Neuropsychology

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Online First Publication, December 29, 2014. http://dx.doi.org/10.1037/neu0000160

CITATION

Bickerton, W.-L., Demeyere, N., Francis, D., Kumar, V., Remoundou, M., Balani, A., Harris, L., Williamson, J., Lau, J. K., Samson, D., Riddoch, M. J., & Humphreys, G. W. (2014, December 29). The BCoS Cognitive Profile Screen: Utility and Predictive Value for Stroke. *Neuropsychology*. Advance online publication. http://dx.doi.org/10.1037/neu0000160

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0894-4105/14/$12.00 http://dx.doi.org/10.1037/neu0000160

The BCoS Cognitive Profile Screen: Utility and Predictive Value for Stroke

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Objective: We examined the utility of the Birmingham Cognitive Screen (BCoS) in discriminating cognitive profiles and recovery of function across stroke survivors. BCoS was designed for stroke-specific problems across 5 cognitive domains: (a) controlled and spatial attention, (b) language, (c) memory, (d) number processing, and (e) praxis. ***Method:*** On the basis of specific inclusion criteria, this cross-section observational study analyzed cognitive profiles of 657 subacute stroke patients, 331 of them reassessed at 9 months. Impairments on 32 measures were evaluated by comparison with 100 matched healthy controls. Measures of affect, apathy, and activities of daily living were also taken. Between-subjects group comparisons of mean performance scores and impairment rates and within-subject examination of impairment rates over time were conducted. Logistic regressions and general linear modeling were used for multivariate analysis of domain-level effects on outcomes. ***Results:*** Individuals with repeated stroke experienced significantly less cognitive recovery at 9 months than those with a first stroke despite similar initial level of cognitive performance. Individuals with left hemisphere lesions performed more poorly than those with right hemisphere lesions, but both groups showed similar extent of recovery at 9 months. BCoS also revealed lesion-side-specific deficits and common areas of persistent problems. Functional outcome at 9 months correlated with domain-level deficits in controlled attention, spatial attention, and praxis over and above initial dependency and concurrent levels of affect and apathy. ***Conclusion:*** The study demonstrates how BCoS can identify differential cognitive profiles across patient groups. This can potentially help predict outcomes and inform rehabilitation.

Keywords: stroke, cognitive screening, aphasia, neglect, attention

Cognitive deficits are prevalent at the acute stage of stroke (Jaillard, Naegele, Trabucco-Miguel, LeBas, & Hommel, 2009). They interfere with the potential benefits of rehabilitation and affect recovery (Ballard et al., 2003; Barker-Collo & Feigin, 2006; de Haan, Nys, & van Zandvoort, 2006; Donovan et al., 2008; Edwards et al., 2006; Fure, Bruun Wyller, Engedal, & Thommessen, 2006; Narasimhalu et al., 2009; Nys et al., 2006; Pohjasvaara et al., 2000; Stephens et al., 2005; van Zandvoort, Kessels, Nys, de Haan, & Kappelle, 2005; Zinn et al., 2004). Moreover, cognitive deficits are associated with a poorer qual-

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This research was supported by the Stroke Association and the United Kingdom National Institute of Health Research (Oxford Cognitive Health Clinical Research Facility). We are grateful to all the participants who took part in the research and to the United Kingdom West Midlands Stroke Research Network for their generous support and advice in patient recruitment. We are thankful for the support of the local principal investigators and collaborators who facilitated data collection in the respective research sites, notably Kate Wilde, Peter Mayer, Don Sims, Carron Sintler, Alexandra Ball, Christine Rolf, Shahid Kausar, Tun Aung, Jane Bisiker, Emma Clayton, Louise Price, John Chambers, E. Smith, David Sandler, Ruth Telfer, Antony Oke, Janine Gall, and Francis Vaz.

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ity of life (Moon, Kim, Kim, Won, & Kim, 2004; Nichols-Larsen, Clark, Zeringue, Greenspan, & Blanton, 2005; Paul et al., 2005) and depression (Kauhanen et al., 1999; Nys et al., 2006).

Neuropsychological assessments have typically divided cognitive functions into several domains (e.g., attention, language, memory; Heilman & Valenstein, 2012), and this division of cognition into different domains is supported by evidence from functional brain imaging in normal participants, where brain activity clusters into different domains for language, memory, attention, and so forth (Laird et al., 2011). Previous studies have shown that the co-occurrence of impairments in two or more domain functions, such as impaired executive functions or sustained attention alongside language impairments or neglect, may adversely affect the rehabilitation outcome of the primary function—that is, in language (Lambon Ralph, Snell, Fillingham, Conroy, & Sage, 2010) or visual attention (Malhotra et al., 2005; Robertson, 2001). Therefore, assessment needs to cover not only primary symptoms but also contributing, co-occurring impairments.

Although early cognitive screening for stroke is well recognized (NICE, 2008), the existing screening tools—for example, the Mini–Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975), the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005), the Addenbrooke's Cognitive Examination III (ACE-III; Hsieh, Schubert, Hoon, Mioshi, & Hodges, 2013), and the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS; Randolph, Tierney, Mohr, & Chase, 1998—are not stroke specific. As a consequence, such screens provide no evaluation of common poststroke deficits such as spatial neglect (Gottesman, 2009) and apraxia (Bickerton et al., 2012), nor do their testing procedures minimize the contaminating effects of aphasia or neglect on performance of nonlanguage and visuospatial tasks (e.g., memory tests). The Birmingham Cognitive Screen (BCoS; Humphreys, Bickerton, Samson, & Riddoch, 2012) aims to address these problems by providing an overarching cognitive screen (covering multiple domains of cognition) specifically designed to be sensitive to the cognitive profile of stroke patients.

The principles of the design of the BCoS and data on its validity and reliability have been published elsewhere (Bickerton et al., 2012; Bickerton, Samson, Williamson, & Humphreys, 2011; Humphreys et al., 2012). The principles include (a) making tests "aphasia and neglect friendly" when language and spatial attention are not measured (to maximize patient inclusion); (b) including assessments of neglect, reading, apraxia, and number processing, which, though common after a stroke (Bickerton et al., 2011, 2012; Bowen, Lincoln, & Dewey, 2002), are not measured in screening tools derived for dementia; and (c) incorporating time-efficient test designs in which single tests measure more than one cognitive process. The BCoS also has a unique reporting system in which the cognitive profile of a patient across the tests is presented in a form that can be grasped at a glance by clinical teams (see the Appendix).

The current article reports data from a large-scale trial that, for the first time, assessed the utility and functional predictive value of this stroke-designed screen across a population of subacute stroke patients. Specifically, we investigated (a) whether the BCoS reveals differential initial profiles of cognition between individuals with first stroke and repeated stroke and between individuals with left hemisphere damage (LHD) and right hemisphere damage (RHD); (b) whether it can predict recovery patterns in patients over and above the effects of affect and initial dependency level; and (c) whether the cognitive profile of performance emphasized by the BCoS (taking into account variation in several domains of cognition) can help predict cognitive and functional performance at 9-month follow-up.

Method

Participants

Stroke survivors were recruited between November 2006 and January 2011 from 12 hospitals in the West Midlands, England, as part of a United Kingdom cognitive screen trial (the Birmingham University Cognitive Screen [http://www.bucs.bham.ac.uk]). Stroke survivors were recruited if medically stable, within 3 months of their latest stroke, and able to give informed consent. Diagnosis of a stroke was based on assessment by the clinical team. Exclusion criteria were (a) insufficient understanding of English; (b) inability to concentrate for 35 min per the clinical judgment of the treatment team and the researcher; and (c) premorbid conditions affecting cognition (e.g., dementia), as shown in case notes.

Lesion information from hospital-based CT or MRI scans (where available as part of the routine stroke care in the region) was obtained. Patients were excluded if there was no observable focal damage or if image quality was poor. About 50% of the participants took part in a 9-month follow-up assessment (see Figure 1 for the flowchart of the patient cohort at baseline and follow-up). Patients who completed fewer than 15 of 22 tasks (10%) were excluded to enable us to have relatively complete datasets for each patient. The most common reasons given for a failure to complete all tasks were fatigue and lack of time. For the analyses related to the lesion side, only patients with an identified unilateral lesion were included. Informed consent was obtained according to the approved ethics protocols of the U.K. National Research Ethics Committee. Data were collected by examiners (psychologists, occupational therapists, or stroke researchers), all of whom attended a full day's training and were assessed and supported by the university team, under the supervision of the chief investigator (Glyn W. Humphreys).

Cognitive Screen Measures

The BCoS assesses five cognitive domains: (a) attention and executive function, (b) language, (c) memory, (d) number, and (e) praxis. Finer grained distinctions can also be drawn within some of the domains, including between (a) spatial attention (e.g., neglect, extinction) and controlled attention (e.g., executive functions, sustained attention), (b) spoken and written language, (c) immediate and delayed memory, and (d) limb apraxia and constructional apraxia. Further descriptions of the tests have been provided elsewhere (Humphreys et al., 2012) and are available at http://www.cognitionmatters.org.uk. There are 32 different submeasures derived from 22 tasks (see the Appendix for brief descriptions of the 22 BCoS tasks). Age group–specific (50–64 years, 65–74, 75 or above) cutoffs (at 5th percentile) for each test were established

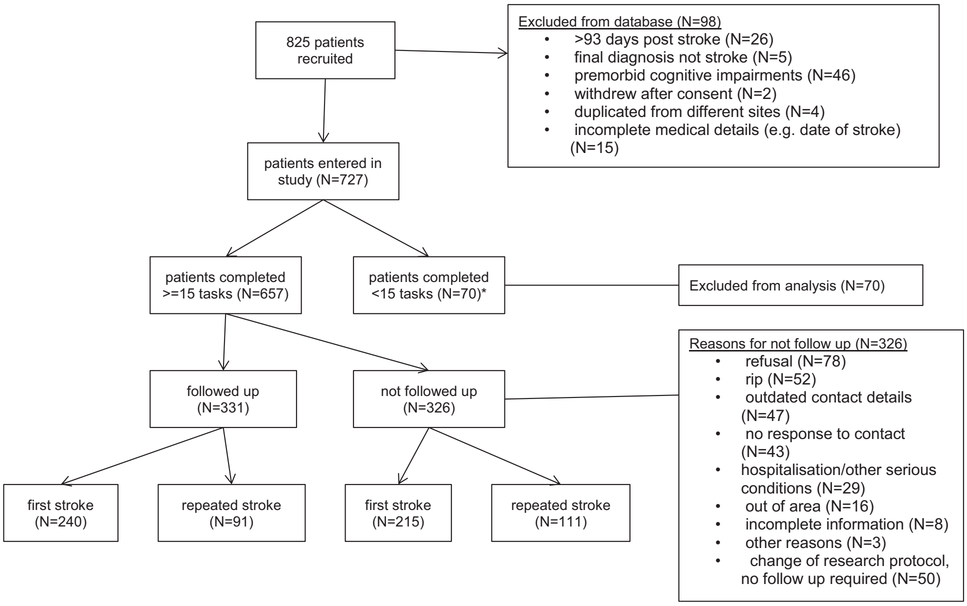

Figure 1. Flowchart of patient cohort at baseline and follow-up.

from 100 controls stratified following the 2001 U.K. population census Age × Sex × Education Level distribution.

Affective and Functional and Dependency Measures

At the initial assessment, affect was measured by the Hospital Anxiety and Depression Scale (HADS; Snaith & Zigmond, 1994), and dependency level was measured by the Barthel Index(Mahoney & Barthel, 1965). At 9-month follow-up, these were repeated, along with the self-rated Apathy Evaluation Scale (AES; Marin, Biedrzycki, & Firinciogullari, 1991) for apathy and the Nottingham Extended Activities of Daily Living Scale (NEADL; Nouri & Lincoln, 1987) for participation in community activities of daily living.

Statistical Analysis

For the comparison of demographic and background details between subgroups of interest, two-tailed Mann–Whitney *U* tests were used for continuous, nonnormally distributed variables, *t* tests were used to compare continuous data and, chi-squares were used to compare categorical data. For the comparisons of cognitive profiles at the cognitive domain level, multivariate analyses of variance were performed on all scores of the subtasks that were part of the same cognitive domain. Subsequent individual task–level analyses used Mann–Whitney *U* tests for raw scores and chi-squares for diagnosis category (unimpaired vs. impaired). McNemar tests were used to compare rates of impairment on each task individually at the initial and follow-up assessments. Bonferroni corrections were made to all multiple comparisons. Linear regressions were used to model effects on functional outcomes while controlling for other confounding factors, and generalized linear modeling was used to conduct multivariate analysis of domain-level effects on outcomes.

Results

Six hundred and fifty-seven participants were included in the analyses. Ninety percent of the patients tested at the initial, subacute stage were able to complete more than 75% of the tests. Four hundred and fifty-five (69%) were survivors of first stroke, and 202 (31%) had had a previous stroke (two or more). The demographic and health measures details of the participants, comparing across groupings of interest, are shown in Tables 1 and 2. We assessed whether stroke history (first or repeated stroke) and unilateral lesion side (left hemisphere or right hemisphere) affected cognitive ability and recovery (BCoS performance) after stroke (Part 1). We then evaluated whether longer term functional outcomes for patients could be predicted from their BCoS scores (Part 2) and whether the cognitive profile provided by the screen can enhance predictions of cognitive and functional performance (Part 3).

Part 1: Stroke Factors Linked to Cognitive Outcomes

First- versus repeated-stroke effects. There was no difference in age, gender, or education across patients with their first or a repeated stroke. There was a significant different in time post-stroke on assessment. Patients who had a first stroke were tested later than those who had a repeated stroke (mean difference = 6 days, $p < .001$). Numerically, there was a trend for higher levels of depression in repeated- compared with first-stroke patients, but this did not reach the corrected level of significance. No other significant group differences were found.

Overall, the cognitive performance of the first- and repeated-stroke groups was very similar at baseline. Both groups completed an equal number of BCoS tasks (see Table 3), and there were no group differences at either the cognitive-domain level (all *p*s $> .01$ [i.e., above the corrected level of significance of .008 {see Table 3}]

Table 1
Demographic and Health Measures of Patients, by Stroke History and Lesion Side

						First stroke only				
	First stroke		Repeated stroke			LHD		RHD		
Variable		*SD*		*SD*	*p*[a]		*SD*		*SD*	*p*[a]
n	455		202			152		181		
Age (years)	69.31	14.34	71.38	12.60	*ns*	69.34	13.93	69.42	14.51	*ns*
Gender (% female)	44.80		39.6		*ns*	46.70		42.00		*ns*
Years of education	11.52	2.76	11.19	2.76	*ns*	11.55	2.79	11.66	2.83	*ns*
Time post current stroke (days)	26.65	22.36	20.44	17.29	.000[**]	28.52	23.96	25.89	21.72	*ns*
Initial Barthel	13.01	5.76	13.34	5.43	*ns*	12.72	5.92	12.63	5.96	*ns*
Initial HADS anxiety	6.22	4.50	6.70	4.98	*ns*	6.11	4.44	6.08	4.62	*ns*
Initial HADS depression	5.71	4.05	6.66	4.29	.009	5.64	4.24	5.64	4.02	*ns*
Followed-up subgroup										
Percentage followed up	52.70		45.00		*ns*	50.00		59.70		*ns*
Barthel	17.00	4.11	17.19	3.84	*ns*	17.39	3.58	16.19	4.78	*ns*
NEADL	12.79	6.48	12.90	6.56	*ns*	12.36	7.01	12.29	6.51	*ns*
HADS anxiety	5.58	4.38	6.21	4.85	*ns*	4.86	3.55	6.08	4.56	.050
HADS depression	5.43	3.71	6.69	4.39	.018	4.96	3.78	5.75	3.72	*ns*
Apathy evaluation score	31.91	9.99	34.36	10.10	*ns*	31.46	8.64	33.00	10.89	*ns*

Note. LHD = left hemisphere damage; RHD = right hemisphere damage; HADS = Hospital Anxiety and Depression Scale; NEADL = Nottingham Extended Activity of Daily Living Scale.
[a] *t* tests were nonsignificant at the .05 level.
[**] *p* (with Bonferroni correction) at .05/7 = .007.

or the task level [raw scores for all ps $> .002$ {see Table 3}]; for the percentages of patients impaired, all ps $> .002$ [see Table 4]).

Significant improvement (based on a reduction in the number of patients diagnosed as impaired; see Table 4) at follow-up was more frequent in the first-stroke group (on average improving on 15 of 32 of the measures) than in the repeated-stroke group (improvements on only four of 32 measures), $\chi^2(df = 1, N = 64) = 9.06$, $p = .003$, odds ratio (OR) = 6.18. This differential improvement did not reflect underlying contrasts in age, gender, education, or initial Barthel score, none of which differed. Patients with multiple strokes tended to be more depressed, which may have reduced their motivation to engage in rehabilitation. However, we found no differences in the extent of task recovery between depressed and nondepressed patients with multiple strokes, $t(86) = -0.92$, $p = .362$. The data also revealed instances of persistent deficits across both groups for spatial neglect (cancellation task accuracy and asymmetry) and verbal memory (immediate and delayed verbal recall and recognition measures). Within the praxis domain, gesture production and recognition deficits were more persistent than other impairments (though note the relatively lower initial impairment rates for gesture production and recognition).

Left versus right unilateral lesion effects in first-stroke patients. Grouping by unilateral brain lesion side revealed no differences in the demographic details, the initial functional performance, or level of affect (anxiety, depression) across the groups (see Table 1).

Overall, the LHD group had more cognitive impairments than the RHD group, completing fewer BCoS tasks ($p < .000$) and showing significantly worse performance in all cognitive domains, with the exception of spatial attention (see Table 3). In the spatial attention domain, the RHD patients performed more

Table 2
Demographic and Health Measures of Patients with First and Repeated Stroke, by Followed-Up Status

	First stroke group					Repeated stroke group				
	Follow-up		No follow-up			Follow-up		No follow-up		
Variable		*SD*		*SD*	*p*[a]		*SD*		*SD*	*p*[a]
n	240		215			91		111		
Age (years)	70.00	13.26	68.53	15.44	*ns*	69.49	11.80	72.92	13.06	*ns*
Gender (% female)	45.00		44.70		*ns*	39.60		39.60		*ns*
Years of education	11.80	2.91	11.20	2.55	.022	11.57	2.97	10.87	2.53	*ns*
Time post current stroke (days)	26.83	20.95	26.46	23.88	*ns*	20.71	18.66	20.21	16.17	*ns*
Initial Barthel	12.60	5.70	13.47	5.80	*ns*	13.89	5.38	12.88	5.45	*ns*
Initial HADS anxiety	6.61	4.59	5.77	4.36	*ns*	6.26	5.15	7.10	4.81	*ns*
Initial HADS depression	6.15	4.13	5.20	3.90	.017	6.32	3.96	6.97	4.57	*ns*

Note. HADS = Hospital Anxiety and Depression Scale; NEADL = Nottingham Extended Activity of Daily Living Scale.
[a] *t* tests were nonsignificant at the .05 level.
[**] *p* (with Bonferroni correction) at .05/7 = .007.

Table 3
Baseline Cognitive Profiles of Patients, by Stroke History, and Lesion Side

		First vs. repeated stroke					LHD vs. RHD (first stroke only)				
		First		Repeated			LHD		RHD		
Domain and measure	Max. score	*M*	*SD*	*M*	*SD*	*p*[a]	*M*[b]	*SD*	*M*[b]	*SD*	*p*[a]
Tasks completed	22	21.03	1.76	20.96	1.71	*ns*	20.58	2.23	**21.35**	1.29	.00
Attention						***ns***					**.00**
Spatial											
Cancellation accuracy	50	39.94	13.14	39.55	13.45	*ns*	**43.27**	9.83	36.20	14.94	.00
Page-based asymmetry (abs)[c]	20	2.69	3.92	2.99	4.89	*ns*	**1.45**	1.89	3.89	4.82	.00
Object-based asymmetry (abs)[c]	20	1.47	3.48	2.02	5.31	*ns*	**0.81**	2.68	2.38	4.46	.00
Left visual bilateral	8	6.95	2.45	6.95	2.49	*ns*	**7.85**	0.65	5.97	3.16	.00
Left tactile bilateral	8	6.95	2.39	7.08	2.18	*ns*	**7.78**	1.00	6.01	3.11	.00
Right visual bilateral	8	7.62	1.49	7.47	1.73	*ns*	7.28	2.12	7.83	0.94	.00
Right tactile bilateral	8	7.63	1.36	7.49	1.57	*ns*	7.09	2.16	**7.92**	0.43	.00
Controlled											
Rule finding and switching	18	7.15	5.86	6.47	5.29	*ns*	7.23	5.79	7.30	5.75	*ns*
Auditory attention accuracy	54	43.64	13.90	43.64	12.42	*ns*	37.89	16.24	**46.91**	11.20	.00
Practice required	3	1.44	0.75	1.52	0.77	*ns*	1.63	0.84	1.35	0.70	.00
Word recalled	3	2.62	0.67	2.55	0.75	*ns*	2.48	0.75	2.70	0.59	.01
Language						***ns***					**.00**
Picture naming	14	11.32	2.67	11.30	2.46	*ns*	10.71	3.14	11.69	2.21	.00
Sentence construction	8	7.06	1.73	7.10	1.60	*ns*	6.95	1.96	7.18	1.41	*ns*
Sentence reading (accuracy)	42	38.88	7.33	37.67	8.31	*ns*	38.07	8.56	39.04	7.08	*ns*
Nonword reading (accuracy)	6	4.58	1.83	4.59	1.91	*ns*	3.86	2.15	**4.92**	1.53	*ns*
Word writing	5	3.24	1.63	3.19	1.73	*ns*	2.80	1.77	**3.48**	1.53	.00
Comprehension	3	2.91	0.30	2.88	0.35	*ns*	2.87	0.36	2.93	0.26	*ns*
Memory						***ns***					**.00**
Personal info	8	7.66	0.99	7.59	1.00	*ns*	7.35	1.42	**7.83**	0.52	.00
Time and space	6	5.62	0.79	5.55	0.84	*ns*	5.61	0.94	5.62	0.69	*ns*
Immediate free recall	15	6.52	3.23	6.16	3.13	*ns*	5.72	3.17	**7.18**	3.15	.00
Immediate recognition	15	12.26	2.85	11.92	3.04	*ns*	11.73	3.27	12.71	2.35	.00
Delayed free recall	15	7.32	4.16	6.45	4.03	.021	6.18	4.37	**7.99**	3.80	.00
Delayed recognition	15	12.96	2.84	12.53	2.92	*ns*	12.27	3.47	**13.34**	2.34	.00
Task recognition	10	8.64	1.89	8.33	1.99	*ns*	8.31	1.97	8.83	1.60	.01
Number						***ns***					**.00**
Number reading	9	7.60	2.51	7.35	2.76	*ns*	6.70	3.29	**8.09**	1.83	.00
Number writing	5	3.89	1.63	3.68	1.74	*ns*	3.39	1.93	**4.25**	1.20	.00
Calculation	4	2.54	1.39	2.37	1.45	*ns*	2.25	1.50	2.71	1.27	.00
Praxis						**.017**					**.00**
Multiple object use	12	10.20	3.28	10.15	3.42	*ns*	9.82	3.78	10.15	3.08	*ns*
Gesture production	12	10.43	2.57	10.55	2.44	*ns*	9.26	3.44	**11.09**	1.43	.00
Gesture recognition	6	5.02	1.19	4.90	1.21	*ns*	4.65	1.44	**5.22**	0.98	.00
Gesture imitation	12	9.44	2.74	9.05	3.09	*ns*	8.86	3.11	9.74	2.47	.00
Figure copy	47	34.86	11.19	32.06	12.79	.007	35.22	11.23	33.79	11.54	*ns*

Note. LHD = left hemisphere damage; RHD = right hemisphere damaged; Max. = maximum; abs = absolute difference in the number of critical items cancelled.
[a] Statistical significance at the domain level (in bold) refers to the multivariate statistics; at task level, it refers to between-subjects effects (nonsignificant at the .05 level). [b] Figures in bold and underlined are the scores showing significantly better performance (i.e., higher scores, except for the cancellation asymmetry scores and the auditory attention number of practice required [task names in italic—these are error-based scores for which the lower the score, the better the performance]). [c] Page-based asymmetry score for the cancellation task indicates extent of egocentric neglect; object-based asymmetry score indicates allocentric neglect.
[**] Significant at the .002 level.

poorly than the LHD patients on the cancellation task (overall scores and lateralized error scores) and on the left visual and tactile extinction tasks (all *p*s $\leq .001$); individuals with LHD were more impaired in the right tactile extinction task ($p < .001$).

The LHD and RHD groups showed comparable extents of recovery (see Table 4; (significant reduction of impairment in four of 32 measures for LHD patients and six of 32 measures for RHD patients). However, the LHD and RHD groups did differ in which specific tasks and domains improved (see Table 4). Some of these differential patterns of recovery can be explained by the higher initial rates of impairment in some tasks, leading to a higher probability of performance improvement (e.g., left visual extinction for RHD vs. LHD patients). However, this was not the case for the sentence construction task, the rule finding and switching task, or the mutiple object use test task, on which in each instance, both groups started with similar rates of impairment, but only the RHD group showed significant recovery; also, the RHD group was less impaired initially at imitation but showed greater improvement.

Table 4
Comparison of Percentages of Impairments Across Assessments in Each Measure Between Groups of Different Stroke History and Different Lesion Sides

	First stroke (n = 240)			Repeated stroke (n = 91)			LHD (n = 76)			RHD (n = 108)		
Domain and measure	Initial	F/U	p[a]	Initial	F/U	p[a]	Initial	F/U	p[a]	Initial	F/U	p[a]
Attention												
Spatial												
Cancellation accuracy	32.80	27.50	*ns*	31.6	20.3	.035	19.70	21.20	*ns*	44.10	36.60	*ns*
Page-based asymmetry (abs)	26.50	18.60	.029	27.8	21.5	*ns*	13.60	15.20	*ns*	38.70	25.80	.043
Object-based asymmetry (abs)	24.90	15.60	.004	17.7	12.7	*ns*	15.20	6.10	*ns*	35.10	24.50	*ns*
Left visual bilateral	20.20	14.20	.016	18.2	10.2	*ns*	5.50	2.70	*ns*	33.60	21.50	.001**
Left tactile bilateral	19.50	13.00	.003	15.6	12.2	*ns*	4.20	2.80	*ns*	32.10	22.60	.013
Right visual bilateral	13.70	8.20	.024	10.2	12.5	*ns*	19.20	9.60	.039	7.50	4.70	*ns*
Right tactile bilateral	13.00	5.20	.001**	12.2	6.7	*ns*	26.80	9.90	.004	5.70	1.90	*ns*
Controlled												
Rule finding and switching	41.00	24.80	.000**	41.7	32.1	*ns*	37.70	26.10	*ns*	38.20	21.60	.002**
Auditory attention accuracy	41.50	28.60	.000**	51.2	32.6	.005	57.40	32.40	.000**	32.40	24.80	*ns*
Practice required	25.90	21.40	*ns*	37.2	16.3	.001**	35.30	32.40	*ns*	20.00	16.20	*ns*
Word recalled	22.00	8.10	.000**	22.4	15.3	*ns*	30.90	11.80	.004	19.00	6.70	.002**
Language												
Picture naming	25.70	16.50	.000**	23.1	14.3	*ns*	41.90	24.30	.001**	13.90	12.00	*ns*
Sentence construction	27.80	9.70	.000**	25	15.9	*ns*	26.20	12.30	.022	28.70	6.50	.000**
Sentence reading (accuracy)	43.90	35.90	.008	50	34.9	.004	52.90	48.50	*ns*	38.30	26.20	.011
Nonword reading (accuracy)	29.70	22.70	.011	22.6	7.1	.001**	48.50	35.50	.022	19.60	15.00	*ns*
Word writing	28.50	19.90	.001**	26.7	23.3	*ns*	43.50	31.90	.039	20.00	13.00	*ns*
Comprehension	11.80	4.60	.002**	7.7	2.2	*ns*	14.70	9.30	*ns*	9.30	0.90	.004
Memory												
Personal info	20.80	14.80	.034	17.8	11.1	*ns*	35.60	19.20	.002**	11.20	12.10	*ns*
Time and space	24.70	13.40	.000**	20.9	16.5	*ns*	25.30	13.30	.049	20.40	11.10	.041
Immediate free recall	25.60	17.20	.011	28.2	18.8	*ns*	30.50	22.00	*ns*	17.50	8.70	.035
Immediate recognition	32.40	26.10	*ns*	30.0	31.1	*ns*	48.70	32.90	.012	20.60	19.60	*ns*
Delayed free recall	26.40	24.00	*ns*	30.6	28.2	*ns*	36.70	31.70	*ns*	16.00	17.00	*ns*
Delayed recognition	27.00	22.60	*ns*	27.8	24.4	*ns*	42.30	32.40	*ns*	14.30	12.40	*ns*
Task recognition	24.60	13.00	.000**	25.6	14.6	.022	30.20	20.60	*ns*	15.30	5.10	.021
Number												
Number reading	23.60	12.30	.000**	20.9	7.0	.000**	33.30	16.70	.007	15.50	8.70	*ns*
Number writing	28.40	18.00	.000**	30.7	19.3	.041	42.90	24.30	.000**	18.60	14.70	*ns*
Calculation	23.30	13.50	.001**	22.2	13.0	*ns*	34.90	18.60	.016	18.30	10.00	*ns*
Praxis												
Multiple object use	22.80	10.50	.000**	15.7	5.6	.022	26.00	12.30	.006	24.50	7.80	.000**
Gesture production	15.40	11.10	*ns*	10.0	5.6	*ns*	29.30	18.70	*ns*	2.90	3.80	*ns*
Gesture recognition	14.70	10.30	*ns*	12.2	15.6	*ns*	25.70	17.60	*ns*	7.70	4.80	*ns*
Gesture imitation	30.20	16.80	.000**	29.2	13.5	.003	38.40	24.70	.031	25.70	9.50	.002**
Figure copy	53.00	42.00	.004	51.8	31.8	.000**	52.90	41.40	*ns*	59.00	45.00	.029

Note. LHD = left hemisphere damage; RHD = right hemisphere damage; F/U = follow-up; abs = absolute difference in the number of critical items cancelled.
[a] McNemar test.
** Significant at the .002 level.

Part 2: Cognitive Predictors of Functional Recovery in First-Stroke Patients

There was a trend for follow-up patients to have more years in education (mean difference = 0.6, p = .022) and to be more depressed than those not followed up (p = .017, *ns* corrected; see Table 2). No other significant differences were found on the demographic, initial functional, and affective characteristics of the groups. Concerning the initial cognitive profile, no significant difference was found between the follow-up and non-follow-up groups.

Using as predictors the overall cognitive impairment at initial assessment (here the proportion of tasks impaired) and controlling for the initial Barthel score, follow-up HADS scores and follow-up apathy scores, the proportion of BCoS tasks impaired was a significant predicting factor for the NEADL score, $B = -3.47$, $SE = 1.22$, $\beta = -0.173$, $p = .005$; see Table 5).

We then used as a predictor a domain level diagnosis: *impaired*, when performance on any one task was impaired or not completed within a domain, versus *not impaired*, when performance was unimpaired on all tasks within a domain (see Table 6). Three domains were significant predictors of the NEADL score: spatial attention ($\lambda = .920$, $p = .001$), controlled attention ($\lambda = .959$, $p = .036$), and praxis ($\lambda = .919$, $p = .001$). No predictors were found for the follow-up Barthel scores.

Part 3: The Importance of Co-occurring Deficits. Long-term performance in the important domains of language and spatial attention could be better predicted when tests sensitive to cross-domain processes (sustained attention, executive function)

Table 5
Multivariate Linear Regression Models for Effects of Physical, Affective, and Cognitive Performance on Functional Outcomes

Model	*B*	*SE*	95% CI	*p*
1 (outcome = Barthel follow-up)				
Barthel	0.36	0.05	[0.264, 0.456]	.000
Anxiety follow-up	−0.02	0.07	[−0.155, 0.121]	.806
Depression follow-up	−0.17	0.10	[−0.364, 0.022]	.081
Apathy	−0.05	0.03	[−0.108, 0.017]	.149
Proportion of tasks impaired	−0.71	0.86	[−2.403, 0.989]	.411
2 (outcome = NEADL)				
Barthel	0.50	0.07	[0.361, 0.633]	.000
Anxiety follow-up	0.13	0.10	[−0.063, 0.327]	.184
Depression follow-up	−0.40	0.14	[−0.672, −0.127]	.004
Apathy	−0.16	0.05	[−0.248, −0.072]	.000
Proportion of tasks impaired	−3.47	1.22	[−5.866, −1.067]	.005

Note. CI = confidence interval; F/U = follow up; NEADL = Nottingham Extended Activities of Daily Living Scale.

were taken into consideration. For example, picture naming and sentence construction at 9 months were better predicted by taking the initial auditory attention score (including verbal working memory and sustained attention) into account along with initial picture naming ($\beta = 0.023$, 95% CI [0.006, 0.040], $p = .01$) and sentence construction ($\beta = 0.013$, 95% CI [0.004, 0.022], $p = .005$). As an index of spatial attention, cancellation accuracy at 9 months was better predicted when taking into account the initial executive function score ($\beta = 0.214$, 95% CI [0.049, 0.378], $p = .011$) along with the initial cancellation task; whereas reductions in cancellation asymmetry (neglect) were better explained by including the initial auditory attention score ($\beta = 0.039$, 95% CI [0.007, 0.070], $p = .018$) alongside the first measure of cancellation asymmetry. The measures of working memory, sustained attention, and response inhibition (assessed in the auditory attention task) and executive function (assessed in the rule finding and switching test from the BCoS) led to better prediction of longer term language and spatial attention problems. There was also better prediction for the NEADL. For example, the praxis domain was linked to the NEADL (see Part 2), but the variance accounted for increased when the attention domains were considered (R^2 increased reliably by 7.5%, $p < .001$, to 55.5%). These data are consistent with the argument that cognitive profiling, taking measures of attention and executive function into account, can add to predictions from single deficits alone.

Table 6
Generalized Linear Modeling of Domain Effects on Long-Term Everyday Functions, Controlling for Initial Barthel Scores, Follow-up Affect, and Apathy Level

Multivariate domain and measure	Wilks's lambda	*p*	η	Power
Spatial attention	.920	.001	.080	.917
Barthel follow-up		*ns*		
NEADL		.003	.072	.930
Controlled attention	.959	.036	.041	.631
Barthel follow-up		*ns*		
NEADL		.035	.028	.560
Language	.978	*ns*	.022	.370
Barthel follow-up		*ns*		
NEADL		*ns*		
Memory	.984	*ns*	.016	.279
Barthel follow-up		*ns*		
NEADL		*ns*		
Number	.971	*ns*	.029	.471
Barthel follow-up		*ns*		
NEADL		*ns*		
Praxis	.919	.001	.081	.922
follow-up		*ns*		
NEADL		.001	.063	.898

Note. All effects are between subjects. NEADL = Nottingham Extended Activities of Daily Living Scale.

Discussion

The BCoS provides a cognitive screen for stroke that is relatively time efficient (completed in around 1 hr) and inclusive (90% of patients tested at a subacute stage were able to complete >75% of the tests). The high inclusion rate is facilitated by the tests being designed to be aphasia and neglect friendly. The BCoS also provides a novel cognitive profile for patients—covering language, memory, number processing, praxis, and spatial and controlled attention—that can be easily reported to clinicians (see the Appendix).

Our results indicate that there were differential effects of (a) whether patients had suffered their first stroke or had a repeat stroke and (b) whether the stroke affected the left or right hemisphere; results also indicate that (c) overall cognitive performance predicted outcome at 9 months, taking into account the initial functional performance score (the Barthel index) and affective characteristics (depression, anxiety, and apathy measures). In addition, predictions of the cognitive and functional abilities of patients improved when performance on domain-general processes (attention and executive functions) were taken into account in addition to performance in single domains. We consider each point in turn.

First Versus Repeat Stroke

There were no reliable differences in overall cognitive performance in patients who suffered their first stroke relative to those who had a prior history of stroke, and for all patients, the spatial attention and verbal memory problems were most persistent (showing fewest gains in terms of the patients who were impaired at follow-up compared with the initial test). There were interesting differences, however, in the numbers of patients who did and did not show recovery. In particular, more first-stroke patients went from an impaired to a nonimpaired category relative to patients with repeat strokes. This was not because of initial differences in task performance, overall physical function (Barthel index), or age (the groups did not differ on any of these variables). There was also no difference in the initial time of testing between patients who did and those who did not show recovery, $t(329) = 0.485$, $p = .612$, and the recovering and the nonrecovering patients did not differ in their initial affect: anxiety, $t(311) = -0.967$; depression, $t(311) = -0.293$. This last result means that the lack of recovery after repeat stroke is unlikely to reflect purely motivational factors. One alternative account is that neural plasticity decreases after there has been an earlier neurological insult. This speculative proposal requires further verification in experimental models; however, it does fit with the relatively high incidence of dementia that can arise after stroke (Narasimhalu et al., 2009).

LHD Versus RHD

Overall, patients with unilateral LHD fared worse than patients with a unilateral RHD. At a domain level, the LHD patients were worse on the language, memory, number, and praxis tests, with the opposite pattern present only for spatial attention. It can be argued that many of these tests required language and communication abilities (language, praxis, and number tests), and this was also the case for memory given that the BCoS features a verbal long-term memory task (though forced-choice tests are used to assess recognition memory). Indeed, many of the tests not showing a reliable contrast between LHD and RHD patients (rule finding and switching task, multiple object use, and figure copy) were putatively less language demanding. The RHD patients were impaired across a range of spatial attention tasks testing neglect and extinction, consistent with the right hemisphere playing a dominant role in controlling human attention (Corbetta & Shulman, 2002).

It is interesting to note that though the LHD and RHD patients were both impaired on the rule finding and shifting task and the multiple object use task, only the RHD patients showed significant recovery of function. The recovery of the patients on the rule finding and shifting task correlated with recovery in neglect, $\chi^2(df = 1, N = 282) = 7.297$, $p = .007$, but this was not the case for the multiple object use task, $\chi^2(df = 1, N = 323) = 0.195$, $p = .659$. If recovery based on reductions in neglect is implausible for the multiple object use task, then an alternative possibility is that, for this task, the presence of relatively spared language abilities in the RHD group enabled them to improve by using a verbal record of the actions carried out (Bickerton, Humphreys, & Riddoch, 2006). One result consistent with this is that the patients who improved on the rule and multiple object tasks tended to have better language functions than did those who did not improve, $t(71) = 3.320$, $p = .002$, and $t(63) = 2.516$, $p = 0017$, for picture naming and sentence construction, respectively.

Predicting Functional Outcome

Previous studies have indicated that functional outcomes can be accounted for by measures of cognitive deficits (Nys et al., 2006). Similar to these studies, we demonstrated that an easy-to-derive index from the BCoS, the number of subtests on which an impairment was detected, predicted our primary outcome measure of function at 9 months—scores on the NEADL. The lack of significant findings relating to the follow-up Barthel index was attributable to a lack of variance in the follow-up Barthel scores given that a large proportion of patients achieved maximum Barthel score at 9 months. Predictions from the BCoS occurred over and above effects attributable to neuropsychiatric symptoms (depression, anxiety, and apathy) and both initial and longer term motor impairment (Barthel index). The domains that were most effective for capturing the NEADL were spatial attention, controlled attention, and praxis (see Table 6). It is interesting that few other general screens for cognitive problems (e.g., the MOCA the ACE-III, the RBANS) provide specific measures of spatial attention and praxis, and none (to our knowledge) capture the conjoint effects of working memory, selective attention, and sustained attention as does the auditory attention task here. Indeed, measures of important cognitive functions such as picture naming, sentence comprehension, and spatial neglect improved when cross-domain assessments of sustained attention, working memory, and executive functions (controlled attention) were taken into account. The finding that deficits in controlled attention predict functional outcome is also of interest, because models of cognition suppose that aspects of controlled attention tests interact with other processes to support different cognitive abilities. For example, working memory and sustained attention are important to support processes ranging from scanning the environment to sentence comprehension and production (Francis, Clark, & Humphreys, 2003; Malhotra et al., 2005), whereas attentional suppression (e.g., affecting the ability to ignore irrelevant stimuli) may facilitate multiple tasks on which distractors are present (Morady & Humphreys, 2011). The data here point to the utility of using a battery such as the BCoS, which derives a cognitive profile including measures of working memory, sustained attention, and executive function. This, coupled with the inclusivity of the battery (e.g., for aphasic and neglect patients) and the sensitivity to important clinical impairments after stroke (e.g., apraxia; Koski, Iacoboni, & Mazziotta, 2002) and neglect (Bowen, McKenna, & Tallis, 1999), affirms the BCoS's potential benefit to stroke care. We also note the utility of the easy clinical reporting scheme for the BCoS, as illustrated by Bisiker and Bickerton's (2013) clinical example.

Limitations of the Study

We note several limitations to the study.

One is that we did not include vascular risk factors in our analysis because such factors have been shown to affect cognitive abilities in stroke-free cohorts (Unverzagt et al., 2011). To improve the validity of our analysis, we also excluded individuals who could not complete the majority of the tasks. Although this last step could potentially induce a selection bias, only 10% of the participants were excluded, and so the effect of this exclusion should be small. This also demonstrates that the BCoS is indeed highly accessible for individuals at a subacute stage of recovery.

A second limitation is that patients with a second stroke were tested earlier on the initial screen than were patients with a first stroke. One possibility is that the tendency for the second-stroke patients to be more depressed led to the clinical teams alerting testers to the patients earlier. However, the earlier testing appears to have had little impact on the results, because the initial levels of cognitive deficits did not differ.

A third limitation concerns dropout. As is common in stroke research, the loss to follow-up was substantial. However, we have shown (see Table 2) that there were no major demographic or cognitive differences across the group that was followed up and the group that was not. Hence, it is unlikely that the study missed out the more severe cases at follow-up. Nevertheless, further research should include more thorough assessment of additional clinical factors and patients' efforts to engage, which might have an impact on cognitive assessment and recovery. As the most widely used cognitive screen measures (e.g., the MMSE, the MoCA) are shorter and less informative than the BCoS, it would also be interesting to formally compare the clinical utility of the BCoS with a non-stroke-specific cognitive screen of similar length—for example, the RBANS.

Conclusion

Early identification of specific and interacting poststroke cognitive deficits would help predict outcomes and inform timely interventions. This study demonstrates how the BCoS can contribute by being an aphasic- and neglect-friendly, domain-specific, and efficient assessment for differential cognitive profiles across patient groups.

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(*Appendix follows*)

Appendix

The Structure and Descriptions of the BCoS Tasks

Test domain	Test	Description	Measures
Attention and executive function	Auditory attention	Remember and respond to occurrences of three word targets while ignoring three related distractor words across three blocks of trials	Working memory, response inhibition, sustained attention
	Rule finding and switching	Find a rule in a visual pattern across trials and switch the rule when it changes	Rule finding and set shifting
	Apple cancellation	Cancel full apples and ignore broken apple distractors	Egocentric and allocentric neglect
	Visual extinction	Detection of one or two visual targets (finger movements by tester)	Neglect (unilateral trials) and extinction (bilateral trials)
	Tactile extinction	Detection of one or two tactile targets (finger touch by testers)	Neglect (unilateral trials) and extinction (bilateral trials)
Language	Picture naming	Name low drawings with low-frequency names	Object recognition and naming
	Sentence construction	Generate a sentence to describe a picture	Syntactic and semantic aspects of speech production
	Instruction comprehension	Clinical judgment of the ability to understand task instructions	Qualitative measures of verbal comprehension
	Sentence reading	Reading sentences aloud, including exception words, regular words, and function words	Different forms of dyslexia
	Read nonwords	Reading nonwords	Phonological dyslexia
	Write words and nonwords	Writing irregular words and nonwords	Different forms of dysgraphia
Memory	Orientation	Understanding time and place	Memory for current circumstances
	Story recall and recognition	Recall and recognition of a story immediately and after a delay	Immediate and delayed recall and recognition (verbal)
	Task recall and recognition	Recall and recognition of stimuli from tasks performed	Immediate and delayed recall and recognition (nonverbal)
Number processing	Number/price/time reading	Read numbers, prices, clock times	Correct parsing and verbal production of numbers
	Number/price writing	Write numbers, prices	Correct parsing and written production of numbers
	Calculation	Calculate additions, subtractions, multiplication, division	Basic math abilities
Praxis	Complex figure copy	Copy a complex figure	Constructional apraxia
	Multistep object use	Carry out a multistep task with objects while ignoring distractor objects	Everyday action object selection, step production, perseveration
	Gesture production	Produce familiar gestures to names	Gesture production for transitive and intransitive actions
	Gesture recognition	Identify familiar gestures produced by the tester	Gesture recognition for transitive and intransitive actions
	Imitation	Copy meaningless gestures produced by the tester	Gesture imitation

Note. BCoS = Birmingham Cognitive Screen.

Received April 9, 2014
Revision received September 12, 2014
Accepted October 10, 2014 ■