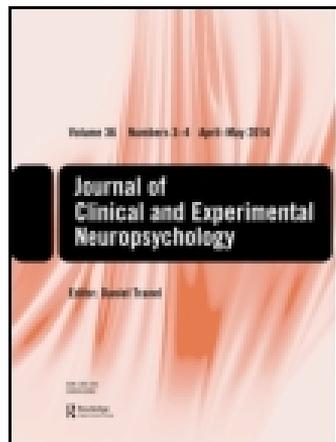


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## Short apraxia screening test

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*Background:* Limb apraxia comprises many different and common disorders, which are largely unrecognized essentially because there is no easy-to-use screening test sensitive enough to identify all types of limb praxis deficits. *Method:* We evaluated 70 right-handed patients with limb apraxia due to a single focal lesion of the left hemisphere and 40 normal controls, using a new apraxia screening test. The test covered 12 items including: intransitive gestures, transitive gestures elicited under verbal, visual, and tactile modalities, imitation of meaningful and meaningless postures and movements, and a multiple object test. *Results:* Interrater reliability was maximum for a cutoff of >2 positive items identifying apraxia on the short battery (Cohen's kappa .918,  $p < .0001$ ), and somewhat less for >3 items (Cohen's kappa .768,  $p < .0001$ ). Although both results were statistically significant, >2 was higher, indicating greater apraxia diagnosis agreement between raters at this cutoff value. *Conclusions:* The screening test proved to have high specificity and sensitivity to diagnose every type of upper limb praxis deficit, thus showing advantages over previously published tests.

**Keywords:** Apraxia evaluation; Screening test; Specificity; Sensitivity.

Limb apraxia comprises a wide spectrum of higher order motor disorders resulting from acquired or developmental brain diseases affecting purposeful posture and movement execution, both learned or novel, as well as action sequences characterized by spatio-temporal and/or conceptual deficit. These deficits may be found superimposed to more elementary disorders, but may also be concealed by these same disorders (e.g., weakness, ataxia, sensory loss, involuntary movements), as well as by dementia, aphasia, and executive dysfunction (Leiguarda & Marsden, 2000; Rothi & Heilman, 1997).

There are two broad groups of apraxic limb disorders affecting the hand and arm, which are classified according to the nature of the errors committed by patients and by the modality through which these errors are elicited. Multimodal or traditional apraxias include apraxic deficits present regardless of triggering stimulus modality—namely, limb-kinetic, ideomotor, conceptual, and ideational apraxias. In turn, modality-specific or dissociation apraxias are deficits evoked by a specific stimulus modality (e.g., auditory, visual, or tactile), making performance abnormal only under one form of elicitation and normal in response to

This article is the final and definitive version of our work. We authorize Taylor & Francis to host our manuscript, and we assign the copyright including abstract, text, bibliography, and all accompanying tables, illustrations, data, and video. Also authors do not have any potential conflict of interest in the publication of the manuscript. The Short Apraxia Screening Test (SAST) we have validated is a modification of a battery outlined during the International Workshop on Ideomotor Apraxia, held in Bethesda, Maryland, on September 2004, sponsored by the Office of Rare Diseases and the National Institute of Neurological Disorders and Stroke at the National Institutes of Health, and by the Movement Disorder Society. The authors thank the following individuals for their participation and contribution in the elaboration of the battery: Richard Andersen, Stephan Bohlhalter, Laurel Buxbaum, Leonardo Cohen, Jose L. Contreras-Vidal, Hans Joachim Freund, Scott Grafton, Leslie J. G. Rothi, Michael Graziano, Kathleen Haaland, Brenda Hanna-Pladdy, Edward B. Heaton, Kenneth Heilman, Anthony E. Lang, Jay P. Mohr, Hiroshi Shibasaki, Angela Sirigu, Alan Sunderland, Ivan Toni, Louis Wheaton, and Steven Wise.

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other types of stimuli. Limb-kinetic apraxia (LKA) is characterized by loss of hand and finger dexterity, mainly affecting manipulative movements; patients are unable to perform precise, independent, coordinated movements (Kleist, 1907; Leiguarda et al., 2003; Liepmann, 1920). Ideomotor apraxia (IMA) is defined as impairment in timing, sequencing, and spatial organization of movements and postures; patients mostly exhibit temporal and spatial errors (Rothi, Ochipa, & Heilman, 1991).

Ideational apraxia (IA) has been defined by Pick (1905) and later on by Liepmann (1908) as an impairment of tasks requiring a sequence of several acts with tools and objects (e.g., prepare a letter for mailing) but other authors use the term to denote a failure to use single tools appropriately (De Renzi, 1989). To overcome this confusion, Ochipa, Rothi, and Heilman (1992) have suggested restricting the term IA to a failure to conceive a series of acts leading to an action goal, and they introduced the term conceptual apraxia (CA) to denote deficits in the different types of tool-action knowledge as proposed by Roy and Square (1994). However, a strict difference between IA and CA is not always feasible, since patients with IA may also perform abnormally when using a single object (De Renzi & Lucchelli, 1988). Patients with IA or CA exhibit primarily content errors or semantic parapraxias (e.g., use a comb as a tooth brush) and show deficits in different forms of tool-action knowledge (e.g., they do not select the proper tool to complete an action). Nevertheless, patients with pure IA show errors only when performing a sequence of actions such as a multiple object test. The most frequent observed errors when patients perform this test are: omission (patient does not carry out an action to complete the task; e.g., he or she neglects to spread the paste on the toothbrush); mislocation (the action performed with the object was appropriate, but carried out at an inappropriate place and/or in a wrong sequence; e.g., first used toothbrush and then put toothpaste on brush); and misuse (the tool or object is used in an inappropriate way; the patient held toothbrush upside down; De Renzi & Lucchelli, 1988). In turn, modality-specific or dissociation apraxias include: auditory (verbal and nonverbal); visual, either by imitation (meaningful or meaningless, postures and/or movements) or after being shown an object; and tactile (somesthetic). Limb apraxias are common but poorly recognized disorders that can result from focal brain lesions, most commonly the result of a stroke, or from diffuse brain damage such as corticobasal degeneration or Alzheimer's disease. While Donkervoort, Dekker, Stehmann-Saris, and Deelman (2000) reported apraxia to be present in at least one third of patients after initial stroke occurring in the left hemisphere, De

Renzi (1989) found it in about 50% of patients with left-hemisphere damage, and in less than 10% of those with right-hemisphere involvement. However, the exact percentage is not known, mainly because to test limb praxis in a manner suitable for assessing it in various forms is time consuming and because there is no screening test able to detect every type of limb apraxia described above.

Contrary to common belief, which is that apraxia has no real implications and is only manifested in the clinical setting, it is well known today that upper limb apraxia does have functional impact on everyday activities. Patients present inaccurate, deficient, and often hazardous use of objects (Goldenberg & Hagmann, 1998), incorrectly selecting tools/objects needed to execute a given activity, or performing a complex action sequence (e.g., preparing an espresso) in the wrong order, or finding themselves unable to complete a task at all (Foundas et al., 1995). Furthermore, limb apraxia per se interferes with stroke patient rehabilitation, even after taking into consideration the fact that apraxic patients are often more impaired in other domains (e.g., language), than non-apraxic individuals with left-hemisphere damage (Sunderland, Bowers, Sluman, Wilcock, & Ardron, 1999; Sunderland & Sluman, 2000; van Heugten, Dekker, Deelman, Stehmann-Saris, & Kinebanian, 2000). Therefore, thorough evaluation of limb praxis is critical, not only to identify its presence, but also to correctly classify the nature of the apraxic deficit, which may help guide rehabilitation treatment (Leiguarda, 2005).

In the last decade, several screening tests have been published to this end (Almeida, Black, & Roy, 2002; Bickerton et al., 2012; Vanbellingen et al., 2011). The one by Almeida et al. (2002) selected three transitive gestures (knife, flipper, tweezers) and two intransitive gestures (okay sign, cab hailing) to capture apraxia in 37 stroke patients. Vanbellingen et al. (2011), prospectively validated a set of 12 gestures in a cohort of 31 patients with stroke. Finally, Bickerton et al. (2012) studied a small group of patients with left or right damage, using a screening battery that included pantomiming six intransitive and transitive gestures, imitating two hand sequences and two finger postures, and performing a multiple object use test and recognizing a gesture. However, none of the above described batteries was able to capture all types of limb apraxia deficits. We therefore set out to develop and validate a short and reliable apraxia screening test, which would be easy for nonspecialists to administer and sensitive enough to identify any type of apraxic upper limb disorder.

## METHOD

### Subjects and procedure

Seventy right-handed patients with single focal lesions of the left hemisphere confirmed by magnetic resonance imaging (MRI) and 40 right-handed normal controls were studied prospectively. No significant difference in age,  $t(51) = -1.52$ ,  $p = .134$ , or gender,  $\chi^2(1) = 0.002$ ,  $p = .97$ , existed between groups. Most patients presented lesions as a result of stroke (secondary to infarct or hemorrhage) while others had well-localized postsurgical lesions. Patients with large infarcts involving the whole territory of the anterior, middle, and posterior cerebral arteries or focal lesions induced by trauma were excluded. All patients were subjected to detailed neuropsychological assessment. No patients presented aphasia severe enough to affect comprehension of commands required to elicit gestures, or dementia (according to *Diagnostic and Statistical Manual of Mental Disorders—Fourth Edition, DSM-IV*; American Psychiatric Association, 1994, criteria) or movement disorders affecting the nonhemiplegic left forelimb. In particular, language was assessed with a new language bedside test for a Spanish-speaking population (Sabe et al., 2008) as well as with the shortened version for the Token Test (De Renzi & Faglioni, 1978).

Participants gave written informed consent, and the study protocol was approved by the Institutional Review Board of the Institute of Neurological Research.

The Edinburgh Handedness Inventory was used to assess handedness (Oldfield, 1971).

Apraxia evaluation was made using a comprehensive apraxia battery, based on the Florida Apraxia Screening Test—Revised (FAST-R; Rothi et al., 1992). FAST-R, which was used as the gold standard for diagnosis of apraxia, is widely used in the literature (Flores-Medina, Chavez-Oliveros, Medina, Rodriguez-Agudelo, & Solis-Vivanco, 2014; Power, Code, Croot, Sheard, & Gonzalez Rothi, 2009), including 30 gestures to verbal commands: 20 transitive and 10 intransitive. Initial assessment with this battery was implemented by three different neurologists, including two of the authors, both with extensive clinical experience in the field of apraxia. The FAST-R maximum score is 30 points, with 1 point for each correct movement. Diagnosis of apraxia was made when the subject's score was <15 points. Ideational apraxia was evaluated with the multiple object test described by De Renzi and Lucchelli (1988). A gesture-recognition test was also administered in

order to rule out severe action recognition deficits (Power et al., 2009).

The screening test was designed based on the cognitive neuropsychological model of limb praxis originally proposed by Rothi, Ochipa, and Heilman in 1991, later modified by the same authors (Rothi et al., 1992) to account for the different types of praxis dissociations observed during performance of patients with brain damage. This later model included selectivity of input modalities of the praxis system (auditory/verbal, tactile, visual object/gestural); separation of praxis reception from production to explain cases of apraxic patients who may or may not present additional difficulty discriminating gestures; a direct route for imitation, in particular of meaningless gestures; and a semantic action system or conceptual praxis system.

Based on our clinical experience in apraxia evaluation and instruments available in current literature (FAST-R; Rothi & Heilman, 1997), we designed the screening test selecting culturally similar gestures, as well as those most sensitive for apraxia identification. It covered 12 items (see Table 1): the first specifically evaluating limb-kinetic apraxia; the next two corresponding to intransitive gestures elicited on verbal command; and another six involving transitive gestures elicited by verbal command (2), after seeing an object (1), after touching an object with eyes shut (1), by imitation of a gesture (1), and using the actual object (1). Imitation of a meaningful movement and of meaningless postures and movements were included. Finally, a multiple object test was also introduced to evaluate subject ability to sequence tool/object use in an everyday setting and to assess possible dissociation between praxic tasks and everyday object use.

Analysis of subject performance was based on presence or absence of errors, using a simplification of the multiple praxis error types described by Rothi and Heilman (1997; Table 2). Left upper limb was selected for assessment in all subjects, since most patients with left-hemisphere damage suffer right-sided hemiparesis or hemiplegia.

All patients, apraxic and nonapraxic, as well as normal controls, were videotaped during evaluations conducted by two examiners. Videos were then shown to two nonspecialist blind raters, briefly trained in correct apraxia diagnosis. Raters were trained using pantomime samples to achieve consensus on the rating system and were shown sample videos with different errors, in order to clarify through examples commonly observed spatiotemporal errors. Training was conducted by two of the authors with extensive experience in apraxia diagnosis. Once raters achieved interrater agreement on training videos, actual patient recordings were

**TABLE 1**  
Short Apraxia Screening Test

<i>Items</i>	<i>Modality of elicitation</i>	<i>Type of apraxia deficit evaluated</i>
1. Rotation of a coin between fingers	Real object use	LKA
2. How to hitchhike	Verbal command	IMA-DA <sub>1</sub>
3. How to make victory sign	Verbal command	IMA-DA <sub>1</sub>
4. How to brush teeth	Verbal command	IMA-CA-DA <sub>1</sub>
5. How to use a hammer to pound a nail into a wall in front of you	Verbal command	IMA-CA-DA <sub>1</sub>
6. How to use a screwdriver	Visual object input	IMA-CA-DA <sub>2</sub>
7. How to use a key	Tactile object input	IMA-CA-DA <sub>3</sub>
8. How to use a nailcutter	Real object use	IMA-CA
9. How to brush teeth with some of these objects: (toothbrush, toothpaste, comb, nailcutter and spoon)	Verbal command	IA-IMA-CA-DA <sub>1</sub>
10. Imitation of drinking water	Visual imitation	VIA-IMA-CA-CoA
11. Imitation of meaningless posture	Visual imitation	VIA-IMA-CoA
12. Imitation of meaningless movement	Visual imitation	VIA-IMA-CoA

*Note.* A total of 12 gestures (items) of the Short Apraxia Screening Test (SAST) together with the modality of elicitation and the type of apraxic deficit evaluated. Noted that more than one type of deficit can be identified by evaluating a single item. LKA = limb-kinetic apraxia; IMA = ideomotor apraxia; DA = dissociation apraxia; DA<sub>1</sub> = patient performs abnormally only under verbal commands; DA<sub>2</sub> = patient performs abnormally only under visual input; DA<sub>3</sub> = patient performs abnormally only under tactile input; CA = conceptual apraxia; IA = ideational apraxia; VIA = visuomimetic apraxia; CoA = conduction apraxia. (3) DA; (7) VIA; (2) COA; (4) DA<sub>1</sub>; (5) DA<sub>2</sub>; (6) DA<sub>3</sub>; (1) CA.

**TABLE 2**  
Apraxic error types

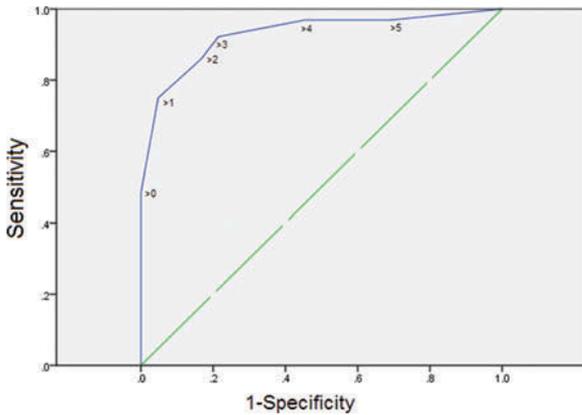
<i>Error types</i>
a <i>Temporal and spatial</i>
1 Finger and hand posture (internal configuration)
2 Configuration (or posture) of the arm (internal configuration)
3 Location of the hand space in relation to the object receiving the action (external configuration—planar orientation)
4 Location of the hand in space relative to the body (external configuration)
5 Interjoint coordination (movement or action), shape of movement (movement or action; e.g., circular vs. linear), direction of movement (movement or action; e.g., side to side instead of back and forth)
6 Amplitude (amplification, reduction, or irregularity of the characteristic amplitude of a target pantomime)
7 Timing (too slow or too fast, irregular rate of production, searching or groping) and occurrence (number of movement cycles)
8 Sequencing (addition, omission, transposition)
9 BPO (body part as object; not modified by instructions)
b <i>Conceptual</i>
10 Content: normal performance of a gesture but otherwise not related with the one requested (semantic or content)
c <i>Special categories</i>
11 Perseveration of early gesture/no response/unrecognizable response

randomly selected for scoring. A total of three consecutive meetings were held, under supervision by one of the authors, during which raters were shown random videos from patients and were asked to score each one separately.

### Statistical analysis

Independent sample *t* and chi-square tests were performed for age and gender comparison between groups, respectively. Interrater reliability for apraxia diagnosis based on potential cutoffs

of the SAST was assessed applying Cohen's kappa coefficient. A receiver operating characteristic (ROC) curve was drawn, and area under the curve (AUC) was calculated in order to evaluate SAST performance for apraxia diagnosis. AUC ranges between 0 and 1 reflect test accuracy to categorize individuals into two groups. Values of .5 represent random classification (as accurate as deciding by chance), whereas values of 1 represent ideal or perfect classification, in which all individuals are correctly classified. PASW Statistics 18 (IBM, SPSS) software was used for all analyses.



**Figure 1.** Receiver operating characteristic (ROC) curve. Each number represents a potential cutoff point. Area under the curve (AUC): .928 (95% confidence interval, CI [.879, .977]). The dashed line represents the mean of a random distribution. To view this figure in color, please visit the online issue of the Journal.

Comparison of potential different cutoff points was based on three features: (a) combination of sensitivity and specificity, shown on Figure 1 (ROC curve), in which higher AUC values (i.e., closer to 1) were associated with more accurate diagnosis; (b) positive predictive value (PPV) and negative predictive value (NPV), obtained by applying potential different cutoff points to three different hypothetical target populations; and (c) interrater reliability for categorization, which was maximized at a cutoff point of >2. We prioritized higher NPV (i.e., lower rates of lack of diagnosis), as the cost of not diagnosing a patient as apraxic would exclude the patient from potential rehabilitation. Taking all features into consideration, >2 emerged as the best cutoff point for the SAST. For clinical use, the recommended cutoff point to categorize a patient likely to suffer from apraxia is therefore >2 errors.

**RESULTS**

The SAST is a highly sensitive and a specific tool for apraxia detection by a nonspecialist. Sensitivity

and specificity rates for the diagnosis of apraxia according to cutoff are listed in Table 3, which shows positive and negative predictive values of each cutoff, for three different levels of hypothetical prevalence of apraxia in the target population.

**Reliability**

SAST AUC for apraxia diagnosis, when compared to the used gold standard (FAST-R), was .928 (Figure 1), with 95% confidence interval ranging between .879 and .977. Interrater reliability was maximum for a cutoff defining apraxia by more than 2 positive items using the SAST (Cohen’s kappa .918,  $p < .0001$ ), followed by >3-item cutoff (Cohen’s kappa .768,  $p < .0001$ ). Although both results were statistically significant, >2 was higher, indicating greater apraxia diagnosis agreement between raters at this cutoff value.

All patients had IMA, meaning they exhibited spatiotemporal errors in particular when performing transitive gestures to verbal commands. Most frequently observed errors were related to internal and external configuration, movement timing, and BPO (“body part as object” error). In addition to IMA, eight patients also had CA, since they committed unrelated content errors. Only two patients with large lesions affecting the postsylvian region failed the multiple object test. None of the patients exhibited LKA. Lesion location was not correlated with type of apraxia error exhibited by patients with IMA. This is part of another study we are conducting at present, since previous research has suggested that cortical (parietal vs. frontal) and subcortical (white matter vs. basal ganglia and thalamus) damage may cause different apraxic error profiles (Leiguarda, 2005).

**DISCUSSION**

The SAST that we have developed and validated allowed identification of all forms of limb praxis

**TABLE 3**  
Sensitivity, specificity, PPV, and NPV of the Short Apraxia Screening Battery

Cutoff	Sensitivity	Specificity	Prevalence					
			.35		.5		.65	
			PPV	NPV	PPV	NPV	PPV	NPV
>1	.97	.55	.54	.97	.68	.95	.80	.90
>2	.92	.79	.70	.95	.81	.91	.89	.84
>3	.86	.83	.74	.92	.84	.86	.91	.76
>4	.75	.95	.89	.88	.94	.79	.97	.67

Note. PPV = positive predictive value; NPV = negative predictive value.

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deficits described to date. However, it is important to emphasize that task-specific forms of apraxia (e.g., constructional apraxia) are not evaluated with our test. Patients with LKA would fail Item 1. This test was normal in all our patients with apraxia, a result explained by the fact that LKA is mainly seen in neurodegenerative diseases (e.g., corticobasal degeneration) or in the opposite hand of patients with premotor lesions, and because as described in the Method section, we evaluated only the ipsilateral left upper limb.

Patients with IMA may exhibit spatial and temporal errors on all screening test items with the exception of the first one, unless the deficit is severe. However, it is well known that IMA is particularly evident when patients pantomime transitive rather than intransitive movements to verbal commands and usually improves on imitation and even more so when handling objects. Therefore, the most sensitive items for IMA diagnosis were 2, 3, 4, and 5, in particular the last two.

Patients with CA exhibited content errors in the performance of transitive movements (e.g., patient pantomimed combing hair instead of brushing teeth or used the toothbrush as if it were a comb) because they were unable to associate tools and objects with the corresponding action. They also lost the ability to associate tools with the target objects receiving the action (e.g., patient may place toothpaste on a spoon rather than on a toothbrush). These patients may fail Items 4 to 10. Patients with IA usually failed to sequence correctly a series of acts leading to an action goal (Item 9), but were able in general to correctly manipulate single objects. The most frequent errors exhibited were omission (patient neglects to spread paste on toothbrush), misuse (held toothbrush upside down), mislocation, and/or incorrect sequence of activity performance (first used toothbrush and then put toothpaste on brush). Occasionally there were patients who, unlike those with IMA who improved on imitation, were more impaired when imitating than when pantomiming commands (conduction apraxia), or could not imitate, but performed flawlessly under other modalities (visuoimitative apraxia). These patients would fail the last three items. Furthermore, deficits could be restricted solely to imitation of meaningless postures and movement with preserved imitation of meaningful gestures, making them fail Items 11 and 12. Finally, some apraxic patients showed deficits when performing exclusively under one but not all modalities, so-called modality-specific or dissociation apraxias. These patients may fail when pantomiming a verbal command, when

seeing an object, or when palpating the object with eyes closed.

Three screening tests for limb apraxia have been published. One by Almeida et al. (2002) evaluated performance of 37 stroke patients with limb apraxia diagnosis, using a standard battery of eight transitive and eight intransitive gestures. Authors selected a combination of five gestures from the battery (three transitive and two intransitive), best capturing apraxic performance. However, this test with limited numbers of gestures failed to diagnose many praxic deficits—namely, limb-kinetic, tactile, and ideational apraxias. Furthermore, authors did not consider content errors in order to easily diagnose conceptual apraxia, nor did they include meaningless gestures or transitive gestures to verbal commands, the latter being the most sensitive for ideomotor apraxia capture.

The second by Vanbellingen et al. (2011) is an apraxia screening test based on a comprehensive standardized test for upper limb apraxia (TULIA). Authors reduced the 48 gestures originally described in TULIA to a set of 12 items and prospectively validated them in a cohort of 31 patients with stroke. Sensitivity and specificity were high. However, no items were included to evaluate limb kinetic, tactile, visual, or ideational apraxias. Further limitations were a small sample size used for validation and, as authors themselves stated, possible examiner bias resulting from TULIA global impression on subsequent short test scoring.

The third and most recent is the Birmingham screen for apraxia published by Bickerton et al. (2012). The test included intransitive and transitive pantomime gestures to auditory/written words, recognition of intransitive gestures, imitation of meaningless gestures, and a multiple object use task. Eighteen patients with right- and left-hemisphere damage took part in the construct validity study, but only eight participated in the interrater study and had performances videotaped for scoring by different trained examiners. Apraxia by definition is a production deficit; so the main criticism to this screening battery would be inclusion of gesture recognition. Action recognition is considered a multicomponent hierarchical process, where hierarchy is driven mainly by the type of task employed, and whose underlying neural substrates are shaped by learning and experience. As a matter of fact, both mirror neurons and the mentalizing system contribute to gesture recognition and involve quite different inter- and intrahemispheric networks (Villareal et al., 2008). Therefore, inclusion of action recognition tasks clearly explains

why this author found a particularly high rate of impairment in right-hemisphere-damaged patients.

As seen in Table 3, the SAST is a highly sensitive, highly specific tool for the detection of apraxia by a nonspecialist. We prioritized, as described above, higher NPV (i.e., lower rates of negative diagnosis) as the cost of not diagnosing a patient with apraxia would prevent him or her from being rehabilitated. Therefore, for clinical use, the recommended cutoff point to categorize a patient as likely to suffer from apraxia is >2 errors.

In conclusion, the SAST has many advantages over previously published tests: in particular, easy administration by nonspecialists and high sensitivity to capture all types of upper limb praxic deficits.

### SUPPLEMENTARY MATERIAL

Supplementary material is available via the “Supplementary” tab on the article’s online page (<http://dx.doi.org/10.1080/13803395.2014.951315>).

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