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Defense Automated Neurobehavioral Assessment Accurately Measures Cognition in Patients Undergoing Electroconvulsive Therapy for Major Depressive Disorder

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Objectives: The Defense Automated Neurobehavioral Assessment (DANA) is an electronic cognitive test battery. The present study compares DANA to the standard Mini-Mental State Examination (MMSE) in subjects undergoing electroconvulsive therapy for the treatment of major depressive disorder.

Methods: Seventeen inpatient subjects in the Johns Hopkins Hospital Department of Psychiatry were administered longitudinal paired DANA and MMSE tests (7.6 ± 4.1 per patient) from January 10, 2014 to September 26, 2014. Regression analyses were conducted (with or without MMSE scores of 30) to study the impact of the MMSE upper limit, and within-subject regression analyses were conducted to compare MMSE and DANA scores over time.

Results: Statistically significant relationships were measured between DANA and MMSE scores. Relationships strengthened when MMSE scores of 30 were omitted from analyses, demonstrating a ceiling effect of the MMSE. Within-subject analyses revealed relationships between MMSE and DANA scores over the duration of the inpatient stay.

Conclusions: Defense Automated Neurobehavioral Assessment is an electronic, mobile, repeatable, sensitive, and valid method of measuring cognition over time in depressed patients undergoing electroconvulsive therapy treatment. Automation of the DANA allows for more frequent cognitive testing in a busy clinical setting and enhances cognitive assessment sensitivity with a timed component to each test.

Key Words: depression, major depressive disorder, cognition, electroconvulsive therapy, Defense Automated Neurobehavioral Assessment

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Major depressive disorder (MDD), a significant public health issue affecting up to 20% of women and 12% of men,[1] cost the United States economy US $210 billion in 2010.[2] It is estimated that approximately half of all individuals who seek pharmacological treatment for MDD do not show an adequate response to first-line drugs, whereas 30% fail to demonstrate a favorable response to multiple antidepressant drug trials.[3–5] For the latter individuals, electroconvulsive therapy (ECT) remains a highly effective next-line therapy for treatment resistant depression.[6] However, historically, there has been stigma associated with the use ECT, in part owing to the concern about the cognitive-impairing effects of the treatment. Reports in the literature are mixed, but the cognitive impairments most commonly associated with ECT are generally mild to moderate in severity, and resolve within a span of weeks to months.[7,8]

The Defense Automated Neurobehavioral Assessment (DANA) is a battery of cognitive and neuropsychological tests delivered on an electronic tablet that was originally developed for the United States Navy.[9] Benefits of this neurocognitive assessment tool include ease of mobility, repeatability, low cost, and inclusion of previously standardized cognitive tests. Defense Automated Neurobehavioral Assessment has demonstrated sensitivity in detecting cognitive impairments due to dementia,[10] concussion,[11] hypoxic conditions,[12] and the autoimmune central nervous system disease neuromyelitis optica,[13] but the assessment has not yet been tested longitudinally in subjects with MDD.

The purposes of the present study were the following: to (1) measure the relationship between DANA and Mini-Mental State Examination (MMSE) scores and (2) measure cognitive changes over time using DANA and MMSE in subjects with MDD undergoing ECT treatment.

METHODS

Participants

A convenience sample of 17 patients diagnosed with MDD who failed to respond to standard pharmacological intervention (eg, selective serotonin reuptake inhibitor) and psychotherapy and were therefore receiving ECT treatment at the Johns Hopkins Hospital Department of Psychiatry were included in the study. Patient demographics are described in Table 1. Exclusion criteria for recruitment included younger than 18 years of age, presence of an eating disorder, preexisting dementia, and active comorbid substance use disorders. Participants were followed during their inpatient stay that occurred between the dates of January 10, 2014 and September 26, 2014. Informed consent was obtained from participants. All protocols were reviewed and approved by the Johns Hopkins University Institutional Review Board.

DANA Cognitive Tests

The DANA battery, conducted on an electronic tablet (32 GB Samsung Galaxy v8.9), included the reaction time (RT), procedural reaction time (PRT), code substitution (CS), spatial processing (SP), and memory search (MS) tests. The RT test requires subjects to tap on the location of a yellow symbol as quickly as possible each time it appears in the center of the screen, assessing pure RT. In the

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TABLE 1. Study Sample Characteristics

Demographic Information	n = 17
Gender, female	12 (70.6%)
Age, y	45.8 ± 15.8
Level of education, y	15.1 ± 4.0
Race, Caucasian	15 (88.2%)
Inpatient Information	
No. inpatient days	56 ± 40.6
No. ECT treatments	10.2 ± 6.0
No. DANA/MMSE administered per subject	7.6 ± 4.1

Data are presented as mean ± SD or number of participants (% total).

PRT task, 1 of 4 numbers ("2," "3," "4," or "5") is displayed on the screen for 3 seconds. The subject is asked to press the left button ("2" or "3") or right button ("4" or "5") to match the category that includes the number presented. Procedural reaction time measures executive functioning and decision-making capabilities. The CS learning test assesses visual scanning and attention, learning, and immediate recall, analogous to the symbol digit modality test. The subject refers to a code of 9 symbol-digit pairs displayed across the upper portion of the screen. A sequence of single symbol-digit pairs is shown below the key, and the subject indicates whether or not the single pair matches the code by pressing "Yes" or "No." The SP test assesses visual-spatial analytic ability. For this task, pairs of 4 connected bar histograms are displayed on the screen simultaneously with one rotated ±90 degrees, and the subject is requested to determine if the histograms are identical (ie, superimposable on one another). Finally, the MS test assesses attention and working memory, analogous to the Sternberg memory test. For this task, the subject memorizes a set of 5 letters, after which letters appear on the screen one at a time, and the subject determines if the letter on the screen is a member of the previously displayed memory set. For each of the 5 tests, 3 outcomes were analyzed to measure accuracy (no. correct), time (mean RT), and accuracy and time (throughput, calculated as [(% correct) / (RT for correct responses) × 60,000]). Mild practice effects between the first and second completions of the DANA test battery have been observed,[9] so baseline DANA test data were omitted from our analyses.

Mini-Mental State Examination

The MMSE is a well-validated cognitive test made up of 11 questions to assess orientation, memory, attention, calculation, recall, and language.[14] The maximum score on the test is 30. This is the test of cognition used for clinical purposes at the Johns Hopkins Hospital to help monitor for signs of cognitive impairment during the course of ECT treatment.

Administration of Tests

Participants were administered the paper-pencil MMSE and tablet-based DANA tests by a coauthor (S.W.) on the inpatient unit at baseline and throughout their inpatient stay. No tests were administered within 6 hours of a patient receiving ECT treatment. Mini-Mental State Examination and DANA scores were matched for analyses if both tests were administered within a 24-hour period and not separated by an ECT treatment.

Electroconvulsive Therapy

Electroconvulsive therapy was performed using a Mecta Spectrum 5000Q device (Mecta Corporation, Tualatin, Ore). Seizure length and postictal suppression were measured using electroencephalography. The electrode configuration placement was unilateral for 12 subjects, bilateral for 1 subject, and initially unilateral and then switched to bilateral in 4 subjects (average number of unilateral ECT treatments before bilateral switch, 7 ± 1.4). Typical pulse width was 0.3 ms at the first treatment and increased to 0.5 or 1 by the final treatment. Stimulus duration was 2 to 8 seconds, and pulse frequency was 30 Hz for all treatments. The number of ECT sessions per patient was determined based on achievement of remission from MDD based on a combination of expert physician judgment and a Montgomery-Asberg depression rating scale score of less than 9.[15]

Statistical Analyses

Data were reviewed to ensure that the appropriate scores for the patients were included. One patient was discharged but readmitted because of worsening depression in the context of lack of durability of the ECT effects, and only scores from the first inpatient stay were included. Education levels were grouped into 3 categories for analyses (no college, some college, professional degree). Summary statistics were calculated to describe the patient population. Generalized least squares regression analyses were used to evaluate the relationships between the MMSE and DANA scores. The analyses were adjusted for the patient's age in years, their education level, and gender. To measure the time trend of cognitive test scores, we also conducted linear regression analyses between time and DANA or MMSE scores.

RESULTS

There Are Significant Relationships Between MMSE and DANA Scores

Analyses revealed statistically significant relationships between several DANA subtest parameters and the MMSE (Table 2). For each DANA subtest (CS, MS, PRT, RT, or SP), 3 outcomes that measured accuracy (no. correct), time to completion (mean RT), and accuracy and time (throughput) were analyzed.

Inclusion of all scores (n = 128) revealed significant relationships between MMSE scores and outcomes on 3 of the 5 DANA subtests, MS, PRT, and SP; MS accuracy (P = 0.006), time (P = 0.024), and throughput (P = 0.019) were related to MMSE scores, whereas PRT time (P = 0.01) and throughput (P = 0.017), and SP accuracy (P = 0.045) and throughput (P = 0.048) correlated to MMSE scores.

Baseline and final MMSE and DANA scores for each subject are included in Table 3, along with the test ceiling distortion (TCD). Test ceiling distortion, the percentage of MMSE tests on which a participant reached the ceiling effect, was calculated by dividing the total number of MMSE tests for each individual by the number of MMSE tests on which the individual scored a perfect 30 and multiplying by 100.

Removal of the MMSE Ceiling Effect Improves the Relationship Between MMSE and DANA Scores

One-half of the MMSE scores recorded in the present study were perfect scores of 30 (n = 64). Exclusion of these and their associated DANA scores revealed significant relationships between MMSE and DANA scores on all 5 subtests. In cases where statistical significance was present before and after the removal of MMSE scores equal to 30, the change in regression coefficients increased in magnitude in all cases. For example, the change in increase of MMSE per unit increase in DANA PRT throughput

TABLE 2. Regression Coefficients (95% CI) Relating MMSE to DANA

DANA Test		Increase in MMSE per Unit Increase in DANA Score		Excluding 30s: Increase in MMSE per Unit Increase in DANA Score	
		Coef. (95% CI)	*P*	Coef. (95% CI)	*P*
CS	No. correct	0.03 (−0.07 to 0.14)	0.53	0.33 (0.19–0.48)	<0.001
	Mean RT/1000	−0.88 (−2.18 to 0.41)	0.18	−2.671 (−4.54 to −0.80)	0.005
	Throughput/10	0.50 (−0.10 to 1.10)	0.10	1.52 (0.34–2.70)	0.01
MS	No. correct	0.21 (0.06–0.35)	0.006	0.28 (0.16–0.40)	<0.001
	Mean RT/1000	−2.61 (−4.89 to −0.34)	0.02	−3.88 (−6.83 to −0.93)	0.01
	Throughput/10	0.51 (0.09–0.94)	0.02	0.85 (0.23–1.48)	0.007
PRT	No. correct	−0.10 (−0.35 to 0.15)	0.44	0.28 (−0.05 to 0.60)	0.10
	Mean RT/1000	−2.82 (−4.97 to −0.67)	0.01	−4.38 (−7.08 to −1.70)	0.001
	Throughput/10	0.33 (0.06–0.61)	0.02	0.59 (0.25–0.92)	0.001
RT	No. correct	0.13 (−0.08 to 0.34)	0.24	0.23 (−0.03 to 0.49)	0.08
	Mean RT/1000	−3.34 (−7.42 to 0.75)	0.11	−7.66 (−13.95 to −1.39)	0.02
	Throughput/10	0.12 (−0.04 to 0.27)	0.14	0.26 (0.03–0.48)	0.03
SP	No. correct	0.26 (0.01–0.51)	0.045	0.51 (0.39–0.64)	<0.001
	Mean RT/1000	−0.68 (−1.58 to 0.22)	0.14	0.12 (−1.05 to 1.29)	0.84
	Throughput/10	0.60 (0.005–1.20)	0.048	0.74 (0.06–1.42)	0.03

Regression analyses were adjusted for the patient's age in years, their education level, and gender and accounted for the within-patient correlation of measurements.

score is 0.33 ($P = 0.02$) using all MMSE scores, but when MMSE scores are equal to 30 were removed, the change is 0.59 ($P = 0.001$).

MMSE and DANA Scores Change Over Time in Subjects Undergoing ECT

Mini-Mental State Examination and DANA data were examined to determine if within-patient relationships exist between the cognitive tests over time. Code substitution throughput was the chosen DANA metric owing to the strong positive relationship between CS throughput scores and MMSE scores (Table 2). One participant had only 2 matched MMSE and DANA scores and was therefore omitted from analyses, but the remaining 16 participants had greater than or equal to 3 matched MMSE and DANA scores and were included. Seven subjects had matching MMSE and DANA score trends over time, with both scores either going up (n = 2) or down (n = 5) over time (Fig. 1A, MMSE slope = −0.038, $P = 0.25$; CS throughput slope = −0.056, $P = 0.35$; Fig. 1B, MMSE slope = −0.024, $P = 0.08$; CS throughput slope = −0.33, $P = 0.0003$). Conversely, 4 individuals had conflicting MMSE and DANA score changes, with 1 test score going up and 1 test score going down over time. The remaining 5 participants achieved relatively constant MMSE scores over time (ie, 1 point variance in score), whereas DANA scores went up (Fig. 1C, MMSE slope = −0.008, $P = 0.61$; CS throughput slope = −0.97, $P = 0.003$) or down (Fig. 1D, MMSE slope = −0.017, $P = 0.27$; CS throughput slope = 0.32, $P = 0.03$).

DISCUSSION

The present study reveals statistically significant relationships between cognitive measures obtained from the DANA and MMSE tests. The DANA measures cognition using 3 key outcomes: RT, accuracy, and combined RT and accuracy (throughput). Electronic delivery of the DANA provides results that are timed to the millisecond. The incorporation of a time component into DANA output eliminates the ceiling effect for the RT and throughput metrics, which is a major limitation of the untimed MMSE. Whereas a subject with a score of 30 on the MMSE has no opportunity for measureable improvement in cognitive function, faster responses on the DANA test yield improved speed and throughput scores when accuracy scores remain perfect. Therefore, calculable gains in cognition are possible in the DANA. Taking that important distinction into consideration, 2 separate analyses were performed using pooled data—one to validate the DANA against MMSE data, and one to measure how the MMSE ceiling effect affected our validation. All cognitive data collected in the study were included in the first analyses to validate DANA when measured against MMSE. Mini-Mental State Examination scores of 30 (along with their corresponding DANA scores) were excluded in the second set of analyses to determine if the relationship between DANA and MMSE scores was strengthened when the MMSE ceiling effect was removed.

The MMSE is the most commonly used and quite often the sole method of tracking cognitive function in ECT studies.[16–20] In fact, a recent study from New Zealand reported that 80% of ECT studies examining cognition used the MMSE and that over 60% of these studies only used one cognitive test.[21] Because of its widespread use in clinical and research settings for over 4 decades, including the Johns Hopkins inpatient Mood Disorder Service setting of the present study, the MMSE was chosen as the "criterion standard" by which to compare DANA test performance in this sample. It is critical to note that the use of only the MMSE and not a more comprehensive cognitive test battery could be viewed as a potential study limitation, but the design was specifically chosen based on the ubiquity of the MMSE in field of ECT research. We not only used the most common test for validation purposes but also highlight the limitations of the MMSE and provide recommendations to use the alternative DANA test battery that overcomes all identified limitations.

Here, we observed statistically significant relationships between DANA and MMSE scores on at least 1 outcome (speed,

TABLE 3. Baseline and Final MMSE and DANA cognitive test scores, and MMSE TCD

					DANA Throughput Scores									
		MMSE Scores			CS		MS		PRT		RT		SP	
Patient	No. ECT Treatments	Baseline	Final	MMSE Test Ceiling Distortion: % MMSE Scores = 30	Baseline	Final	Baseline	Final	Baseline	Final	Baseline	Final	Baseline	Final
1	12	25	22	0.0%	20.13	23.88	39.84	26.64	65.95	72.16	82.02	114.29	50.61	27.39
2	22	29	30	33.3%	43.18	47.01	73.20	73.30	85.94	92.31	186.34	183.49	36.31	31.76
3	8	25	29	33.3%	27.01	26.42	30.86	42.41	81.41	86.71	72.48	137.30	23.84	24.59
4	7	28	30	60.0%	34.88	41.24	52.43	52.00	87.14	83.39	146.70	121.85	23.79	18.93
5	3	30	29	50.0%	32.28	35.02	39.57	62.43	77.19	77.60	166.67	164.38	15.59	19.57
6	14	30	30	90.0%	53.03	43.08	66.59	60.01	88.17	79.10	154.64	144.23	37.78	30.42
7	4	29	30	66.7%	29.14	22.76	57.86	16.81	74.17	63.27	124.74	94.61	16.40	20.33
8	13	28	29	11.1%	29.47	28.57	44.35	49.24	74.49	61.38	148.15	100.19	29.84	25.44
9	18	30	30	87.5%	61.32	42.39	86.83	54.74	109.05	76.63	185.19	155.06	40.96	32.53
10	10	30	28	33.3%	26.34	24.15	28.39	35.97	54.29	53.44	111.16	88.11	14.81	13.22
11	1	30	30	66.7%	18.60	14.06	26.28	26.13	68.14	59.60	85.86	100.88	8.56	15.51
12	3	30	29	87.5%	45.64	36.12	76.62	59.90	93.00	93.31	165.29	147.06	40.54	37.46
13	19	29	30	25.0%	23.42	29.61	43.51	39.32	64.07	49.08	102.56	75.59	21.59	17.91
14	11	29	27	11.1%	16.71	16.63	20.01	16.78	44.58	49.48	133.01	115.54	24.30	24.91
15	15	30	30	77.8%	32.53	44.15	49.16	47.39	77.67	94.12	117.88	140.49	20.57	23.59
16	6	30	27	66.7%	25.35	32.87	38.23	46.51	73.81	73.25	110.56	152.67	11.08	16.68
17	6	29	29	60.0%	49.20	36.04	57.11	39.17	96.39	85.84	172.41	155.04	35.26	16.06

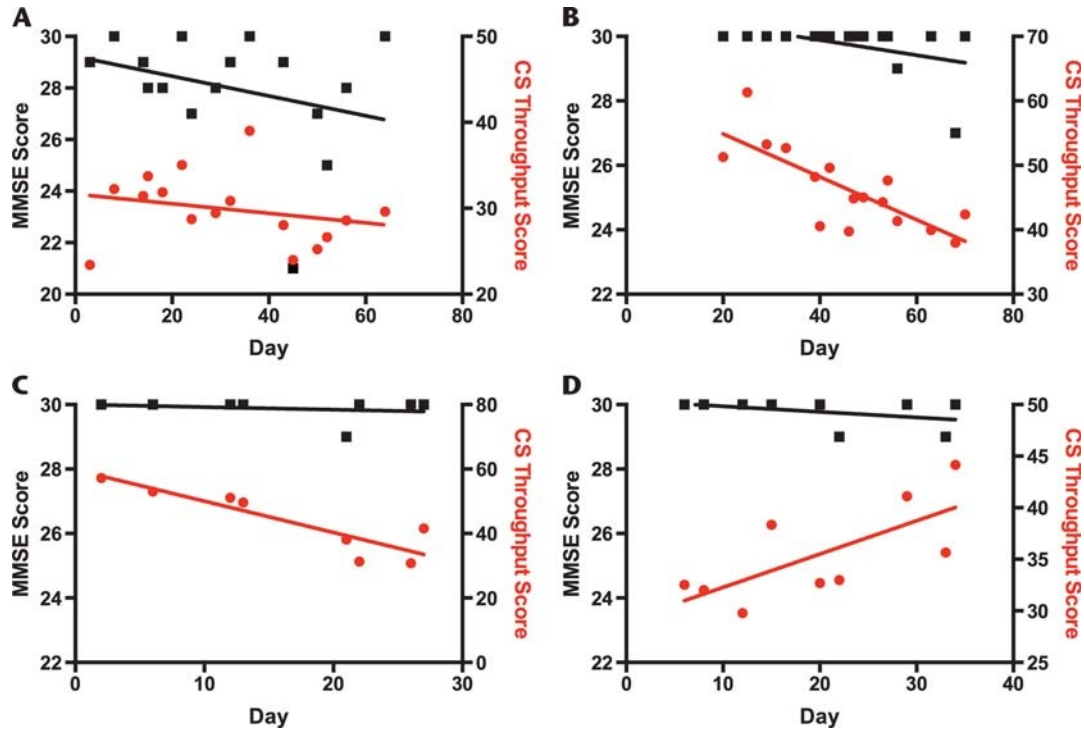

FIGURE 1. Mini-Mental Status Examination and DANA CS throughput data from 4 representative patients undergoing ECT for the treatment of MDD. In some patients: (A) CS throughput and MMSE cognitive test scores follow similar trends over time; (B) CS throughput was more sensitive at detecting cognitive impairment over time than MMSE; (C) MMSE remained constant whereas CS throughput decreased; (D) MMSE remained constant whereas CS throughput increased.

accuracy, or throughput) in 3 out of 5 DANA subtests. When MMSE upper limit scores of 30 were removed, however, significant relationships were observed between MMSE and all 5 DANA subtests. Furthermore, the exclusion of MMSE scores of 30 led to a measurable increase in the magnitude of regression coefficients in all analyses, despite the fact that elimination of MMSE scores of 30 decreased the number of measurements in half and thus reduced statistical power. Taken together, these findings highlight the limitations of MMSE related to its ceiling effect, particularly in premorbidly high-functioning patients, and thus the enhanced sensitivity of the DANA battery as compared with the MMSE.

Examination of DANA and MMSE data within patients over time revealed several interesting observations. First, nearly half of all patients had similar trends in DANA and MMSE scores over time, meaning that, when MMSE scores went up or down over time, DANA scores went up or down over time, respectively. These findings further validate the DANA to the MMSE. Second, as depicted in Figure 1B, some patients experienced declines in both MMSE and DANA scores over time, but at different rates. In the given example, MMSE scores did not decline until the very end of the testing period, whereas DANA tests demonstrated a steady, linear performance decline over the entire testing period. The observation that DANA allows for discrete, measurable changes whereas MMSE cannot detect impairment suggests an enhanced sensitivity of the DANA test as compared with MMSE. Third, and similar to what was observed in the pooled set of analyses, a clear MMSE upper limit was detected in the 5 patients who experienced no change in MMSE scores over time whereas DANA scores went up or down. In all 5 cases where MMSE scores remained constant over time, the scores were maintained at or near the upper limit (ie, 29 or 30). Although DANA scores improved and MMSE scores remained constant, the highest score possible on the MMSE (ie, 30) was achieved on the first day of testing. Because there was no room for improvement on the MMSE test, it was not possible for the MMSE score to increase alongside the DANA score. In the case of DANA scores going down while MMSE scores remain constant at 30 from baseline, it is likely that the untimed MMSE test was too simple for the patient and that it was therefore insensitive to measurable declines in cognitive function. Both instances highlight the ceiling effect limitation of the MMSE.

The TCD was calculated as a way to quantify the frequency with which the MMSE ceiling effect affected each participant. Test ceiling distortion scores ranged from 0% to 90% in our relatively small sample size of 17 subjects. Interestingly, a regression calculation of the highest level of education versus the MMSE TCD revealed a trend relationship between higher education achieved and a higher TCD percentage ($P = 0.29$), suggesting that this ceiling effect might be observed more frequently in individuals with more advanced education. We hypothesize that a larger sample size would reveal a significant relationship between the 2 variables, and future studies in larger populations will include this outcome.

It was interesting that some subjects experienced cognitive impairment whereas others made it through their ECT treatments with cognitive domains intact or even improved. Others have similarly reported variable effects of ECT on cognitive function.[22] We hypothesize that these mixed results occurred owing to a combination of the cognitive impairing effects of ECT and the association between cognitive impairment and depression. Many investigators have attempted to determine which aspects of treatment are associated with cognitive impairments, and pulse width duration,[23] presence of global cognitive impairment before ECT treatment,[24] delirium after treatment,[24] and age[25] are a few factors that have

been linked to the severity of cognitive decline observed following treatment. The pulse width of the first ECT treatment for 14 of 17 of our ECT subjects was ultrabrief (0.3 ms), but increased to 0.5 to 1 ms by the final ECT treatment in 11/14 of these subjects, and we did not observe relationships between cognitive performance and pulse width or total charge received. Initial MMSE scores, delirium after treatment, and age were also not found to be predictive of cognitive changes in our sample, potentially owing to a small sample size. Cognitive impairment is a recognized feature of MDD, and studies have shown that the resolution of depression coincides with improvements in cognitive function in many patients.[26,27] Therefore, it is logical that some patients experienced improvements in cognitive function, despite exposure to repeated and potentially cognitive impairing ECT treatment, as depression symptoms improved. In addition to our small sample size, it is possible that other factors not collected in our study that have been linked to cognitive changes in ECT, such as cognitive reserve,[28] would have been predictive of cognitive decline or improvement. Future studies will explore these factors and add to our preliminary findings.

Developed in 1975 in a sample of patients with dementia, depression, schizophrenia, and other cognitively impairing conditions,[14] the MMSE persists as a mainstay for the clinical assessment of cognition in present day.[29,30] The MMSE was initially validated against the Wechsler Adult Intelligence Scale test, which at the time was routinely used to assess cognition but took over 30 minutes to complete.[14] More recently, the MMSE has been corroborated to many other cognitive tests, such as the Montreal Cognitive Assessment, the Mini-Cog, and the General Practitioner Assessment of Cognition.[31–34] The MMSE was studied in a large population (n = 18571), with normalized scores established based on age and highest level of education.[35] Mini-Mental State Examination scores greater than or equal to 24 are generally considered normal, with 19 to 23 indicating mild cognitive impairment. Although ECT can cause cognitive impairment,[7,8] only 2 out of 17 subjects in the present study scored below 24 on one or more MMSE test. Nineteen was the lowest recorded score, indicating that ECT did not cause moderate or severe cognitive impairment in our sample.

The MMSE tests 7 cognitive domains: orientation to time, orientation to place, registration, attention and calculation, recall, language, and visual construction.[36] Scoring weight places emphasis on language, orientation, and attention and calculation. It is interesting, therefore, that the strongest relationships between MMSE scores and DANA tests were found in the CS, MS, and SP subtests, because SP is a test of orientation and CS and MS require attention. The tests differ, however, in that there is no language fluency component to the DANA battery, only letter recognition. The MMSE relies heavily on verbal responses and/or writing, so communication disorders could negatively and erroneously impact cognitive score. A limitation of the present study includes the lack of complete overlap between the cognitive domains tested in DANA and MMSE, and the aspects of memory that are not evaluated in either test (eg, autobiographical memory). It is possible that the opposite results in test performance over time in some patients were due to different domains being measured in the tests. Future directions to validate DANA against the MMSE will include comparing MMSE domain subscores with relevant corresponding DANA subtests. It is also important to note that subjects received variable numbers of ECT treatments in the present study. Future studies to expand upon our preliminary findings will include subjects experiencing approximately equivalent numbers of ECT treatments to normalize the sample and better correct for the variable effects of ECT exposure on cognition, which will likely decrease the somewhat large confidence intervals observed in our some of our DANA subtest analyses.

Validation of the DANA battery in ECT has widespread implications for the study of cognition in MDD and other neuropsychiatric and neurological diseases and disorders. Use of an automated and timed test battery at the patient's bedside improves ease-of-use and provides unambiguous results. Tests that are easier to direct can be administered more frequently, providing the opportunity to more closely track changes in cognitive function in diseases, including MDD in ECT, over time. For example, whereas most studies measuring cognition in ECT measure cognitive function at only 3 time points,[8,37] the present study had an average of 7.5 measures per patient in the relatively short time frame of 8 weeks. More frequent cognitive testing will enhance our overall understanding of how neurological diseases affect cognition over time.

In summary, we have found a relationship between pooled DANA and MMSE scores in individuals undergoing ECT for the treatment of MDD. The timed component of DANA provides an additional and critical dimension to the evaluation of cognitive function, thereby producing a more sensitive overall measurement of cognition as compared with the MMSE and making DANA an appropriate method of measuring changes in cognitive function over time.

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