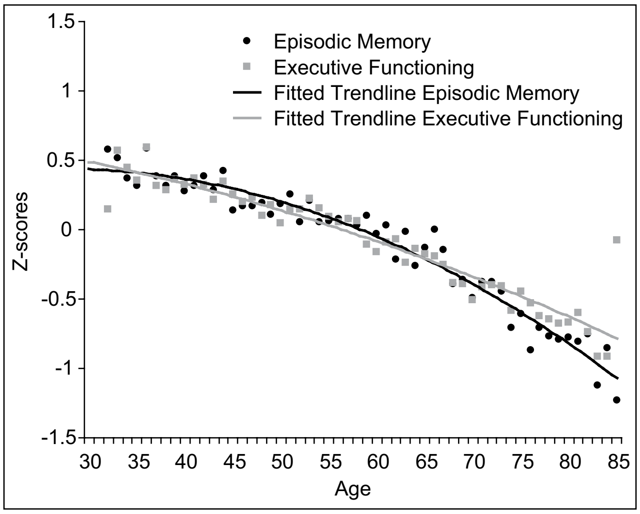

Figure 2. BTACT cognitive factors by age.
Note. BTACT = Brief Test of Adult Cognition by Telephone. The points represent the averages within each age.

analysis showed a good fit for a two-factor solution with episodic memory and executive functioning (Jurado & Rosselli, 2007; Royall et al., 2002). For researchers who have limited time to devote to cognitive testing, yet would like to give a short battery either by telephone or in person that is more sensitive to differences across a wide age range than a dementia screening test, the BTACT offers a viable option. The factor score composites provide a valid aggregate assessment of cognitive performance in cases when more specific measures of cognitive functioning are not of interest.

Validation of the auditory BTACT tests was conducted in relation to an in-person Boston cognitive battery, which differed in terms of both modality of input (auditory vs. visual) and mode of response (oral vs. manual), as well as the length and specific tests. However, the strong correlations between these test batteries provide evidence that the short format and mode of administration do not affect the results. This was further demonstrated by administering the BTACT tests both in person and over the phone to a subgroup of subjects.

A key contribution of the BTACT is that it features two unique and innovative tests for telephone administration, the 30-SACT and the SGST (Lachman & Tun, 2008; Tun & Lachman, 2008), which provide measures of simple speed of processing as well as latencies on a complex task-switching test that taps executive function. The 30-SACT, a 30-second oral assessment of speed of processing, shows significant correlations with longer standard speed tasks such as letter comparison ($r = .46$) and digit symbol substitution ($r = .55$), which require visual presentation of stimuli and motor speed via handwriting rather than speech. The SGST measure of task switching adds an important new tool to research using a cognitive telephone battery, as switching ability has been assessed primarily in laboratory settings, typically with small numbers of research participants, and the selectivity of the participants who are willing and able to come into a laboratory. With the SGST, it is feasible to expand the range of participants and shed new light on individual differences in executive processes. The SGST showed a substantial correlation with an in-person measure of task switching. It is noteworthy that the Trails B task, one that is often used for neuropsychological assessment in clinical settings and requires visual and motor skills (Lezak, Howieson, & Loring, 2004), was significantly correlated with the SGST mixed-task trials and with the BTACT executive functioning factor.

The BTACT was sensitive to age differences in a sample of community-residing adults from young adulthood through middle age and older age. As typically found in longitudinal studies, the Time 2 sample showed evidence of positive selection, in this case on education and self-rated health. Nevertheless, the size (over 4,000 participants) and diversity of the cognitive data collected from the MIDUS national sample allows us to provide normative data on cognitive performance by gender and education level as well as age. We found significant sex and education differences in addition to age differences, but no interactions among the demographic variables.

In addition to its usefulness as a telephone cognitive battery for research studies of normal adults, the BTACT has the potential for use in special populations with visual impairment, traumatic brain injury, attentional issues, mild cognitive impairment, or other clinical groups. A key advantage of the BTACT is that it is a reliable and valid, yet short, assessment tool that taps into multiple dimensions of cognitive functioning relevant for assessing well-functioning and clinical populations. The BTACT has potential as a screener for early detection and monitoring of cognitive changes, either for declines due to cognitive impairment and/or improvements due to treatments for brain injury or attentional deficits, as it can be given repeatedly at low cost and with little burden to tester or respondent. For repeated cognitive measures, the alternate Form B of BTACT can also be used.

We investigated the correlations among the two BTACT forms with a small sample. For the alternate version of category fluency, we assessed the commonly used category, foods (Strauss et al., 2006). It is typical to find fewer words on average for the foods than for the animals category, although it is the correlation of the measures that is more important for examining comparability of the alternate forms. The correlation of the categories from the two BTACT forms was significant, yet it was somewhat lower than would be expected for parallel forms. This finding is consistent with other studies that have reported that correlations across categories are not typically high enough to establish equivalency across forms

(Strauss et al., 2006). We will further investigate the concordance of the alternate forms in future studies with larger, more representative samples.

Some of the BTACT tests may be useful to identify early warning signs of dementia, given that speed of processing and inhibitory control problems may surface earlier than memory deficits (Storandt, 2008). We are currently investigating whether the BTACT can be useful for discriminating those with normal cognitive functioning who have memory complaints from those who have mild cognitive impairment or early signs of dementia. The BTACT includes multiple tests of cognition and can be administered in its entirety, or using selected subtests, depending on the specific aims and needs of the study.

There are some noteworthy limitations with telephone testing. There is less flexibility than in the laboratory in terms of stimuli and equipment (Senior et al., 2007). Cognitive testing by phone is limited to auditory stimuli and tasks, whereas in-person testing can also assess cognitive skills (including spatial skills) using visual or tactile modalities. It is essential that the respondent can hear stimuli clearly, and with declines in auditory acuity with age, it is important to rule out hearing problems, which could be exacerbated over the telephone. Although the brief hearing check and self-reported hearing measures provided some preliminary indication that results were not affected by hearing problems, in future studies, more sensitive audiometric hearing assessments would be valuable for a more complete analysis of the impact of hearing (Wingfield et al., 2005). In telephone assessment, distractions to the participants, variations in the quality of the phone connection, and other technical problems must be considered especially for the timed tasks, as they can be a source of measurement error.

The BTACT can be used both for cognitive assessment purposes and for empirical studies of cognitive functioning as antecedents to or consequences of outcomes in studies of health and well-being in diverse samples (Agrigoroaei & Lachman, 2011; Lachman, Agrigoroaei, Murphy, & Tun, 2010; Seeman et al., 2011; Stawski, Almeida, Lachman, Tun, & Rosnick, 2010; Tun & Lachman, 2010; Tun, Miller-Martinez, Lachman, & Seeman, 2013; Whitbourne et al., 2008).The BTACT offers a promising and efficient tool for clinicians and researchers to assess individual differences in cognitive functioning in adulthood and to expand our understanding of the processes of cognitive change over time in relation to disease and health.

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Notes

1. We developed an alternate version of the BTACT (Form B) that will be useful in studies with multiple assessments (see Whitbourne et al., 2008). There is also a back-translated Spanish form of the BTACT available.
2. The Boston cognitive composite was computed as the mean of the z scores for the nine cognitive tests (forward digit span, backward digit span, serial sevens, vocabulary, letter series, Raven's matrices, digit symbol substitution, letter comparison, task-switching mixed-task composite latency).
3. The BTACT composite was computed as the average of the standardized values for all seven cognitive tests

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