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Systematic assessment of apraxia and functional predictions from the Birmingham Cognitive Screen (BCoS)

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Objective: The validity and functional predictive values of the apraxia tests in the Birmingham Cognitive Screen (BCoS) were evaluated. BCoS was developed to identify patients with different forms of praxic deficit using procedures designed to be inclusive for patients with aphasia and/or spatial neglect.

Method: Observational studies were conducted from a university neuropsychological assessment centre and from acute and rehabilitation stroke care hospitals throughout an English region. Volunteers from referred patients with chronic acquired brain injuries, a consecutive hospital sample of patients within 3 months of stroke (n=635) and a population based healthy control sample (n=100) were recruited. The main outcome measures used were the Barthel Index, the Nottingham Extended Activities of Daily Living Scale as well as recovery from apraxia.

Results: There were high inter-rater reliabilities and correlations between the BCoS apraxia tasks and counterpart tests from the literature. The vast majority (88.3%) of the stroke survivors were able to complete the screen. Pantomime and gesture recognition tasks were more sensitive in differentiating between individuals with left hemisphere damage and right hemisphere damage whereas the Multistep Object Use test and the imitation task had higher functional correlates over and above effects of hemiplegia. Together, the initial scores of the four tasks enabled predictions with 75% accuracy, the recovery of apraxia and independence level at 9 months.

Conclusions: As a model based assessment, BCoS offers a quick and valid way to detect apraxia and predict functional recovery. It enables early and informative assessment of most stroke patients for rehabilitation planning.

INTRODUCTION

Limb apraxia is one of the family of apraxic disorders generally defined as a non-motoric deficit reflecting impaired purposive upper limb movement¹. It is a common and important²⁻⁵ but relatively poorly understood^{6, 7} sequelae of stroke and can persist well after the acute phase^{8, 9}. There is also evidence that apraxia is a significant predictor of functional motor skills¹⁰ more so than aphasia or primary motor deficits¹¹. Given this link to functional performance it is important that early assessments are made to inform treatment. However, a review of current cognitive assessments suggests that there is no accepted screening for apraxia¹².

Cognitive models describe the functional architecture of the praxis system and illustrate the different ways that apraxia can arise. One influential model is that put forward by Rothi and colleagues¹³ (see¹⁴⁻¹⁶) which has also been used to account for data from functional imaging studies of healthy participants¹⁷. Figure 1 illustrates the cognitive mechanisms of the different commonly used praxis assessment tasks using a model incorporating recent extensions of Rothi's original model¹⁷. In particular, the addition of the 'body part coding' mechanism for the imitation of meaningless gestures, which converts the visual appearance of the demonstrated gestures by an examiner to spatial relationships between discrete body parts.^{16 17}

A cognitive theory driven approach to assessment is appealing. It can provide a diagnosis of specific deficits and can lead to appropriate targeting of treatment. However, there can be problems for day-to-day clinical application. For this, several batteries of apraxia tests have been developed recently.^{18 19} However, there can be problems for day to day clinical application. A comprehensive apraxia assessment can be time consuming,¹³ and the absence of consistent scoring criteria across different tasks may hinder meaningful interpretation of the performance profile. Moreover, as spatial neglect is prevalent among

stroke patients with right hemisphere lesions²⁰ and aphasia among stroke patients of left hemisphere lesions,²¹ and both impairments are linked to sites in the posterior parietal cortex also linked to apraxia,¹ then assessment procedures need to facilitate the participation of patients with aphasia and spatial neglect to maximise involvement.

To address these issues, a novel set of model based apraxia tests were created as part of the cognitive screening battery (the Birmingham Cognitive Screen (BCoS)). This paper describes the development, validation and utility of these tests. An initial validation study, carried out with a set of patients with chronic lesions, examined inter-rater reliability and construct validity for the assessments relative to other published tests. Subsequently, we assessed the utility of the apraxia tests in BCoS for patients in their early stage of recovery from stroke, along with the functional relations between the BCoS measures and assessment of functional activities (eg, the Barthel Index).

METHODS

Design

Phase 1 validated inter-rater reliability and the construct validity of the BCoS tests with a sample of participants with established brain injuries. Phase 2 examined the utility and ecological validity amongst participants at a sub- acute stage after stroke.

Participants

Phase 1 participants were individuals with acquired brain damage who were either self-referred or referred by others (eg, hospital consultants) and attended the School of Psychology regularly for neuropsychological assessments and rehabilitation (hereafter referred to as 'chronic acquired brain injured chronic ABI-participants'). They were selected to represent a wide range of praxis abilities. Eighteen chronic ABI participants took part in

the construct validity studies. Eight individuals took part in the inter-rater study and had their performance videoed for scoring by different raters. Two trained examiners independently scored performance on the BCoS tests using the instructions given in the examiner booklet. No communication took place between the raters, and their scores were subsequently compared.

Phase 2 data collection was conducted by trained examiners from the university and from the West Midlands Stroke Research Network who conducted weekly visits to the stroke wards in 12 local hospitals as part of a cognitive screen trial (the Birmingham University Cognitive Screen Trial, <http://www.bucs.bham.ac.uk>). In addition to assessments of apraxia, BCoS measures performance across four other cognitive 'domains': language, spatial and controlled attention, memory and number processing. All tests in the battery are designed to optimise time efficient data collection and to maximise patient inclusion. Any stroke survivors who were medically stable, within 3 months of their latest stroke and able to give consent, were approached. Six hundred and thirty-five participants recruited between November 2006 and September 2010 were entered into the study (hereafter referred to as 'hospital patients'). Lesion information from hospital based axial CT scan reports was available for 80% of the hospital patients and revealed definitive lesions in 93% of patients who were scanned. A subset of 253 hospital participants were invited to take part in a 9 month follow-up assessment.

Healthy controls ($n=100$) were recruited according to the 2001 UK population census age 3 sex 3 education level distribution. The 18 university participants and 14 controls were also assessed with conventional apraxia tests.

Informed consent was obtained according to the approved ethics protocols of the UK National Research Ethics Committee and the Birmingham University ethics procedures.

Measures

BCoS tasks

Selection of the praxis screen tests in BCoS was governed by the need to minimise administration time while maximising inclusion and attempting to be as sensitive as possible. The aim was to assess the cognitive processes that support praxis and so tests covered: (1) input processing of visually conveyed gestures, (2) the coding of body part and position, (3) access to stored knowledge about the meanings of gestures (action semantics) and (4) access to appropriate motor output routines which transform spatiotemporal concepts of gestures into motor innervations, to produce gestures (gesture output processing) (figure 1). To assess these processes, BCoS contains three praxis tasks: pantomime to auditory/written words input (pantomime), forced choice recognition of pantomime (recognition) and imitation of meaningless gestures (imitation). Table 1 summarises analyses of deficits with different performance profiles. In addition to the assessments using single actions, a further test of Multistep Object Use (MOT) (assembling and then switching on a torch) was included to assess patients' ability in the use of objects in an everyday situation. This allowed us to assess step sequencing to achieve a goal along with the ability to select an appropriate object among distractor objects. The MOT task has added functional relevance as studies have shown dissociable abilities between everyday object use and praxis tasks.^{15 22} All tasks are illustrated in figure 2 (see appendix I, available online only, for administration and scoring details). Moreover, several principles were followed in the selecting and designing of both the tasks and items to make the screen rigorous (box 1).

Conventional praxis tasks

To assess pantomime, the Florida Apraxia Screening Test²³ was adapted. For gesture recognition, the principles of Peigneux et al's design²⁴ were adopted. For the conventional imitation test, De Renzi et al's Movement Imitation Test² protocol was used. For the object use assessment, a procedure based on De Renzi's Single Object Use test (SOT)²⁵ was employed (see appendix I, available online only, for administration and scoring details).

Functional evaluation

Within the protocol of the BCoS study, hospital participants were assessed initially with the Barthel Activities of Daily Living (ADL) Index,²⁶ a well established and validated functional measure for acute stroke patients.²⁷⁻³⁰ At the 9 month follow-up assessment, the Nottingham Extended ADL scale (NEADL)³¹ was added to measure higher level community based daily activities. The presence of hemiplegia was recorded when participants could only use one hand to complete the bilateral MOT task (see appendix I, available online only).

Table 1 Cognitive deficits analysis through comparing performance profiles

Praxis screening tasks				Possible deficits (process)
<i>Pantomime</i>	<i>Recognition</i>	<i>Imitation</i>		
spared	spared	impaired	→	body coding (link from input to output)
spared	impaired	impaired	→	visual gesture analysis (input)
impaired	impaired	spared	→	action semantics (conceptual)
impaired	spared	impaired	→	gesture output processing (output)

Box 1: Principles in apraxis tasks selection and design

1) to be inclusive of different gesture types which could be differentially impaired in patients - hence both transitive (object related) and intransitive (symbolic) gestures were included in both the pantomime and recognition tasks, while the imitation task required coding and production of both hand position and finger postures;

- 2) as many apraxic patients also have hemiplegia, only actions that could be performed with one hand were selected for the pantomime and imitation tasks;
- 3) for aphasic patients, instructions used high frequency words and were presented multi-modally where possible - in written form, verbally and with photographic illustration to maximise understanding; in addition, forced-choice responses were used for the recognition task, with no verbal demands on patients.
- 4) all visual stimuli (objects, pictures, words, gestures) were presented vertically across the midline in front of the patient, to rule out the potential confounding effects of spatial neglect.

Statistical analyses

Descriptive analyses were conducted for all measures by group. Inter-rater reliability was examined by Pearson's correlations and the Kappa test. Sensitivity and specificity were evaluated using binary classification as described by Greenhalgh³². Log linear regression was conducted for the analysis of multiple categorical variables in a model. Between two groups, Chisquare tests were used to compare categorical data and t-tests were used to compare interval data.

The functional analyses focused on the effect of the presence and recovery of apraxia on ADL outcomes. The presence of apraxia was defined by an impairment in any one of the praxis tasks. Based on the assumption that some action processes recruited by each task are specific to that particular task, we also conducted task by task analyses to examine task specific effects. To investigate the relations between recovery from apraxia and functional outcome, the follow-up participants were divided into three groups: (1) those with no apraxia (no impairment in any one task); (2) those recovered from apraxia (failed at least one task on initial assessment but passed all tasks on follow-up); and (3) those with persistent apraxia (failed at least one task even on follow-up). First, discriminatory function analyses were used

to assess the predictability of the four apraxia task scores on recovery from apraxia at 9 months. This was followed by correlations and ANCOVA analyses for ADL outcomes. Post hoc comparisons were conducted with the Sidak correction.

RESULTS

Participant characteristics and praxis abilities

Table 2 details the demographic characteristics and praxis abilities in each of the study groups. The 100 controls were divided into three age groups (<65 years, 65-74 years, >74 years), each with gender and education profiles comparable to that of the 2001 census population profile. Cut off scores for each of the BCoS apraxia tests were set at 5th percentile of control performance (Table 3).

Table 2 Demographic details and praxis performance of participants

		Chronic ABI participants			Hospital patients		Controls	
		inter-rater reliability	construct validity	initial assessment	initial profile of subgroup of patients who were followed up	subgroup at follow-up assessment	conventional assessment	praxis screen
N		8	18	635	253	253	14	100
<u>Characteristics</u>								
Age (y±SD)		62.8±14.3	66.8±17.2	70.3±13.9	69.5±13.2	70.2±13.4	65.3±12.5	70.6±10.5
Education (y±SD)		12.1±4.0	11.9±3.8	11.1±2.8	11.3±2.9	11.2±2.9	12.5±4.01	11.6±2.5
Gender (M:F)		6:2	13:5	351:284	145:108	145:108	7:7	46:54
Months post ABI (range)		88.4±37.2	43.6±64.1	0.8±0.7	0.9±0.7	10.2±1.1	---	---
<u>BCoS apraxia tests</u>								
max								
MOT	12	8.8±4.6	9.0±3.8	9.9±3.6	10.0±3.3	11.0±2.6	---	11.5±0.8
Pantomime	12	9.6±3.1	9.7±2.7	10.2±2.9	10.4±2.8	10.8±2.0	---	11.4±0.9
Gesture recognition	6	4.5±0.93	4.4±1.2	4.9±1.3	5.1±1.2	5.2±1.1	---	5.6±0.7
Imitation	12	6.0±4.1	7.0±3.3	9.2±3.0	9.2±2.9	10.2±2.1	---	11.0±1.1
<u>Conventional praxis tests</u>								
Single object use test	40	---	34.2±5.9	---	---	---	37.8±1.9	---
FAST	64	---	40.1±15.1	---	---	---	51.2±5.5	---
Gesture decision	24	---	21.4±2.9	---	---	---	23.8±0.4	---
Gesture naming	24	---	15.8±7.0	---	---	---	20.9±1.7	---
Movement imitation test	72	---	43.9±17.3	---	---	---	69.3±2.4	---

Abbreviations: ABI, acquired brain injuries; BCoS, Birmingham Cognitive Screen; MOT, multi-step object use test; FAST, Florida Apraxia Screening Test

Table 3 Cut off scores based on 5th percentile of control performance within each age group

BCoS praxis tasks	Age group		
	<65 N=34	65-74 N=33	>74 N=33
Multi-step object use	11	10	10
Pantomime	10	9	9
Recognition	5	5	4
Imitation	9	9	9

Phase 1 studies

Inter-rater reliability

The pantomime and imitation scores given by the raters were significantly correlated ($r=0.94$ and 0.86 respectively). Using the cut off points from control performance, there was 100% agreement between the raters on impairments for the two tasks. For the MOT, the percentage agreement on individual error scores was 92.7% resulting in a Kappa value of 0.82 ($p<0.001$). The total scores given to the performance of the chronic ABI participants on each task were highly correlated across the raters: 0.99 ($p<0.001$). Three of eight participants failed the torch task and the resulting agreement on impairment was 100%.

Sensitivity and Specificity

The standard deviations in the conventional praxis tasks (Table 2) suggested that the chronic ABI participant group represented a wide range of praxis abilities. The variability was maintained in performance on the BCoS praxis tasks. This confirms that the praxis screen can distinguish different levels of patient performance. All screen tasks correlated well with their conventional counterparts except for the MOT (against the SOT) (Table 4). Apart from the MOT, all the tasks in the screen demonstrated substantial sensitivity and specificity values (Table 4). However, the wide 95% confidence intervals call for further studies with a larger sample size. Corresponding to the poor correlation between the SOT and MOT tasks

reported above, low sensitivity (50%) was demonstrated. These data suggest that performance on the MOT and SOT tests might be supported by different cognitive processes (see the Discussion below).

Table 4 Correlations between the screen tasks and the conventional apraxia assessment tasks.

	MOT vs. SOT	Pantomime vs. FAST	Imitation vs. MIT	Recog vs. Deci.	Recog vs. Name
Pearsons r	0.19	0.801	0.811	0.77	0.732
P value	ns	<0.001	<0.001	0.001	0.004
Sensitivity (%)	50.50%	71.40%	100.00%	100.00%	80.00%
95% CI	21.5-78.5	35.9-91.8	74.1-100.0	61.0-100.0	37.6-96.4
Specificity (%)	72.70%	91.70%	75.00%	87.50%	75.00%
95% CI	43.4-90.3	64.6-98.5	40.9-92.9	52.9-97.8	40.9-92.9

Abbreviations: MOT = Multi-Object Use Test; SOT = Single Object Use Test; FAST = Florida Apraxia Screening Test; MIT = Movement Imitation Test; Recog = Recognition Test; Deci = Gesture Decision Test; CI = confidence interval.

Phase 2 studies

One of the aims of the BCoS assessment was to maximise the inclusion of patients, including patients with aphasia and/or visuospatial deficits. Out of the 635 hospital patients, 585 (92.1%) were assessed on at least one of the apraxia tests and 561 (88.3%) completed all four apraxia tasks. Only one patient was unable to participate in some praxis tasks due to aphasia and no patient had a problem participating due to visuospatial neglect. This confirmed that the BCoS is indeed aphasia and neglect friendly.

Assessments were performed within the first week post stroke for 22.0% of patients and 81.6% were assessed within 6 weeks post stroke (this is the period proposed by the UK National Institute for Health and Clinical Excellence Quality Standards for Stroke 2010).

The mean “period after onset” on testing was 25.2 days (SD=21.3).

To allow comparisons across test sessions and individual tasks, table 5 summarises the task specific findings for the subgroup who completed all four tasks and were followed-up (n=231). In this group, 46% were impaired in at least one praxis task. Therefore, using only one praxis task would result in 30% under detection of impairments. On the other hand, there were individuals who were impaired in only one out of the four praxis tasks (percent impairment in single task). Such unique impairments occurred in each of the four tasks and among 22% of the patients in the initial session and 18% of the patients in the follow-up session, indicating dissociations of processes underlying each task.

Praxis performance data were analysed and contrasted across patients with unilateral lesions (left vs right) who were tested for apraxia. Left hemisphere damage (LHD) was identified in 74 patients and right hemisphere damage (RHD) in 84. A four way log linear analysis of assessment session (initial vs follow-up), tasks (the four praxis tasks), lesion (left vs right) and impairment (impaired vs not impaired) produced a final model (that showed significant interaction only at the three way level of tasks $\times$ lesion $\times$ impairment) ($\chi^2(3)=13.97$, $p=0.003$). This suggested that the profile structure was maintained across the assessment sessions. Across assessments, only pantomime and recognition tasks consistently showed a differential impairment profile between the LHD and RHD groups (table 5).

Prediction of recovery

Of those who showed signs of apraxia in the first assessment, 107 participated in the follow up assessment where 51(48%) showed no further sign of deficit across all tasks (recovered) and 56 (52%) showed persistent signs of apraxia. Based on their initial scores of the 4 praxis tasks, discriminant function analysis was conducted to predict praxis recovery (recovered vs. persistent, see definitions) at 9 months. Using the 4 initial scores, 75% of the cases were correctly classified in the recovered group (centroid=0.489) and the persistent group

(centroid=-0.445). The discriminating power was significant (Wilks' Lambda=0.82, $\chi^2(4)=20.62$, $p<0.001$). The loading correlations between the predictor variables and the discriminant function were 0.86 for the pantomime task, 0.54 for the imitation task, 0.51 for the MOT and 0.28 for gesture recognition, suggesting that the first three tasks contributed more in differentiating between the recovered and persistent group than the gesture recognition task.

Functional analyses

The *presence* of apraxia (an impairment in any one of the BCoS apraxia tasks) related to lower mean Barthel score both initially (mean(sd)=10.92 (5.67) vs. 15.04 (5.13) and at 9 months (16.00 (4.83) vs. 17.83 (3.51)). With hemiplegia partialled out, the effect of apraxia on the Barthel remained significant (initial: $F(2,513)=57.85$, $p<0.001$) (9 months: $F(2,214)=8.81$, $p=0.003$). The same result arose for the Nottingham Extended ADL (NEADL) measure at 9 months (mean(sd)=11.08 (6.96) vs. 14.40 (5.94), $F(2,218)=13.05$, $p<0.001$).

Moreover, with hemiplegia again controlled for, the scores of each initial praxis assessment were correlated with the initial Barthel, follow-up Barthel and the NEADL (table 5). At the $p=0.001$ level, these showed low but consistent correlations between the MOT and the imitation with functional assessments (Barthel at initial assessment and NEADL at follow-up), explaining between 7% and 10% of the variance.

For those who were assessed, 124 (54%) had no apraxia, 51 (22%) recovered from the signs of apraxia and 56 (24%) showed persistent signs of apraxia. Classifying the patients as having no apraxia, recovered apraxia or persistent apraxia, ANCOVAs examined the impact of apraxia on everyday abilities at different stages of recovery, with the effects of hemiplegia (covariate) partialled out (table 6). Both the recovered and persistent apraxia groups had

significantly lower initial Barthel scores compared with the non-apraxic group ($p<0.001$) but they did not differ from each other ($F<1.0$; indeed the recovered patients, if anything, had lower initial scores). The difference disappeared for the follow-up Barthel scores. However, the persistent apraxia group were still significantly lower in the NEADL score at follow-up relative to the no apraxia group ($p=0.002$).

Table 5 Praxis task specific impairment rates, functional correlates and predictions

	Praxis task	MOT	Pantomime	Recognition	Imitation
Initial scores (mean (SD))	Overall	10.2 (3.2)	10.4 (2.7)	5.1 (1.2)	9.2 (3.0)
	In LHD	9.6 (3.8)	9.5 (3.7)	4.6 (1.5)	8.3 (3.3)
	In RHD	10.3 (2.7)	11.1 (1.6)	5.3 (0.9)	9.9 (2.4)
	L vs R t	-1.3	-3.6***	-3.8***	-3.5***
% Impairment	In single task	7.4	1.7	2.6	10.4
% Total impairment	Overall	22.5	16.9	16.0	33.3
	In LHD	25.7	25.7	29.7	47.3
	In RHD	26.2	6.0	7.1	23.8
	L vs R χ^2	0.0	11.9***	13.8***	9.6**
FU scores (mean (SD))	Overall	11.1 (2.5)	10.9 (1.8)	5.3 (1.0)	10.2 (2.1)
	In LHD	11.1 (2.6)	10.6 (2.1)	5.2 (1.0)	9.9 (2.3)
	In RHD	11.2 (2.0)	11.3 (1.3)	5.5 (0.9)	10.4 (2.0)
	L vs R t	-0.2	-2.5*	-2.3*	-1.6
%Impairment	In single task	2.6	2.6	6.1	6.9
% Total impairment	Overall	9.5	12.1	13.9	18.2
	In LHD	8.1	16.2	20.3	24.3
	In RHD	9.5	6.0	7.1	14.3
	L vs R χ^2	0.1	4.3*	5.9*	2.6
Functional correlations (controlling for hemiplegia)	Initial Barthel	0.29***	0.25***	0.25***	0.31***
	FU Barthel	0.13	0.05	0.01	0.18**
	NEADL	0.32***	0.16	0.10	0.27***
Loading correlation with discriminant function for praxis recovery		0.51	0.86	0.28	0.54

Analyses were conducted on subgroups of patients who completed all four praxis tasks and were followed-up.

Significance levels: *0.05, **0.01, ***0.001.

FU, follow-up; LHD, left hemisphere damage; MOT, Multistep Object Use test; NEADL, Nottingham Extended Activities of Daily Living Scale; RHD, right hemisphere damage.

Table 6 Effects of apraxia and recovery on everyday living abilities in the hospital patients

	Apraxia group			Controlling for hemiplegia		Posthoc with Sidak correction
	Non (N)	Recovered (R)	Persistent (P)	F	p	
N	124	51	56			
Initial Barthel, mean (sd)	14.95 (5.17)	10.55 (5.98)	11.00 (5.80)	12.11	<0.001	N>R, N>P
FU Barthel, mean (sd)	17.91 (3.61)	17.26 (3.75)	16.02 (4.82)	2.61	NS	
NEADL, mean (sd)	14.91 (6.12)	12.48 (5.57)	10.87 (6.96)	6.59	0.002	N>P

Abbreviations: FU, follow up; NEADL, Nottingham Extended Activities of Daily Living Scale

DISCUSSION

The past 20 years have seen substantial advances in our theoretical understanding of the neural and cognitive mechanisms of apraxia.^{13 16 17 33} The apraxia tests within the BCoS were developed to capitalise on these advances to enhance identification and understanding of praxis deficits in clinical settings. The current study shows promising results for these tests in terms of inter-rater reliability and construct validity although further studies on this are desirable as the current validation and reliability tests were based on relatively small numbers. To further ensure standardisation of practice, the study team have additionally developed videos with testing demonstrations and example performances to give consistency to training.

The tasks were designed to overcome the assessment barriers imposed by aphasia, neglect and hemiplegia. As a result, it was possible to administer the screen to the vast majority of the hospital participants very early on after their stroke. Signs of impairment in the individual praxis task ranged from 16% to 33%. Taking into account performance across all tasks, BCoS identified signs of praxis deficits in 46% of the acute hospital stroke survivors (62% in the LHD, 37% in the RHD group). These figures are somewhat higher than other studies.^{2 3 5} The difference can partly be accounted for by our relatively more acute patients

(mean days post stroke=25.2) whereas the other studies recruited participants at a later stage; in addition, our use of procedures to include patients with neglect, aphasia and hemiplegia may have led to a greater range of deficits being sampled. In our 9 month follow-up assessment, about half of the apraxic patients had recovered which would have brought the impairment rates to a more comparable level to the other studies. Moreover, in an attempt to capture all types of praxis deficits, we included a larger range of tasks than the previous studies, all of which have functional implications (see discussion below). The rate of impairment in our sample was particularly high in RHD patients compared with other studies. This could be due to our inclusion of the meaningless gesture imitation and the MOT. With the imitation task, the meaningless nature of the gestures and the inclusion of trials where finger postures had to be reproduced may lead to significant contributions from the right hemisphere for high level visuospatial analysis (although the LHD patients remained worse).^{34 35} Meaningful gestures (via the semantic route, requiring retrieval from the long term memory store) and the hand to head postures may rely more heavily on the left hemisphere processing of body structure.³⁴ With the MOT, impairment rates did not differ across the two unilateral lesion groups. This task simulates a naturalistic situation requiring multiple cognitive abilities (eg, sequencing, selection of correct objects from distracters, online spatial analyses in assembling different components of the torch, as well as higher level attentional control). Therefore, it is no surprise that both hemispheres contribute to satisfactory performance.³⁶

Our findings on the lack of correlation between the SOT (a common test of apraxia) and the MOT (a more naturalistic assessment) present in the BCoS confirms earlier findings³⁷ and supports the notion that MOT and SOT call on at least some distinct processes.³⁸ For example, the contextual information from related object in the MOT might cue relevant actions for some patients who are impaired in the SOT, while the presence of distracters and

the demand on sequencing abilities might lead to more opportunities for errors in other patients (eg, those with frontal lobe lesions). It can also be argued that unlike MOT, SOT can be performed without access to semantic memory, working memory and attentional processing; impairments in these ancillary cognitive mechanisms could differentially affect MOT performance.

Measures of apraxia related to functional outcome, both initially and at follow-up. This supports the argument for early diagnostic testing of apraxia after stroke. One might wonder if early assessment would overdiagnose problems (eg, failure of praxis assessment due to the effects of post stroke fatigue³⁹) which could be spontaneously resolved at a later stage. Against this, our data showed that information obtained from the early assessment of praxis was indicative of sustained deficits at 9 months over and above the effects of hemiplegia. The mean initial Barthel scores of the apraxic group (10.92) fell within the moderate dependency level whereas those of the non-apraxic group (15.04) fell within the low dependency.⁴⁰ This difference has implications for the costs of health and social care in the first year after stroke.⁴¹ In our follow-up assessment, patients with persistent apraxia were still disadvantaged in the more community based, higher level ADL detected in the NEADL scale (eg, making a hot drink). Interestingly, patients with persistent problems were not necessarily worse at the initial assessment, suggesting that functional recovery is not simply related to the overall level of impairment.

As well as the value in predicting recovery from apraxia and functional outcomes when used together, each of the apraxia tasks can provide information about different aspects of a patient's action related ability which can be used for clinical reference and/or targeting rehabilitation. The ecological relevance of the MOT has already been discussed above. For stroke survivors with aphasia (ie, difficulties in producing and/or understanding speech), measures of gesture production and recognition would allow the therapist to ascertain if

patients can reliably produce and understand gestures as an alternative means of communication. In addition, imitation of meaningless gestures can inform the rehabilitation team about a patient's ability to relearn movement patterns for everyday activities when patient can no longer access the meaning and functions of such movements from stored knowledge.⁴² Therefore, the BCoS apraxia tests have not only theoretical significance but also functional relevance. To further inform clinical applications, future investigations are required to (1) evaluate the use of training videos on improving the reliability between raters, (2) investigate the different recovery patterns between LHD and RHD patients, (3) examine the interactions between praxis abilities and other cognitive functions as well as (4) the relationship between different praxis abilities and specific different types of ADL activities.

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Competing interests None

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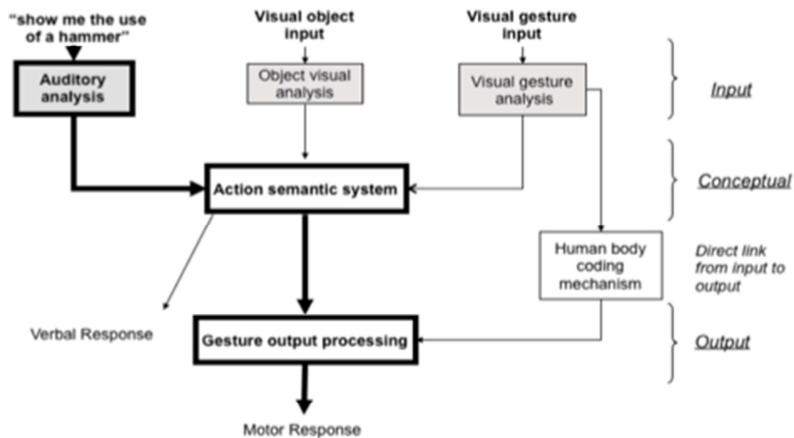
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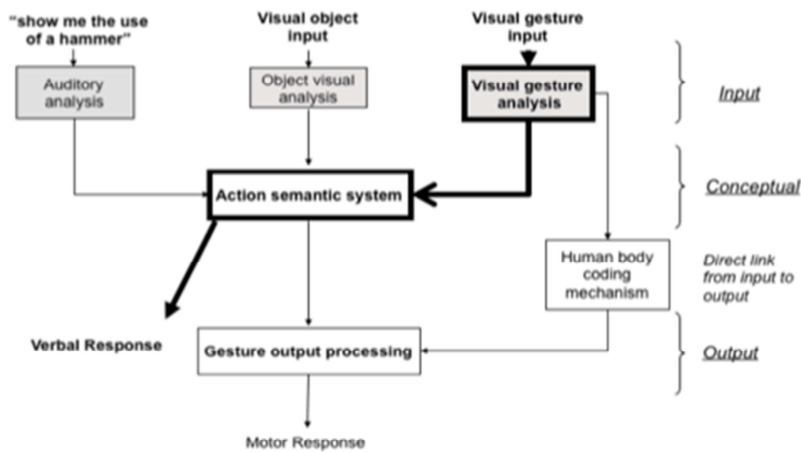
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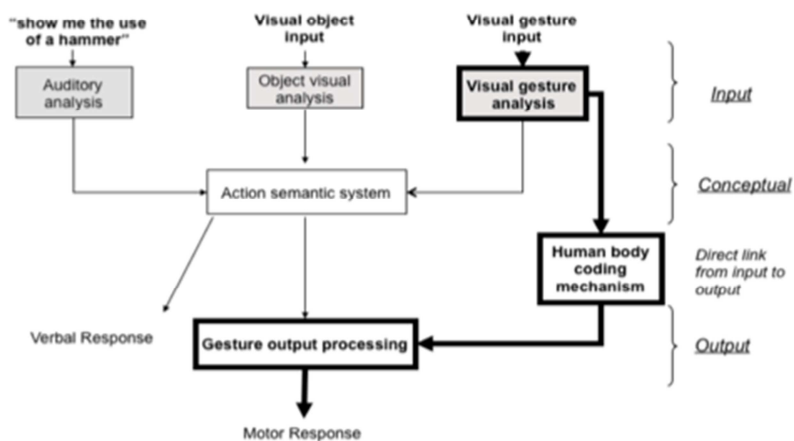
Figure 1 The different cognitive processing pathways for different praxis assessment tasks.



1. Pathway for processing of pantomime by verbal command (in bold lines)



2. Pathway of processing of gesture recognition (in bold lines)



3. Pathway for imitation of meaningless gesture (in bold lines)

Figure 2 Illustrations of the four Birmingham Cognitive Screen apraxia assessment tests.

Pantomime: (Max. score = 12, cut off = 10)

3 Intransitive gestures

e.g. "can you show me the gesture for "military salute"

3 Transitive gestures

e.g. "can you show me the gesture for "use of a hammer"

Recognition: (Max. score = 6, cut off = 5)

Examiner
presents



Patient
chooses

Hitch-hiking
Applause
I swear
Good

Imitation: (Max. score = 12, cut off = 10)

2 hand sequences
e.g.



2 finger postures
e.g.



Multiple Object Use (MOT): (Max. score =12, cut off = 10)

"Please can you make the torch work..."



Appendix I Scoring and administration of BCoS and conventional apraxia tests

BCoS

For *pantomime*, a score of 2 was given for accurate performance, 1 for a recognisable but poorly executed actions, and 0 for unrecognisable actions or incorrect performance. The maximum possible score for the 6 items was 12 points. For *recognition*, one point was given for each target selected to match with the examiner's demonstration, giving a maximum possible score of 6. For *imitation*, a flawless performance on first demonstration by the examiner scored 3, a flawless performance on second demonstration scored 2, a single error (e.g., an orientation error in one item in the sequence but NOT both) on the second trial was given a score of 1, and 0 was recorded when there was more than one error on second demonstration of the action. The maximum possible score was 12 points. For the *MOT*, explicit criteria were devised to ensure consistency of online scoring. The patients' actions were compared with a step-by-step 12-item checklist of acceptable performance. The checklist described the correct selection of object, the spatial orientation of the components of the objects, the sequencing of steps, goal attainment and appropriate problem solving. A flawless performance was given a score of 12.

For the production tasks (*pantomime and imitation*), patients were asked to use their ipsilesional or least affected side to avoid interference from any primary motor deficits. For patients with significant bilateral motor deficits, the production tasks were not tested. The MOT (fitting batteries into a torch) would normally be conducted bilaterally. However, when participants could only use one hand due to hemiplegia, the examiner could help where necessary and specified by the participant (e.g. holding the torch still while the participant screwed the torch lid on). The hand(s) used in all tasks were recorded in the examiner's booklet. Patients with impaired comprehension (assessed across a number of BCoS subtests)

were excluded. Where testing was not possible, examiners recorded specific reasons for each omission.

Conventional apraxia tests

To assess pantomime, the Florida Apraxia Screening Test (FAST)¹ was adapted. For gesture recognition, there is no standard task in common use - individual research studies have their own versions, which may vary according to the research focus²⁻⁵. Based on the principles of Peigneux et al.'s design³, patients were shown 24 pairs of photographs of an actress demonstrating a series of gestures (12 transitive gestures using an object; 12 demonstrating an intransitive gesture), and individuals were asked to select from each pair the "real" one representing a meaningful, familiar and correctly executed action. The distractor picture in each pair showed an erroneous action based on the position/orientation of the hand, the posture of the grip or finger, or the content of the action (e.g., one object being used in the manner of another objects). Across the 24 trials, all error types were represented equally. The alternative actions were placed in a vertical line with the positions of the correct and incorrect gestures counterbalanced across trials. Following each *recognition decision* (real/not real), patients were also asked to *name* the gesture. For the conventional imitation test, De Renzi et al.'s Movement Imitation Test (MIT)⁶ protocol was used and the cut off point of 53/72 was applied. For the conventional object use assessment, a procedure based on De Renzi's Single Object Use test (SOT)^{7, 8} was employed. The list of objects was derived from the 20 transitive gestures in the pantomime test. When scoring performance two points were given for a correct response on the first attempt, 1 for a correct response on the second attempt. This gave a maximum possible score of 64 for pantomime and 40 for object use. For the recognition test, a score of 1 was given for each correct *decision* (maximum score = 24) and a score of 1 for a correct *name* (maximum score = 24). For the Imitation test, a score of 3 was

given for a correct response in the first attempt, 2 for a correct response in the second attempt and 1 in the third attempt. This gave a maximum score of 72. For the adapted FAST test, the SOT test and the gesture recognition and naming tests, cut off points were based on 2SD from the mean performance across controls (N=14, mean age=65, SD=13; 7 female).

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Figure 1 The different cognitive processing pathways for different praxis assessment tasks

Figure 2 Illustrations of the four BCoS apraxia assessment tests