The Northwick Park Examination of Cognition (NPEC): a brief cognitive assessment tool for use in acute stroke services

Original Research Article

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Keywords: stroke; executive function; language; episodic memory; perception

Abbreviations

ACE-R: Addenbrooke's Cognitive Examination, Revised

AUC: Area under curve

CT: Computed Tomography

HASU: Hyper Acute Stroke Unit

MMSE: Mini Mental State Examination

MoCA: Montreal Cognitive Assessment

MRI: Magnetic Resonance Imaging

NPEC: Northwick Park Examination of Cognition

RBANS: Repeatable Battery for the Assessment of Neuropsychological Status

ROC: Receiver Operating Curve

TIA: Transient Ischaemic Attack

VESPAR: Verbal and Spatial Reasoning Test

Abstract

Background and Objective: Assessment of cognitive impairment following stroke forms an important part of diagnosis, treatment and rehabilitation planning. However, none of the available and widely-used tools were developed specifically for use in stroke services. Most screening tools were developed for dementia, and consequently are biased toward evaluation of memory function, provide inadequate assessment of executive function and are mainly verbally administered, limiting their utility in aphasic patients.

Methods: 166 stroke patients admitted to a hyper acute stroke unit and 100 controls completed the Northwick Park Examination of Cognition (NPEC). The NPEC includes 22 subtests in the domains of reasoning, episodic memory, language, perception and attention/executive function. Multiple input (verbal, visual) and output (spoken, written, gesture) modalities increase accessibility to patients with various deficits/lesion locations.

Results: Mean time from stroke to assessment was 5.6 days (SD=7.9). 75% of patients gained impaired scores (mild, moderate or severe impairment), evident at the group level on all subtests. Left and right cortical stroke patients differed significantly ($P<0.05$) on specific verbal (R>L) and spatial attention (L>R) subtests. Sensitivity and specificity for the detection of cognitive impairment (sensitivity=0.90; specificity=0.80; area-under-curve [AUC]=0.93) were equivalent or superior to data reported for established cognitive screening tools (AUC=0.53-0.89). Patients were disproportionately impaired on high-vs-low attentional-demand cancellation tasks ($P<0.0001$).

Conclusions: The NPEC is brief, freely-available and has good sensitivity and specificity for differentiating stroke patients from controls in terms of cognitive functioning. The inclusion of timed executive function measures and comparable verbal and nonverbal subtests permits characterisation of cognitive dysfunction in different stroke subtypes.

Keywords: stroke; executive function; language; episodic memory; perception

Introduction

Identifying cognitive impairments following stroke is a critical step in the creation of appropriate, effective, person-centred treatment and rehabilitation plans for patients. Early cognitive assessment is also endorsed by national professional and regulatory bodies (National Institute for Health and Clinical Excellence, 2010; Royal College of Physicians, 2008). However, no cognitive brief assessment tools have been designed specifically for the purpose of assessing stroke patients in the acute phase, with clinicians typically relying on measures designed for use in dementia screening. This project aimed to develop a brief cognitive assessment tool that was designed specifically for use in a hyper acute/acute stroke in-patient setting.

A number of screening tools for cognitive impairment are available (e.g. Mini-Mental State Examination [MMSE], Folstein et al., 1975; Montreal Cognitive Assessment [MoCA], Nasreddine et al., 2005; Addenbrooke's Cognitive Examination Revised [ACE-R], Mioshi et al., 2005; Repeatable Battery for Assessment of Neuropsychological Status [RBANS], Randolph et al., 1998). However the utility of these tools in patients with acute stroke is limited by the fact that they were all developed in non-stroke settings (e.g. dementia services, general neuropsychiatry) and because most questions and responses require speech and language skills that are impaired in many stroke patients. For example, many tasks are administered verbally (e.g. "what were those three words I asked you to remember?") which may not be optimal for individuals with expressive dysphasia following a left hemisphere stroke (e.g. who may remember the items but not be able to express them). The diversity of post-stroke cognitive and sensorimotor impairments means that no set of screening tests could have optimal validity for all stroke patients. However the current study attempts to improve task appropriateness by including verbal and non-verbal subtests within certain cognitive domains (e.g. verbal and visual memory), and where possible presenting items and accepting responses in multiple modalities (e.g. spoken/written/pictorial/gestural).

A small number of studies have explored the utility of non-stroke-specific cognitive assessment tools within acute or chronic stroke populations. Some studies suggest that the MoCA is more sensitive

than the MMSE to post-stroke cognitive impairment (Nys et al., 200; Pendlebury et al., 2010), whilst others cast doubt upon this claim (Godefroy et al., 2011) or question recommended cut-off scores (Rossetti et al., 2011). A direct comparison of the MMSE, MoCA and ACE-R in detecting cognitive impairment in patients >1 year post-stroke/TIA revealed greatest sensitivity and specificity for the MoCA and ACE-R and ceiling effects in the MMSE (Pendlebury et al., 2012). However, the authors noted that both the MoCA and ACE-R were better at detecting amnestic than non-amnestic mild cognitive impairment, perhaps reflecting both a lack of timed measures of processing speed and a concentration on measuring memory function owing to both tasks' origins within dementia rather than stroke clinical services.

The current study describes a new, freely available brief assessment tool, the Northwick Park Examination of Cognition (NPEC), in a consecutive series of patients admitted to a busy London hyper acute stroke service. The NPEC provides brief assessments of memory, language, perception, and executive/reasoning functions. The NPEC was designed to be a stroke-specific equivalent of the widely used and effective ACE-R cognitive assessment tool for dementia. The NPEC was designed as a 100-point test which takes approximately 30 minutes to administer, and so is more detailed than brief 30-point measures such as the MoCA and MMSE but nonetheless more simple and brief than formal neuropsychometry so that it can be administered at the bedside by multidisciplinary staff. By including both verbal and non-verbal components, the NPEC is designed to enable clinicians to identify rapidly not only cognitive impairments but also preserved cognitive skills that might otherwise be masked by collateral deficits. Consequently the NPEC is designed to be appropriate and accessible for individuals with strokes of varying severity and location.

Methods

Participants

A pilot version of the NPEC was administered to 131 stroke patients between July and December 2010. Pilot data was used to evaluate and revise individual subtests and to generate speed and

accuracy cut-off scores for the timed measures of attention and executive function. The revised version of the NPEC was considered for use with a non-consecutive series of 191 patients evaluated for possible cognitive impairment by ward-based psychologists during admission to the Hyper Acute Stroke Unit (HASU) between January and September 2011. Patients underwent clinical, neuroradiological (CT, MRI) and laboratory investigation, with additional psychology, physiotherapy, occupational therapy, speech and language therapy and dietetic review as indicated by the initial clinical examination. Diagnosis was made by the consultant stroke physician (JD, RB or DC) using all available clinical information.

Patients admitted to the stroke unit were not administered the NPEC if they were judged to have inadequate levels of attention and alertness during an informal pre-assessment interview and it was deemed to be inappropriate. Patients with a prior medical history suggestive of dementia were also not administered the task. Of the 191 patients reviewed by the psychology team, 25 were excluded from the current analysis because they did not have a clinical diagnosis of stroke . Of the remaining 166 stroke patients, 77 (46%) had a left hemisphere stroke, 81 (49%) had a right hemisphere stroke, and 8 (5%) showed bilateral damage. Thirty-six (22%) patients showed evidence of primary subcortical involvement, 11 (7%) cerebellar involvement and 17 (10%) of those assessed showed evidence of a previous stroke. A subset of 106 patients with a first unilateral cortical stroke (no prominent subcortical or cerebellar involvement or evidence of previous stroke) were selected for subsequent subgroup comparison (52 left and 54 right hemisphere). Although patients with previous stroke or dementia were excluded from this analysis, some pre-existing cognitive impairment cannot be ruled out, and this reflects real life practice on most stroke units.

One hundred healthy control participants were also administered the revised NPEC. Control participants were recruited from among relatives and friends visiting the HASU (N=32) and from an established research volunteer database (N=68). Participants with a history of cognitive or neurological dysfunction were excluded. Demographic information on patients (whole sample and subgroups) and controls are shown in Table 1.

- insert Table 1 about here -

Test materials: Northwick Park Examination of Cognition (NPEC)

The NPEC is a cognitive assessment tool developed for use on a hyper acute stroke unit. The assessment comprises 22 subtests, has a maximum score of 100 points, and yields subtotal scores corresponding to the 5 cognitive domains of orientation (5 points), reasoning/executive function (15 points), memory (20 points), language (25 points) and perception (16 points; see Supplementary Material). Where possible, tasks were designed to include independent verbal and non-verbal forms and multiple response options (spoken, written, pointing) to increase opportunities for the meaningful assessment of patients both with acquired language and acquired visual deficits. The orientation component probes awareness of time and place. The reasoning component comprised verbal and non-verbal odd-one-out judgements drawn from the Verbal and Spatial Reasoning test (VESPAR; Langdon and Warrington, 1995) and dual number cancellation tests of selective and sustained attention adapted from the Ruff 2 & 7 test (Ruff and Allen, 1996). The memory component comprised immediate and delayed recognition of words and faces. The language component consisted of naming (to confrontation/verbal description), comprehension (word-picture matching and commands), repetition (word, sentence and cliché), reading (single word and text) and spelling. The perception component consisted of figure copying of a diamond and exploded pyramid, fragmented letter identification (from the Queen Square Screening Test for Cognitive Deficits; Warrington, 1989), dot counting, and circle cancellation. Additional tests of short term memory (auditory-verbal and spatial span, adapted from the Corsi blocks test; Corsi, 1982), calculation (auditory and visual multiple choice), praxis (verbal and visual command), and verbal fluency (words beginning with P, animals) were also administered. Raw scores were used for the majority of subtests. Adapted raw scores were used for span, naming, repetition, reading and spelling subtests. Scalar scores based on performance of a pilot patient sample were employed for verbal fluency, circle cancellation and dual number cancellation tasks based on accuracy (fluency) or a combination of accuracy and speed (cancellation). Administration takes approximately 30 minutes.

Group and subgroup comparisons of total, subtotal and subtest scores were conducted using Wilcoxon rank-sum tests. A receiver operating characteristic (ROC) function was used to plot the relationship between sensitivity (true positive rate) and 1-specificity (false positive rate). For the analysis of cancellation task performance, a corrected time measure was generated for every participant by calculating the mean time for each detected target (mean detection time = uncorrected total time/number of targets detected) and then adding the mean detection time for each target missed (corrected total time = uncorrected total time + (n x Mean detection time), where n is the number of missed targets). Group, task and interaction effects upon these corrected time measures were explored using analysis of variance (ANOVA).

Results

Wilcoxon rank-sum tests revealed that patients and controls did not differ significantly in age ($z = 0.38$, $P > 0.7$) or handedness ($\chi^2_{[1]} = 0.27$, $P > 0.6$) but there was a lower proportion of men in the control group ($\chi^2_{[1]} = 40.8$, $P<0.001$). However, comparison of the performance of male and female participants revealed no effect of gender upon NPEC total score among either controls ($z = 1.04$, $P = 0.3$) or patients ($z = 0.6$, $P > 0.5$). The left and right cortical stroke patient groups did not differ in gender, age, handedness or time to assessment.

The mean and standard scores achieved by all stroke patients, the left and right cortical stroke subgroups, and the healthy controls on each subtest of the NPEC, together with their total and subtotal scores, are shown in Table 2. At the group level, scores were significantly lower in the stroke patients than the controls on all measures. Comparing patients with left and right cortical stroke, patients with left cortical stroke were significantly more impaired than patients with right cortical stroke on a number of verbal tasks (verbal reasoning, immediate verbal memory, digit span, naming and verbal fluency). These differences yielded significantly lower scores on the NPEC total score and on the language subtotal score, but there were no significant differences between patient subgroups on the memory, perception or executive subtotal scores. By contrast, the right cortical

subgroup scored significantly lower than the left cortical subgroup on the circle cancellation test of spatial attention. The magnitude of differences between the left and right cortical subgroups are likely underestimates of the true value of differences owing to the probability of a proportion of the patients having an atypical pattern of hemispheric dominance.

- insert Table 2 about here -

Cut-off scores: Cut-off scores and categorisations of performance level were generated from the normative data sample. For the NPEC total and subtotals, scores were classified into 5 bands: normal range (>25th percentile), weak (5-25th percentile), mildly impaired (1-5th percentile), moderately impaired (top 50% of patient scores falling below the lowest control score) and severely impaired (bottom 50% of patient scores falling below the lowest control score). The percentages of participants scoring within each performance band on the total NPEC score and each subtotal score are shown in Figure 1. Similar classifications were generated for the 22 individual subtests. However, owing to the distribution and clustering of control scores on some measures, a more coarse-grain tripartite classification procedure was employed to describe performance on individual subtests: normal range (>10-20th percentile), weak (<10-20th percentile), and impaired (<lowest control score). These classifications were incorporated into a semi-automated report writing algorithm, with individual test and total/subtotal scores automatically classified and total/subtotal scores presented as a line graph to illustrate an individual's cognitive profile across the different domains tested.

- insert Figure 1 about here -

Sensitivity and specificity: Examination of the sensitivity and specificity of the NPEC for detecting post-stroke cognitive impairment was limited by the fact that not all strokes result in cognitive deficits. Nonetheless in the absence of a reliable stroke-specific comparator cognitive test, the clinical diagnosis of stroke was used as the distinguishing factor to determine the criterion validity of the NPEC for detecting cognitive impairment following stroke. A receiver operating characteristic (ROC) function plotting the relationship between sensitivity (true positive rate) and 1-specificity (false positive rate) is shown in Figure 2. The area under the ROC curve is 0.93 (95% CI 0.91-0.96),

which suggests that the NPEC has high specificity and sensitivity for detecting cognitive impairment following stroke. The optimum cut-off score for maximising the correct classification of patients and controls was a total NPEC score of <91/100 (87% classification accuracy). However a lower cut-off of <81/100 provided 100% specificity for cognitive impairment following stroke, though with poorer sensitivity (54%) to potentially milder yet still clinically significant profiles of impairment. A range of other sensitivity, specificity and classification rates intermediate to these two extreme cut-offs and corresponding to standard percentile-defined levels of control performance (20^{th}, 10^{th}, 5^{th} and 1^{st} percentiles) are shown in Table 3. These values may represent an underestimate of the true sensitivity and specificity of the NPEC for detecting post-stroke cognitive impairment as not all strokes result in cognitive deficits.

- insert Figure 2 about here -

- insert Table 3 about here -

Cancellation task performance: Performance was compared across the simple circle cancellation task (no distractors) and both components of the number cancellation task: sustained attention (different category distractors [letters]) and selective attention (same category distractors [other numbers]). An ANOVA comparing the circle and combined number cancellation tasks revealed main effects of group ($F(3,418)=94.09$, $P<0.0001$), task ($F=130.95$, $P<0.0001$) and a significant group by task interaction ($F=22.86$, $P<0.0001$). The task effect and interaction appeared to be driven more by the selective than sustained component of the number cancellation task: comparison of circle and sustained attention tasks revealed a group effect ($F(3,418)= 103.71$, $P<0.0001$) but no main effect of task or group by task interaction ($F=0.33$, $P=0.56$ and $F=3.52$, $P=0.06$), whereas comparison of the circle and selective attention tasks showed main effects of group ($F(3,418)=111.76$, $P<0.0001$) and task ($F=13.87$, $P=0.0002$) and a significant group by task interaction ($F=4.36$, $P=0.04$). This group evidence of the increasing attention demands of the three tasks (circle cancellation < sustained attention < selective attention) was reflected at the clinical level in the performance of a number of individual patients, whose spatial attentional problems were not evident on the easiest circle

cancellation tasks but was indicated by a rightward bias on the more attentionally demanding number cancellation tasks (see Figure 3).

- insert Figure 3 about here -

Discussion

The NPEC shows good sensitivity and specificity for differentiating stroke patients from controls in terms of cognitive functioning. Direct comparisons with other studies are difficult given differences in the clinical and demographic profile of participants, clinical service entry procedures and intervals between stroke and assessment. However, NPEC detection rates (sensitivity 0.90, specificity 0.80, AUC 0.93) compare favourably with previously reported data on cognitive impairment rates in acute stroke patients using the MoCA (e.g. sensitivity 0.67, specificity 0.90; AUC 0.89; Godefroy et al., 2011), ACE-R (e.g. sensitivity 0.80, specificity 0.40, AUC 0.53; Morris et al., 2012) and MMSE (sensitivity 0.70, specificity 0.97, AUC 0.88; Godefroy et al., 2011; sensitivity 0.55, specificity 0.60, AUC 0.53; Morris et al., 2012). The NPEC detection rates for cognitive impairment post-stroke may reflect the wide range of cognitive functions tapped by the 22 subtests. Previous studies have particularly highlighted the inadequacy of other screening tools to quantify executive dysfunction; this issue is addressed by the NPEC with 20% of available marks awarded for reasoning and simple, sustained and selective attention. The significant group by task interaction observed for these latter cancellation tasks provides evidence of their capacity to detect both subtle and pronounced impairments of executive function in individual patients.

Several features of the NPEC make the test particularly suitable for use in acute stroke settings. The NPEC is freely available, takes approximately 30 minutes, and can be administered by multidisciplinary staff at the bedside (see Supplementary Material for test material, scoresheets and administration and scoring instructions). Thus the NPEC is more detailed than brief screening tools (it is not designed to be a pocket-test for clinicians) but more feasible to administer on a busy stroke unit than lengthy formal neuropsychological tests. As such, it is particularly aimed at psychologist,

occupational therapist, and speech and language therapist members of the multidisciplinary teams which typically staff most stroke units. The NPEC yields not only total and individual subtest scores, but also composite scores in the domains of memory, language, perception, and reasoning/executive functions. The resulting profiles of cognitive function, illustrated within automated report sheets, provide a structured and consistent framework for helping patients, carers and staff to understand an individual's cognitive deficits and for planning physical and occupational rehabilitation. With continuing pressure to shorten lengths of stay and limitations on recruitment of specialist psychologists this brief assessment meets a need for a tool that can be used by other multidisciplinary staff. It is envisaged that the NPEC would require brief training and minimal supervision from psychologically trained staff around test interpretation, validity, reliability and testing error in order for it to be utilised by other stroke practitioners. A rapid overview of cognitive function may prevent the premature discharge of patients with relatively good physical function but cognitive problems that are not so readily apparent but may limit independence and require further, more comprehensive assessment.

Several limitations of the current study, caveats and areas for further test validation are of note. Performance on the NPEC was assessed as part of routine clinical practice on a busy stroke unit and as such, unsuccessful attempts to assess patients were not recorded. In some cases patients who were initially too unwell to complete the NPEC may have completed it at a later point in their admission. Measures of stroke severity (e.g., NIHSS scores) were not routinely collected at the time of testing, but this may have been a useful way to determine the patients for whom the measure is suitable.

Although not appropriate within the acute stroke setting described in the current study, future studies to further validate the NPEC against formal neuropsychological assessments in chronic stroke patients are warranted. This applies to the validation of the overall test score as a global marker of cognitive impairment, and the validation of individual cognitive subtests (e.g. comparing visual and verbal recognition memory subtests against standardised tests of episodic recall and recognition).

Similarly, direct comparisons of the NPEC with cognitive screening tools not designed specifically for stroke services (e.g. MoCA, RBANS) with a single group of participants will be required to demonstrate formally the utility and value of the new measure. It should also be noted that the NPEC was designed to provide more than a pass/fail cognitive screening measure but is not intended to replace more extensive and expensive formal neuropsychological batteries (e.g. the Birmingham Cognitive Screen; Humphreys et al., 2012) for patients requiring more detailed assessment in the more chronic phase of their illness. The current study is also purely cross-sectional in design, so a further goal will be to establish how effectively NPEC scores in the acute phase predict cognitive outcome at 3-6 months, both in their own right and relative to other non-stroke-specific cognitive assessments (Dong et al., 2012).

Conclusions

The Northwick Park Examination of Cognition (NPEC) is intended as a brief cognitive assessment tool for use in acute stroke services. It is designed to characterise sphere of cognitive dysfunction (i.e. memory, executive functioning, perception etc) and to accommodate multiple assessment input (verbal, visual) and output (spoken, written, gesture) modalities to increase accessibility to patients with varied stroke lesions. The performance of 166 stroke patients admitted to a hyper-acute stroke unit in London was compared with a control sample of 100 healthy participants. Results indicated that the NPEC has good specificity and sensitivity in differentiating stroke from control participants in terms of cognitive functioning, suggesting that the NPEC provides a useful, brief cognitive assessment tool on a busy stroke ward.

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Disclosures

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Table 1. Demographic and basic stroke data on patient and control participants.

	Pilot study patients	NPEC patients			Controls
		All	L cortical	R cortical	
		M (SD)	*M (SD)*	*M (SD)*	
N	131	166	52	54	100
Gender (%male)	61	66	60	67	25
Age	70.4	69.2	68.8	72.1	70.8
	(14.8)	(14.1)	(14.4)	(14.2)	(10.8)
Handedness (%R)	-	93	90	95	91
Time to test (days)	3.5	5.6	5.2	5.2	-
	(3.9)	(7.9)	(6.0)	(7.3)	

Table 2. Mean (and standard deviation) scores for each NPEC subtest, total and subtotal, with group comparisons based on Wilcoxon rank-sum tests.

	Max	Stroke pts	L cortical	R cortical	Controls	SvC	LvC	RvC	LvR
Orientation	5	4.1 (1.2)	3.8 (1.3)	4.2 (1.1)	4.9 (0.4)	***	***	***	ns
Verbal reasoning	5	3.4 (1.2)	3.1 (1.3)	3.7 (1.2)	4.4 (0.8)	***	***	***	* (L<R)
Non verbal reasoning	5	3.6 (1.1)	3.7 (1.1)	3.5 (1.1)	4.5 (0.7)	***	***	***	ns
Immediate visual memory	5	3.9 (1.3)	3.9 (1.2)	3.9 (1.2)	4.8 (0.4)	***	***	***	ns
Immediate verbal memory	5	3.4 (1.4)	2.9 (1.4)	3.6 (1.4)	4.5 (0.7)	***	***	***	* (L<R)
Delayed visual memory	5	3.8 (1.3)	3.9 (1.2)	3.8 (1.3)	4.7 (0.6)	***	***	***	ns
Delayed verbal memory	5	3.3 (1.1)	3.1 (1.3)	3.5 (1.2)	4.3 (0.8)	***	***	***	ns
Digit span	3	1.7 (1.0)	1.4 (1.1)	1.9 (0.8)	2.7 (0.5)	***	***	***	* (L<R)
Spatial span	3	1.9 (0.8)	1.9 (0.9)	2.0 (0.8)	2.2 (0.7)	*	*	*	ns
Naming	8	6.5 (2.4)	5.5 (3.0)	7.2 (1.8)	7.8 (0.7)	***	***	**	* (L<R)
Comprehension	9	7.4 (2.0)	6.8 (2.6)	7.6 (1.6)	8.7 (0.8)	***	***	***	ns
Repetition	3	2.6 (0.9)	2.4 (1.1)	2.7 (0.6)	3.0 (0.0)	***	***	***	ns
Reading	3	2.5 (0.9)	2.3 (1.1)	2.6 (0.7)	2.9 (0.2)	***	***	***	ns
Spelling	2	1.5 (0.8)	1.4 (0.9)	1.6 (0.7)	2.0 (0.2)	***	***	***	ns
Calculation	3	2.5 (0.8)	2.3 (0.9)	2.5 (0.7)	2.9 (0.3)	***	***	*	ns
Praxis	4	3.7 (0.7)	3.6 (0.8)	3.8 (0.5)	4.0 (0.0)	***	***	*	ns
Figure copy	4	3.2 (1.2)	3.3 (1.0)	3.0 (1.3)	4.0 (0.3)	***	***	***	ns
Fragmented letters	3	1.8 (1.3)	1.9 (1.3)	1.7 (1.2)	2.8 (0.5)	***	***	***	ns
Dot counting	4	3.4 (1.0)	3.5 (1.0)	3.2 (1.3)	3.9 (0.3)	***	***	***	ns
Verbal fluency	6	3.1 (1.6)	2.4 (1.8)	3.7 (1.1)	5.1 (0.8)	***	***	***	* (L<R)
Circle cancellation	5	3.9 (1.5)	4.3 (1.2)	3.6 (1.6)	4.9 (0.3)	***	***	***	* (R<L)
Number cancellation	5	3.2 (1.9)	3.1 (1.8)	3.1 (2.0)	4.8 (0.3)	***	***	***	ns
Total NPEC	100	71.0 (18.7)	66.0 (20.5)	73.7 (16.7)	93.7 (4.3)	***	***	***	* (L<R)
Reasoning / Executive	15	9.7 (3.6)	9.4 (3.6)	9.8 (3.5)	13.6 (1.3)	***	***	***	ns

Memory	20	13.7 (4.1)	13.1 (4.0)	14.1 (4.4)	18.3 (1.7)	***	***	***	ns
Language	25	19.5 (6.9)	17.1 (8.0)	20.8 (6.1)	24.4 (1.3)	***	***	***	** (L<R)
Perception	16	12.0 (3.7)	12.2 (3.8)	11.5 (4.1)	15.6 (0.8)	***	***	***	ns

***P<0.0001,**P<0.001,*P≤0.05, ns = not significant (P>0.05)

Table 3. Sensitivity, specificity and percentage of participants correctly classified for different cut-off scores and percentiles.

NPEC cut-off score	Control Percentile	Sensitivity	Specificity	Correctly classified
<91	<20th %ile	90%	80%	87%
<89	<10th %ile	84%	88%	85%
<86	<5th %ile	75%	95%	82%
<81	<1st %ile	61%	99%	74%
<80	<worst control	54%	100%	70%

Figure 1.

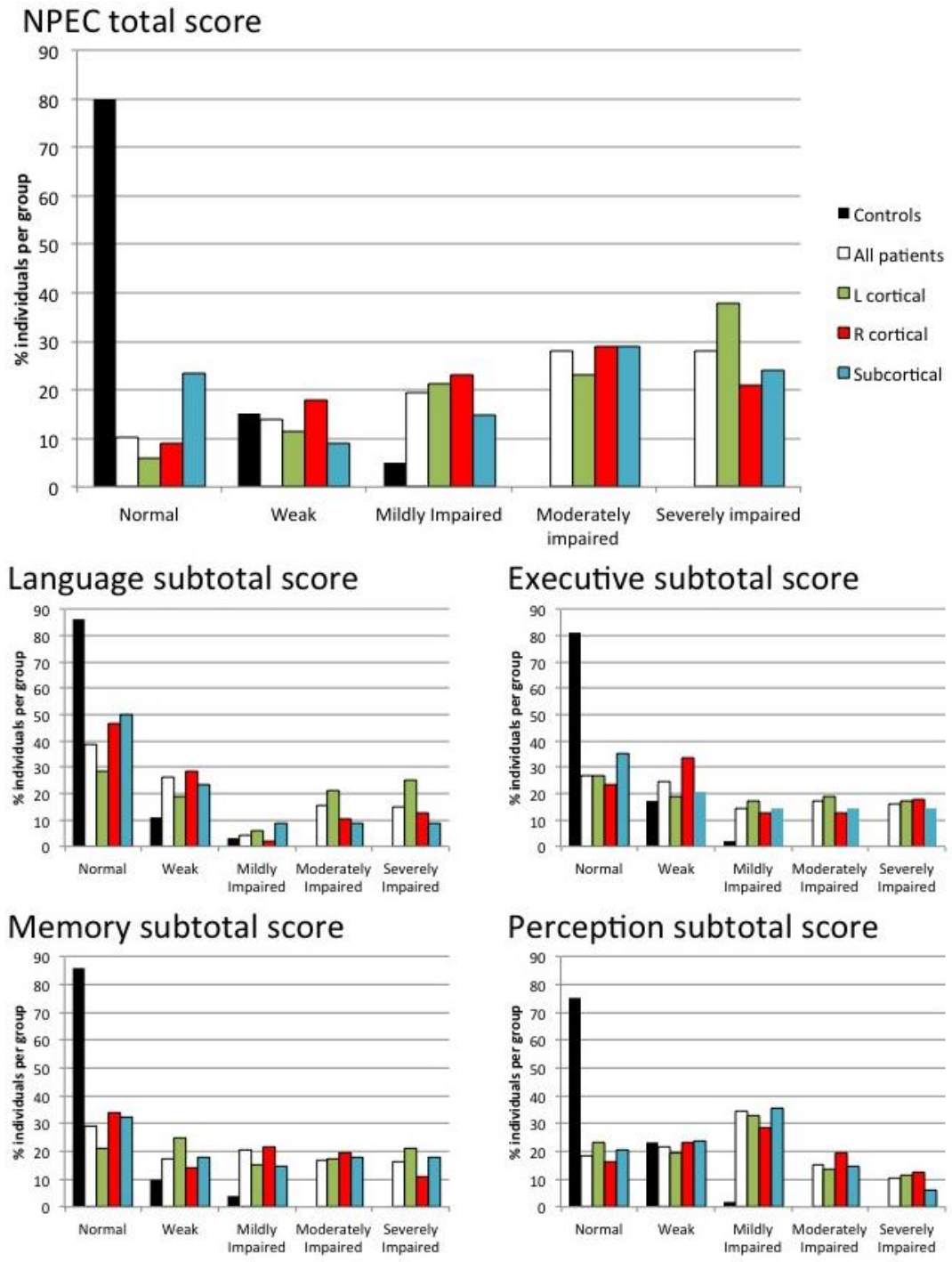
NPEC total score
% individuals per group
Controls
All patients
L cortical
R cortical
Subcortical
Normal
Weak
Mildly Impaired
Moderately impaired
Severely impaired
Language subtotal score
Executive subtotal score
Memory subtotal score
Perception subtotal score
Mildly Impaired
Moderately Impaired
Severely Impaired

Figure 2.

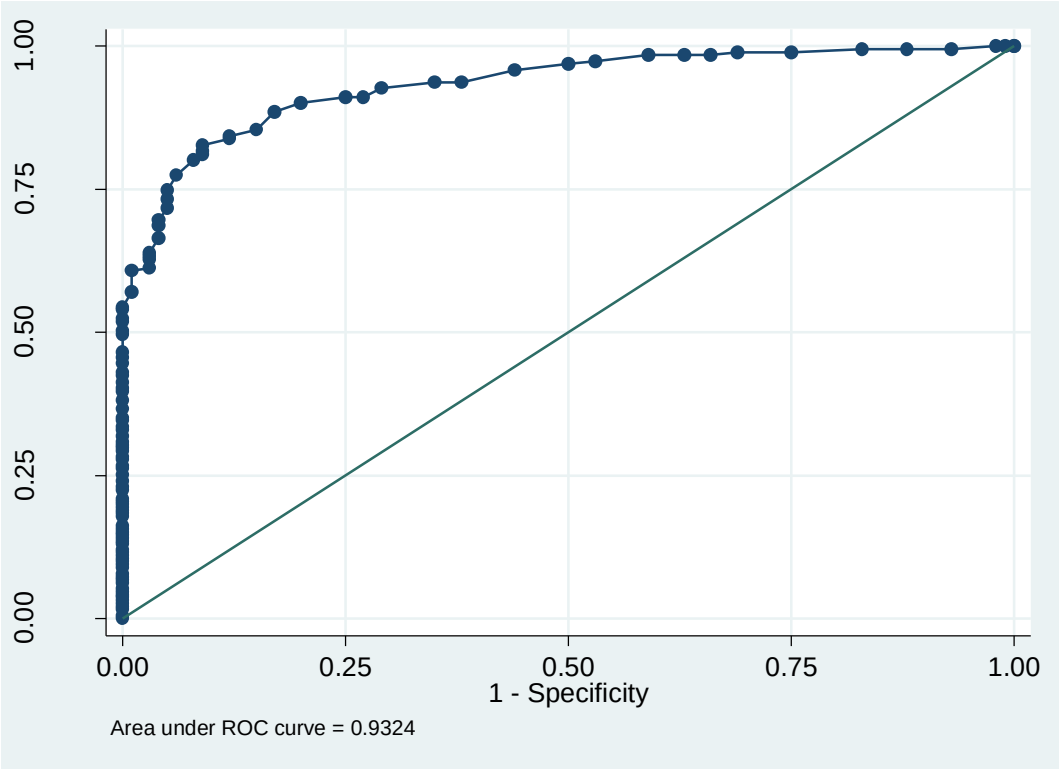
1.00
0.75
0.50
0.25
0.00
0.00
0.25
0.50
0.75
1.00
1 - Specificity
Area under ROC curve = 0.9324

Figure 3.

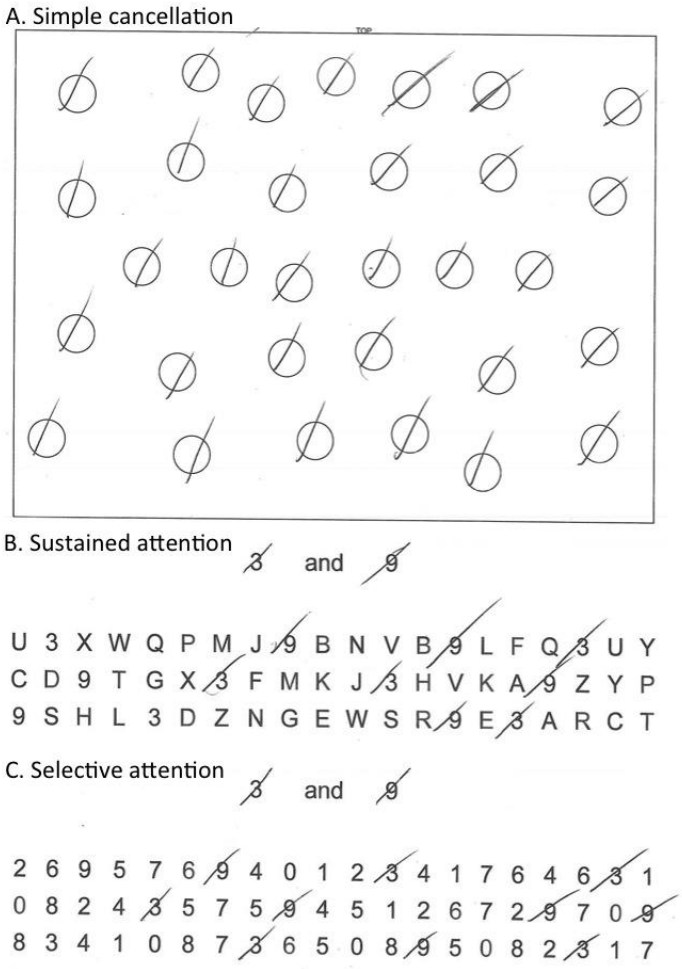

Figure 1. Percentage of controls and patients (whole group and subgroups) scoring in each of the five performance bands on the total NPEC measure and four subtotal scores.

Figure 2. Receiver operating characteristics of the NPEC as a test for cognitive impairment following stroke.

Figure 3. Example circle and number cancellation data. This patient exhibited a spatial attention deficit characterised by a rightward bias which was only evident on more attentionally demanding tasks (B and C).