RESEARCH ARTICLE

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Performance of a computer-based assessment of cognitive function measures in two cohorts of seniors†

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Background: Computer-administered assessment of cognitive function is being increasingly incorporated in clinical trials; however, its performance in these settings has not been systematically evaluated.

Design: The Seniors Health and Activity Research Program pilot trial ($N = 73$) developed a computer-based tool for assessing memory performance and executive functioning. The Lifestyle Interventions and Independence for Elders investigators incorporated this battery in a full-scale multicenter clinical trial ($N = 1635$). We describe relationships that test scores have with those from interviewer-administered cognitive function tests and risk factors for cognitive deficits and describe performance measures (completeness, intraclass correlations [ICC]).

Results: Computer-based assessments of cognitive function had consistent relationships across the pilot and full-scale trial cohorts with interviewer-administered assessments of cognitive function, age, and a measure of physical function. In the Lifestyle Interventions and Independence for Elders cohort, their external validity was further demonstrated by associations with other risk factors for cognitive dysfunction: education, hypertension, diabetes, and physical function. Acceptable levels of data completeness (>83%) were achieved on all computer-based measures; however, rates of missing data were higher among older participants (odds ratio = 1.06 for each additional year; $p < 0.001$) and those who reported no current computer use (odds ratio = 2.71; $p < 0.001$). ICCs among clinics were at least as low (ICC < 0.013) as for interviewer measures (ICC < 0.023), reflecting good standardization. All cognitive measures loaded onto the first principal component (global cognitive function), which accounted for 40% of the overall variance.

Conclusion: Our results support the use of computer-based tools for assessing cognitive function in multicenter clinical trials of older individuals. Copyright © 2013 John Wiley & Sons, Ltd.

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Introduction

Computer-based assessments of cognitive function offer many advantages for use in clinical trials compared with assessments based on questionnaires or interviews. These include the potential for better standardization of test administration (APA, 1987; Fillit *et al*., 2008; Fredrickson *et al*., 2010); richer sources of data on performance measures such as response times, latency, and variability (APA, 1987; Hogervorst *et al*., 2008; Ichimura *et al*., 2010; Maerlender *et al*., 2010); the ability to assess greater number of domains (Parsons and Rizzo, 2008; Lee et al., 2012); increased sensitivity (Koski *et al*., 2011; Becker et al., 2011); the potential for reduced cultural biases (Doniger *et al*., 2009); greater consistency across clinical cohorts (Doniger *et al*., 2006); opportunities for greater efficiency and improved quality control for data management (Fredrickson *et al*., 2010), and as being less stressful and providing a greater sense of mastery and control for participants (APA, 1987; Clark *et al*., 2006; Collerton *et al*., 2007). Computer-based assessments can be integrated with information from other assessment modes to provide greater reliability (O'Halloran *et al*., 2008; Fillit *et al*., 2008). Because of these advantages, computer-based assessment tools are increasingly being incorporated in clinical trials and multicenter cohort studies (Calkins *et al*., 2010; Carroll *et al*., 2011; Edwards *et al*., 2011; Bryan and Hernandez, 2012; Velligan *et al*., 2012) and are promoted by federal sponsors (Nowinski *et al*., 2010).

This paper describes the computer-based cognitive assessment battery developed in the Seniors Health and Activity Research Program (SHARP) pilot trial and implemented in the Lifestyle Interventions and Independence for Elders (LIFE) full-scale trial. It is used as a model to address questions important for decisions whether to use computer-administered batteries in multicenter trials. Can good standardization and quality control be achieved? Do measures have consistent relationships with interviewer-administered cognitive test scores? Between cohorts, are there consistent relationships between cognitive deficits and risk factors of particular interest to the SHARP and LIFE trials: age and 400-m walk performance? In the larger LIFE trial, we also consider relationships with other major risk factors: education, hypertension, diabetes, and physical performance. In doing so, we provide benchmark data for test scores and performance measures and support for the use of computer-administered cognitive function testing in multicenter clinical trials.

Methods

The SHARP pilot study was a single-center, randomized clinical trial that involved the delivery of physical activity training and/or a cognitive training intervention in a 2×2 factorial design to gather information and experience critical to planning and conducting larger, more definitive trials (Espeland *et al*., 2011; Legault *et al*., 2011). Participants were community-dwelling persons, aged 70–85 years, who had a range of normal global cognitive functioning. Inclusion criteria included a total score >88 (>80 for <8 years education) on the Modified MiniMental State Exam (3MSE) (Teng and Chui, 1987) and a sedentary lifestyle, that is, not actively participating in a formal exercise program within the past 1 month (yes/no).

The LIFE is an eight-center, randomized controlled clinical trial comparing a physical activity intervention with a control condition featuring didactic presentations related to healthy aging, with the primary outcome based on the ability to walk 400 m in 15 min. Participants are non-disabled, community-dwelling, and aged 70–89 years (Fielding *et al*., 2011). Inclusion criteria include a summary score <10 on the Established Populations for the Epidemiological Study of the Elderly Short Physical Performance Battery (SPPB) (Guralnik *et al*., 1994; Guralnik *et al*., 1995), a sedentary lifestyle (spending less than 20 min per week in regular physical activity), ability to walk 400 m within 15 min without sitting or help from another person or the use of a walker, and absence of dementia based on a 3MSE score above cut points based on age, language, and race/ethnicity-appropriate norms ranging from >76 to >80 for >9 years of education and >70 to >79 for <8 years of education.

The SHARP and the LIFE provide contrasting cohorts for examining relationships that computer-based tests of cognitive function have with other measures of cognitive function and its correlates. SHARP targeted sedentary individuals with self-reported concerns about memory. LIFE targeted sedentary individuals who had deficits in physical function and were at increased risk for mobility disability. Both studies excluded individuals with self-report of dementia. All participants signed an informed consent document and the study protocols were approved by institutional review boards.

Computer-based cognitive function battery

The computer-based battery developed by SHARP and implemented in LIFE was designed to tap specific

aspects of executive functioning. Executive functions included tasks measuring working memory, which sustains and manipulates representations of information for use in current tasks, and higher order supervisory or attentional processes that facilitate goal-oriented behavior.

The **N-Back Test** measures aspects of working memory (Awh *et al.*, 1996; Jennings *et al.*,). Participants see individual letters at a 2-s rate on a computer screen and are asked to indicate whether the presented letter is the same as the *nth* back letter, with *n* equal to 1 and 2. The ability to continuously store, update, and monitor information was assessed as the difference between hits (correctly identifying an item occurring "*n*" back in the series) and false alarms (identifying an item as occurring "*n*" back when it had actually occurred earlier or later). The **Eriksen flanker task** measures selective attention and response inhibition (Eriksen and Eriksen, 1974). Participants are presented with an arrow facing either right or left and are asked to press a key to indicate its direction as quickly as possible while remaining accurate. The target displays are congruent (flanker arrows point in the same direction as the target arrow) or incongruent (the flanker arrows point in the opposite direction). Median reaction times are collected for both displays and response inhibition, the difference between the reaction times to incongruent and congruent displays, assesses executive function, with smaller differences reflecting better performance. The **Task Switching** task measures attentional flexibility (Rogers and Monsell, 1995; Kramer *et al.*, 2001). Participants are asked to quickly alternate between performing two different tasks, which requires executive function to reconfigure the cognitive system each time the task demands shift. They are shown single digit numbers and asked to determine if they are odd or even. This is alternated with presentation of single letters, for which participants indicate whether the letter was a consonant or vowel. For both tasks, participants are asked to respond as quickly as they can while remaining accurate. Median reaction times are recorded. Switch cost, the difference in reaction times when tasks are switched compared with not switched, is a measure of executive function, with smaller switch costs reflecting better performance. Technicians who administered the computerized tests results were centrally trained and certified by one of the authors (JMJ) for both trials.

Interviewer-based cognitive function battery

The SHARP and the LIFE each included batteries of interviewer-administered cognitive tests, three of which were used in both studies. The **Hopkins Verbal Learning Test** (HVLT), a measure of episodic verbal memory (Brandt, 1991), requires participants to listen to a list of 12 words, repeating as many as possible over three consecutive trials and after 20 min. The participant is then asked to identify words from a list that contains the original words plus distractor words for the delayed recognition trial. For this analysis, scores for immediate recall (total of three trials) and delayed recall are calculated.

The **3MSE** served as a measure of global cognitive function (Teng and Chui, 1987) in both studies. Its scores range from 0 to 100, with a higher score reflecting better functioning. Included are items measuring temporal and spatial orientation, immediate and delayed recall, executive function, naming, verbal fluency, abstract reasoning, praxis, writing, and visuoconstructional abilities.

The **Digit Symbol Coding** (DSC) is a measure of attention and processing speed in which subjects are given a series of numbered symbols and then asked to draw the appropriate symbols below a list of random numbers (Salthouse, 1978). The score is the number of correctly made matches in 120 s.

Cohort characteristics

Demographic data were collected by self-report. SHARP and LIFE conducted standardized assessments of the 400-m walk times. In SHARP, participants were asked to walk "as quickly, but safely, as possible;" and in LIFE, they were asked to walk at a "usual pace." LIFE included additional risk factors for cognitive deficits. Diabetes was based on self-report. Hypertension was based on self-report or measurement. The SPPB includes timed measures of standing balance, walking speed (over 3 or 4 m), and ability to rise from a chair (Guralnik *et al.*, 1994; Guralnik *et al.*, 1995). A summary score (range 0–12) orders individuals from lowest to highest performance.

Statistical analyses

Raw test scores on the cognitive assessments used in both the SHARP and LIFE cohorts were described with means and interquartile ranges and compared using *t*-tests. The correlations that computer-administered measures had with interviewer-administered measures, age, and 400-m walk times were computed. Within the LIFE cohort, we examined relationships that computer-administered test scores had with risk factors for

cognitive deficits (education, hypertension, diabetes, and SPPB scores), using analyses of covariance to adjust for age, clinic site, race/ethnicity, and gender. To reduce the influence of extreme scores and to facilitate comparison among tests, we computed standardized scores by dividing the difference between 5% winsorized scores (in which scores below the 5th percentile are replaced with its value and, similarly, scores above the 95% percentile are replaced with its value) from their mean by their standard deviation. This approach provided reasonably symmetric distributions; inferences based on log-transformed data yielded comparable results. We report raw means and standard deviations but conduct inference on winsorized values. To examine the consistency of scores across testing sites, we computed intraclass correlation (ICC) coefficients from the winsorized scores for both computer-administered and interviewer-administered test scores after covariate adjustment to account for differences in the cohorts enrolled by the clinics with respect to age, race/ethnicity, gender, education, 400-m walk times, SPPB, hypertension, and diabetes. ICCs assess the degree to which scores cluster within clinical centers compared with their general distribution across the entire cohort. Principal components analysis was used to describe the correlation structure linking cognitive test scores. All analyses were conducted using (SAS 9.2 software, SAS Institute, Inc., Cary NC, USA).

Results

The SHARP enrolled 73 individuals, mean age 76.4 years; LIFE enrolled 1635 individuals, mean age 78.3 years. Compared with SHARP, LIFE included relatively more women (67% versus 51%, $p = 0.004$) and individuals from racial/ethnic minorities (24% versus 10%, $p = 0.004$). The two trials had fairly comparable levels of education: 25% of SHARP participants and 34% of LIFE participants reported no formal education after high school ($p = 0.11$). LIFE targeted individuals with deficits in lower extremity function: the 400-m walk times averaged 8.48 min (standard deviation = 1.90) in LIFE compared with 5.71 min (0.93) in SHARP ($p < 0.001$), which may reflect, in part, differences in instructions given participants.

The computerized assessments were typically administered in >30 min. In LIFE, the yields of completed and valid tests were 91.4% (1-back test), 83.4% (2-back), 87.3% (task switching), and 96.0% (flanker). Overall, 1.8% of the participants were missing all computerized test data; however, 27.5% of the participants were missing at least one measure. Reasons for missing data included initial difficulties in implementing programs across different operating systems, computer failure, and errors in data uploading but also included participants failing to respond quickly enough to trials that were computer-paced (i.e., n-back), refusals, and unacceptably high error rates rendering reaction time data unreliable (i.e., flanker and task switching). Missing data were more common among older participants ($OR = 1.06$ for each additional year; $p < 0.001$), among those with lower scores on the 3MSE test ($OR = 1.10$ for each point lower; $p < 0.001$), among those who reported no current use of a computer ($OR = 2.71$; $p < 0.001$), and among ethnic/racial minority participants ($OR = 1.55$; $p = 0.003$) but did not differ by gender ($p = 0.15$). By protocol, the 3MSE was required on all participants prior to randomization. The yields of data for the HVLT and DSST interviewer-administered cognitive function tests in LIFE exceeded 99%.

Table 1 contrasts mean scores of the SHARP and the LIFE participants with respect to the computer-administered tests. LIFE participants tended to have poorer scores on all tests of cognitive function; the most marked differences were for the task switching, flanker tests, 3MSE, and DSC tests.

Table 2 lists correlations that some of the computer-administered cognitive function test scores had with interviewer-administered scores, age, and 400-m walk times in SHARP and LIFE. Figure 1 is a scatterplot of all pairwise correlations. Overall, there were reasonable levels of agreement between the two studies. In particular, there was good concordance for relationships with age and 400-m walk times, although strength of these in LIFE appeared to be generally lower than seen in SHARP. One exception was for the flanker response inhibition score, which had modest associations in the expected direction to interviewer-administered cognitive function tests in LIFE, but not in SHARP.

The large size of the LIFE cohort allows greater power to explore associations that cognitive function scores have with risk factors for cognitive impairment. Table 3 presents some of these associations in the LIFE cohort, ordering each index so that higher scores reflect better performance. More highly educated individuals had better standardized 2-back scores and task switching and flanker reaction times. Hypertension and diabetes were most strongly related to flanker reaction times. Better SPPB performance appeared to be related to better cognitive function with respect to all measures, except the flanker response inhibition.

We examined whether there was evidence for systematic differences in the cognitive test scores

Table 1 Comparison of scores from tests of cognitive function collected in the LIFE and SHARP pilot studies at baseline: means (standard deviations) and interquartile (IQ) ranges of raw scores.

Measure	LIFE $N = 1635$		SHARP $N = 73$		t-test
	Mean (SD)	IQ range	Mean (SD)	IQ range	p-value
1-back (rate hits-false alarms)	0.82 (0.18)	0.75, 0.93	0.85 (0.16)	0.82, 0.94	0.17
2-back (rate hits-false alarms)	0.51 (0.21)	0.37, 0.67	0.54 (0.21)	0.39, 0.70	0.34
Task switching (msecs)					
No switch reaction time	1476 (940)	986, 1649	1152 (435)	858, 1314	0.004
Switch reaction time	2461 (1244)	1715, 2814	1996 (852)	1421, 2292	0.002
Switching cost	985 (636)	587, 1220	845 (562)	477, 970	0.07
Flanker (msecs)					
Congruent reaction time	652 (215)	530, 708	557 (115)	482, 590	<0.001
Incongruent reaction time	730 (294)	530, 788	598 (134)	504, 629	<0.001
Response inhibition	78 (131)	30, 95	42 (48)	12, 56	<0.001
HVLT					
Immediate recall	23.21 (5.27)	19, 27	23.40 (4.30)	21, 26	0.77
Delayed recall	7.70 (2.84)	6, 10	7.92 (2.15)	6, 9	0.51
3MSE	91.52 (5.54)	88, 96	94.77 (3.54)	92, 98	<0.001
DSC	46.30 (12.72)	38, 54	53.63 (11.61)	45, 62	<0.001

LIFE, Lifestyle Interventions and Independence for Elders; SHARP, Seniors Health and Activity Research Program; HVLT, Hopkins Verbal Learning Test; 3MSE, Modified MiniMental State Exam; DSC, Digit Symbol Coding

among the LIFE clinics, after adjustment for differences in the characteristics of the enrolled cohorts (Table 4). Low ICCs are consistent with highly standardized test administration. Among the computer-administered tests, all ICCs were acceptably low: the largest were for reaction times for the task switching test: ICC = 0.013 ($p = 0.02$) for no switching and ICC = 0.012 ($p = 0.03$) for switching. ICCs were also low for the interviewer-administered tests, with the largest correlation for the digit symbol substitution test, ICC = 0.023 ($p < 0.001$), and a modest correlation for 3MSE, ICC = 0.008 ($p = 0.05$).

Results from principal component analysis of the correlation structure among the cognitive function tests from the LIFE trial appear in Table 5. The first principal component, which accounted for 40% of the overall variance, essentially averages scores across all tests and reflects overall level of cognitive function. The second principal component (17% of the variance) contrasts performance on the flanker tests, representing a measure of selective attention and response inhibition, with those on the HVLT and 3MSE. The third principal component (11% of the variance) contrasts 1-back, 2-back, and task switching performance with flanker, 3MSE, and HVLT performance, representing a measure of working memory and attentional flexibility. The fourth principal component (9% of the variability) reflects relative performance on the 1-back and 2-back tests versus task switching, that is, working memory.

Conclusions

Use of computer-based batteries to assess cognitive function in multicenter clinical trials is becoming widespread. The introduction of the NIH Cognitive Toolbox in the fall of 2012 is likely to increase uniformity of approaches and further increase their use (Nowinski *et al.*, 2010). The experience of SHARP and LIFE supports use of such batteries and demonstrates that they can be successfully mounted in large multicenter clinical trials involving at risk seniors.

Our analyses yielded three principal findings, which we will discuss in turn. First, the computer-based assessments in LIFE appeared to provide at least as high a degree of standardization in delivery among clinical sites as interviewer-administered tests but resulted in higher rates of missing data. Second, the associations that computer-administered test scores had with interviewer-administered test scores, age, and 400-m walk times were consistent in the small SHARP pilot trial and the large LIFE trial. Finally, within the LIFE cohort at baseline, computer-administered test scores had significant relationships with known risk factors for cognitive deficits and extended the domains being assessed.

Quality control of computer-administered cognitive function tests. The SHARP and the LIFE used central training sessions to certify staff for the administration of cognitive function tests. Standardized protocols for data

Table 2 Pearson correlations (*p*-values) that computer-based cognitive assessment scores have with age, Modified MiniMental State Exam (3MSE) scores, Hopkins Verbal Learning Test (HVLT) immediate recall, Digit Symbol Coding (DSC) scores, and 400-m walk times in the LIFE and SHARP pilot studies at baseline.

Computer-based cognitive assessment task	HVLT immediate		3MSE		DSC		Age		400-m walk time	
	LIFE	SHARP	LIFE	SHARP	LIFE	SHARP	LIFE	SHARP	LIFE	SHARP
1-back (rate hits-false alarms)	0.22 (<0.001)	0.27 (0.02)	0.24 (<0.001)	0.29 (0.01)	0.34 (<0.001)	0.40 (<0.001)	-0.10 (<0.001)	-0.32 (0.008)	-0.06 (0.02)	-0.32 (0.008)
2-back (rate hits-false alarms)	0.29 (<0.001)	0.22 (0.07)	0.29 (<0.001)	0.29 (0.01)	0.34 (<0.001)	0.25 (0.03)	−0.09 (0.001)	−0.16 (0.19)	−0.06 (0.03)	−0.16 (0.19)
Task switching (secs)										
No switch reaction time	−0.29 (<0.001)	−0.32 (0.006)	−0.34 (<0.001)	−0.33 (0.005)	−0.36 (<0.001)	−0.50 (<0.001)	0.11 (<0.001)	0.18 (0.12)	0.13 (<0.001)	0.26 (0.03)
Switch reaction time	−0.31 (<0.001)	−0.43 (<0.001)	−0.32 (<0.001)	−0.32 (0.006)	−0.26 (<0.001)	−0.58 (<0.001)	0.16 (<0.001)	0.25 (0.03)	0.13 (<0.001)	0.39 (0.001)
Switching cost	−0.19 (<0.001)	−0.41 (<0.001)	−0.14 (<0.001)	−0.24 (0.05)	−0.21 (<0.001)	−0.49 (<0.001)	0.16 (<0.001)	0.24 (0.04)	0.06 (0.01)	0.39 (0.001)
Flanker (secs)										
Congruent reaction time	−0.21 (<0.001)	−0.00 (0.98)	−0.30 (<0.001)	−0.13 (0.29)	−0.42 (<0.001)	−0.30 (0.009)	0.10 (<0.001)	0.19 (0.10)	0.18 (<0.001)	0.29 (0.01)
Incongruent reaction time	−0.16 (<0.001)	0.04 (0.71)	−0.25 (<0.001)	−0.12 (0.30)	−0.35 (<0.001)	−0.27 (0.02)	0.10 (0.001)	0.17 (0.15)	0.16 (<0.001)	0.36 (0.003)
Response inhibition	−0.03 (0.29)	0.13 (0.26)	−0.08 (0.003)	0.04 (0.73)	−0.09 (<0.001)	−0.01 (0.94)	0.06 (0.02)	0.01 (0.95)	0.06 (0.02)	0.29 (0.01)

LIFE, Lifestyle Interventions and Independence for Elders; SHARP, Seniors Health and Activity Research Program

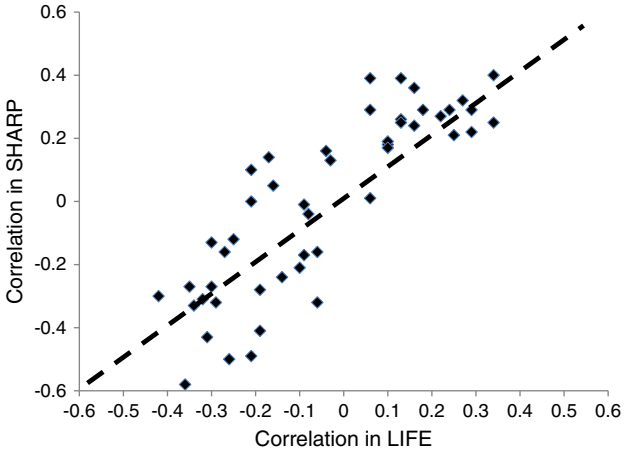

Figure 1 Correlation coefficients linking computer-administered test scores to interviewer-administered tests, age, and 400-m walk times in SHARP versus LIFE.

management that included logic checks and web-based tracking and reporting were used to promote quality control. These were expected to provide greater fidelity by avoiding the data entry required for interviewer-administered tests. Data were reviewed centrally to ensure adherence to the protocol and validity. Overall, these protocols appeared to have resulted in good standardization of the tests among clinical sites, as exhibited by the low ICCs, which in general were at least as low as for the interviewer-administered tests.

Rates of missing data were higher among the computer-administered compared with the interviewer-administered tests in LIFE. This may reflect, in part, the requirement that one interviewer-administered test (i.e., 3MSE) be completed on all participants to determine study eligibility prior to randomization, which may have selected for individuals who were willing to undergo interviewer-administered cognitive testing. Of concern is that the rates of missing data were increased among older participants, those who reported no current use of computers, ethnic minority groups, and those with lower global cognitive function. This suggests that missing data are "non-ignorable" so that additional statistical approaches may be required to control biases (e.g., National Research Council, 2010). Some of the reasons for missing data were related to technical issues involving differences in operating systems among computers: these were overcome with experience. Others were related to participants' inexperience with the specific keyboard functions required to complete the assessment: participants sometimes pressed incorrect keys when responding to tests. To prevent this, we fashioned a template and placed over computer keyboards that only allowed participants access to keys used in the task switching and flanker tasks. Overall, participants were very willing to undergo computerized testing, as has been reported elsewhere (Collerton *et al.*, 2007; Becker *et al.*, 2011).

Consistency of risk factor relationships between SHARP and LIFE. The SHARP and the LIFE cohorts differed with respect to many factors, including performance on many measures of cognitive function. Despite this, scores from computer-administered tests of cognitive function had reasonably similar relationships with age and interviewer-based cognitive assessment in the two cohorts. The associations that these tests had with 400-m walk times in LIFE were consistent with, but perhaps weaker than those seen in SHARP: SHARP participants were encouraged to perform more closely to their maximum functional capacity so that their times may reflect both mobility and aerobic capacity and thus may better discriminate cognitive performance; however, we are not able to test this speculation directly. As seen in Figure 1, there was good overall concordance in the direction and strength of associations, despite the relatively small sample size of SHARP. This supports the utility of pilot studies in the development and the initial evaluation of computer-based instruments.

Relationships with other risk factors in LIFE. Within the larger LIFE cohort, each of the computer-based cognitive function measures had significant associations with age and 400-m walk times. Components of the cognitive battery variously had independent relationships with four other known risk factors for cognitive deficits: education, hypertension, diabetes, and physical function. Most consistent were for SPPB, which had strong ($p < 0.001$) to moderate ($p < 0.10$) relationships with each computer-based cognitive function measure except flanker response inhibition.

The correlation structure among the computer-administered and interviewer-administered tests in the LIFE study demonstrates internal consistency. All measures contributed to the first principal component, a measure of overall cognitive function. Subsequent components identified and contrasted performance within individual cognitive functions. Importantly, the computer-administered tests appear to broaden the range of domains and functions being assessed and were targeted by major principal components.

Limitations

Both the SHARP and the LIFE cohorts, comprised of individuals who volunteered and met eligibility criteria for clinical trials, do not represent more general populations. Also, as we note, these cohorts differ from

Table 3 Associations that computer-based cognitive assessment scores had with education, history of hypertension, history of diabetes, and SPPB in the LIFE cohort at baseline, with adjustment for age, clinic site, race/ethnicity, and gender. Scores (after 5% winsorization to reduce the influence of extreme values) were standardized by dividing differences from the mean by the standard deviation and ordered so that higher scores reflected better performance.

	N-back test z-scores (SE)		Task switching reaction times z-scores (SE)			Flanker test reaction times z-scores (SE)		
Risk factor	1-back	2-back	No switch	Switch	Switching cost	Congruent	Incongruent	Response inhibition
Education*								
High school or less ($N = 529$)	−0.07 (0.05)	−0.14 (0.05)	−0.22 (0.05)	−0.15 (0.05)	−0.02 (0.05)	−0.18 (0.04)	−0.15 (0.04)	0.00 (0.05)
Some college ($N = 641$)	0.03 (0.04)	0.02 (0.04)	0.06 (0.04)	0.02 (0.04)	−0.01 (0.04)	0.05 (0.04)	0.03 (0.04)	−0.05 (0.04)
College graduate ($N = 402$)	0.04 (0.05)	0.11 (0.05)	0.14 (0.05)	0.13 (0.05)	0.06 (0.05)	0.10 (0.05)	0.10 (0.05)	0.06 (0.05)
p-value	0.21	0.004	<0.001	<0.001	0.50	<0.001	<0.001	0.28
Hypertension								
No ($N = 470$)	0.10 (0.05)	−0.02 (0.05)	0.06 (0.05)	0.07 (0.05)	0.03 (0.05)	0.10 (0.04)	0.10 (0.05)	0.03 (0.05)
Yes ($N = 1151$)	−0.03 (0.03)	−0.00 (0.03)	−0.04 (0.03)	−0.04 (0.03)	−0.01 (0.03)	−0.06 (0.03)	−0.06 (0.03)	−0.02 (0.03)
p-value	0.03	0.84	0.07	0.07	0.47	0.004	0.003	0.40
Diabetes								
No/not sure ($N = 1214$)	0.02 (0.03)	−0.01 (0.03)	0.01 (0.03)	0.01 (0.03)	0.00 (0.03)	0.05 (0.03)	0.04 (0.03)	0.00 (0.03)
Yes ($N = 414$)	−0.05 (0.05)	0.02 (0.05)	−0.08 (0.05)	−0.05 (0.05)	−0.01 (0.05)	−0.19 (0.05)	−0.17 (0.05)	−0.02 (0.05)
p-value	0.23	0.59	0.13	0.32	0.86	<0.001	<0.001	0.76
SPPB								
<8 ($N = 731$)	−0.06 (0.04)	−0.06 (0.04)	−0.12 (0.04)	−0.14 (0.04)	−0.11 (0.04)	−0.13 (0.04)	−0.11 (0.04)	−0.01 (0.04)
8–9 ($N = 904$)	0.05 (0.04)	0.04 (0.04)	0.07 (0.03)	0.09 (0.03)	0.08 (0.04)	0.08 (0.03)	0.07 (0.03)	0.00 (0.03)
	0.04	0.07	<0.001	<0.001	<0.001	<0.001	<0.001	0.75

*Excludes 64 with "other" or missing education levels
SPPB, Short Physical Performance Battery

Table 4 Intraclass correlations among LIFE clinical sites after adjustment for age, race/ethnicity, gender, education, 400-m walk times, Short Physical Performance Battery (SPPB) scores, hypertension, and diabetes.

Cognitive assessment	Intraclass correlation	*p*-value
Computer-administered		
1-back	0.000	0.82
2-back	0.000	0.60
Task switching		
No switch reaction time	0.013	0.02
Switch reaction time	0.012	0.03
Switching cost	0.006	0.11
Flanker		
Congruent	0.000	0.62
Incongruent	0.003	0.29
Response inhibition	0.005	0.15
Interviewer-administered		
HVLT		
Immediate recall	0.004	0.13
Delayed recall	0.000	0.33
3MSE	0.008	0.05
DSC	0.023	<0.001

3MSE, Modified MiniMental State Exam; HVLT, Hopkins Verbal Learning Test; DSC, Digit Symbol Coding

Table 5 Principal components analysis of cognitive function tests from LIFE: eigenvector weights.

	Principal component			
	1st	2nd	3rd	4th
1-back	0.23	−0.01	0.46	0.56
2-back	0.26	0.08	0.34	0.42
Task switching*				
No switch reaction time	0.38	−0.04	0.33	−0.49
Switch reaction time	0.37	−0.04	0.36	−0.48
Flanker*				
Congruent	0.32	−0.51	−0.31	0.08
Incongruent	0.31	−0.51	−0.33	0.08
HVLT				
Immediate recall	0.31	0.45	−0.30	0.00
Delayed recall	0.31	0.46	−0.27	0.02
3MSE	0.32	0.23	−0.26	0.05
DSC	0.33	−0.08	0.01	0.16
Proportion of variance explained	0.40	0.17	0.11	0.09

*Re-ordered so that higher scores reflect better function.
3MSE, Modified MiniMental State Exam; HVLT, Hopkins Verbal Learning Test; DSC, Digit Symbol Coding

each other. We present only cross-sectional data: of great importance will be how computer-administered and interviewer-administered measures detect changes in cognitive function that occur over time, which will be seen at the end of the LIFE trial. LIFE will also assess associations that these measures have with the risk of mild cognitive impairment and dementia. Other computerized batteries have been shown to provide reasonable levels of discrimination for identifying cognitive impairment elsewhere (de Jager *et al.*, 2009; Doniger *et al.*, 2006; Doniger *et al.*, 2009). It is not clear how our results may generalize to other studies conducted with cohorts at other levels of cognitive function.

Summary

Our experience supports the use of computer-based measures of cognitive assessments in multicenter trials. However, care must be taken to limit missing data from these tests; augmenting them with interviewer-administered batteries may provide more complete coverage of the cohort.

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Conflict of interest

The authors acknowledge no conflicts.

Key points

- In multicenter studies, computer-based measures of cognitive function provide high levels of standardization and sensitivity to expected risk factor relationships.
- Compared with interviewer-administered batteries, computer-based batteries may yield greater rates of missing data. These may be increased among older participants, those without current computer use, and those with lower levels of cognitive function.

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