

Assessing limb apraxia in traumatic brain injury and spinal cord injury

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1. ABSTRACT

People with traumatic brain injury (TBI) may demonstrate action planning disorders and limb apraxia. Many patients, who sustain a spinal cord injury (SCI), sustain a co-occurring TBI (11-29 percent of people with SCI) and therefore are at risk for limb apraxia. People with SCI and TBI (SCI/TBI) rely on powered assistive devices which amplify movement. Their ability to learn complex motor compensatory strategies, that is, limb praxis, is critical to function. We wished to identify methods of screening for apraxia in patients with SCI/TBI. We reviewed instruments available for limb praxis assessment, presenting information on psychometric development, patient groups tested, commercial/clinical availability, and appropriateness for administration to people with motor weakness. Our review revealed that insufficient normative information exists for apraxia assessment in populations comparable to SCI/TBI patients who are typically young adults at the time of injury. There are few apraxia assessment instruments which do not require a motor response. Non-motoric apraxia assessments would be optimal for patients with an underlying motor weakness.

2. INTRODUCTION

One of the primary goals of neurological rehabilitative programs is to maximize the safety and adaptive ability of people with disorders of the central and peripheral nervous system. People with acquired neurological disorders have been shown to benefit from intensive, multi-disciplinary rehabilitation that may include learning to use sophisticated adaptive and assistive devices (i.e. power wheel chairs, modified utensils and tools) (1).

3. APRAXIA

3.1. Definition

Limb apraxia is a loss (as a result of a neurologic disorder) of the ability to perform learned voluntary actions where this loss is not attributed to elemental motor (tremor, weakness of the limb) or elemental sensory deficits(1). Apraxia is a disorder of performing purposeful skill movements which cannot be explained by other cognitive deficits. For example, if a patient has global aphasia and is asked to pantomime a command and does not perform this command it would not be called an apraxia. Deficits in

motor planning-sequencing, a loss of knowledge about the mechanical advantage of tools and the means by which one moves the joints to perform a skilled movement as well as the ability to perform deft movements can all occur in patients where cognition in other domains may be intact or not intact. The praxis system is critically supported by a neuroanatomic network composed of the left parietal, supplementary motor, and dorsolateral frontal cortex of the brain(2).

Limb apraxia is best defined by a loss of deft, precise independent but coordinated finger and limb movements (limb-kinetic apraxia), a specific problem in executing skilled learned purposive movements (ideomotor apraxia), a problem with knowledge about movements or tool use (conceptual apraxia), or a problem in planning or organizing actions (ideational apraxia) (1,2). Problems with translating movement concepts into action result in ideomotor apraxia. Subjects with ideomotor apraxia may make spatial and temporal errors, for example holding a toothbrush in an improper orientation so that it touches the nose. Deficient action semantics or movement knowledge (conceptual apraxia) is associated with abnormal gesture recognition and tool selection. For example the patient may not recognize what an examiner is doing who pantomimes using a spoon to stir coffee or a patient chooses a hammer to remove a screw from a board. Subjects with ideational apraxia, which may be considered a type of conceptual apraxia, have problems in sequencing actions. For example they might put a toothbrush in the mouth before taking it out to put toothpaste on it. Limb-kinetic apraxia refers to the inability to make skilled, fine movements and may present on physical examination as clumsiness in hand movements. The assessment of limb apraxia becomes especially difficult in patients with elemental motor or sensory deficits like those with SCI/TBI, since tool use errors may be mistakenly attributed to paralysis alone. Although it is important to test performance as well as discrimination and comprehension, apraxia testing must also be based on the patient's motor ability. Any test that requires movement which the patient cannot make is meaningless. If the muscle groups that enable the performance of certain movements can overcome gravity and even sustain some resistance (4/5) then these movements should be tested.

4. TRAUMATIC BRAIN INJURY (TBI) AND SPINAL CORD INJURY (SCI)

Traumatic brain injury (TBI) can be associated with limb apraxia in up to 35-60 percent of cases. Patients may demonstrate errors in skilled learned movement and errors in Activities of Daily Living (ADLs) as measured in a controlled laboratory environment, a condition which is well-studied in neurodegenerative disorders such as Alzheimer's (3-5). The type of apraxia that is observed in a patient may be affected by the part of the brain damaged (6). Although limb apraxia is commonly assumed not to have functional correlates, a large number of studies show it impairs skilled learned movement which can include activities of daily living (5, 7-12). The impact of limb

apraxia in stroke and neurodegenerative disease has been reviewed by Barrett and Foundas(12).

4.1. The unique impact of apraxia in TBI/SCI

Especially vulnerable to disability related to limb apraxia may be TBI patients with a co-occurring spinal cord injury (SCI/TBI). These patients, many of whom are dependent upon complex assistive devices, must commonly instruct others in motor tasks. A person with SCI may need to instruct a caregiver in how to use a Hoyer lift, how to perform a bowel program, how to empty a urine collection system. These may be paid caregivers who vary in experience and training. The SCI patient who is either tetraplegic or paraplegic may need to provide these instructions in an exclusively verbal system or they may be able to use gestures to augment communication. In a subject with SCI/TBI, limb apraxia may be a devastating disorder, impeding device use, or even making learning to use assistive devices unsafe. The presence of SCI, especially if it affects arm and hand function can make limb apraxia very difficult to assess because many limb apraxia assessment instruments require movement on the part of the patient.

The spinal cord model systems data collection center, the National Spinal Cord Injury Statistical Center (NSCISC) reports that 28.2 percent of patients with SCI have at least a minor brain injury with loss of consciousness, and 11.5 percent of patients have a TBI severe enough that cognitive and behavioral changes can be witnessed(13, 14). However, no information is available about the incidence of impact of limb apraxia on recovery in SCI/TBI patients. In many rehabilitative settings, limb apraxia or cognitive motor ability may not be routinely assessed.

A patient with undiagnosed limb apraxia may injure themselves or others if they use mechanical devices, such as power wheelchairs, which amplify and add power to movement. This may result in safety risk and inconvenience for the patient, surrounding personnel, and infrastructure. These inefficiencies which may result from undiagnosed cognitive motor dysfunction may be preventable with more accurate assessment and device management. However, such practice is not yet standard in SCI/TBI survivors. A more thorough and formal assessment of the patient, including limb apraxia, may identify the appropriateness of devices for particular patient. Both quality of life, if devices are inappropriately dispensed, and increased cost of care, if devices are dispensed then abandoned, can be favorably impacted by apraxia assessment in patients with SCI and TBI. It may be even more important to detect limb apraxia in SCI/TBI patients than it is in patients with stroke, neurodegenerative diseases or dementia because patients with limited mobility may use power devices, which can exaggerate movement errors exponentially, such that errors otherwise of trivial importance might pose a risk of physical harm.

It is worth emphasizing that SCI/TBI patients frequently are required to instruct or supervise others in the use of assigned assistive devices or planning movements

(such as placing a portable ramp or using a Hoyer lift). A deficit affecting movement concepts or action planning can make the supervisory role impossible. However, because people with limb apraxia are commonly unaware of the deficit, either through never being informed of a diagnosis or through anosognosia, subjects may still attempt to supervise or instruct others, incorrectly and with disastrous consequences (2).

The present standard of care for SCI/TBI patients in acute rehabilitation settings requires the therapy team to observe, train, and monitor the patient's ability to plan and perform movements. Detecting limb apraxia in SCI/TBI patients could potentially make selection of suitable adaptive devices much more accurate and efficient, saving patients and payers time and money. Planned re-assessment may allow prompt re-evaluation of device prescription in late recovery or chronic stages, when many people with SCI/TBI are no longer under close monitoring by a therapist.

4.1.1. Case example of error in power wheelchair use

A case in point is the example of Mr. M, a 50 year old man admitted for acute rehabilitation with a diagnosis of new onset paraparesis. His traumatic SCI occurred when he fell at a construction site, his place of employment. Previously independent in ambulation and activities of daily living, he was skilled at operating power devices such as forklifts. His past medical history was remarkable only for hypercholesterolemia and mild hypertension. He is married, smokes two packs of cigarettes daily, ingests alcohol weekly, and does not wear corrective lenses. By history, he is an excellent candidate for power mobility.

Standard practice in prescribing power wheelchairs for inpatients, at the acute care rehabilitation facility where he was admitted, is for the SCI survivor initially to practice using the wheelchair during therapy sessions, under the supervision of an occupational therapist. The goal is to trial various models of power wheelchairs so that an appropriate prescription could be written at discharge. These practice sessions include obstacle courses but do not include assessment for limb apraxia. When deemed safe by therapists, patients are typically allowed to use the power wheelchair during the rest of their stay. Assessment for known neurologic disorders such as apraxia or visual spatial neglect is frequently not performed in traditional wheelchair prescription.

Mr. M had been through the standard obstacle courses and received clearance for using a power wheelchair. One night, on a weekend, Mr M propelled himself incorrectly to the sink in his room. His wheelchair struck the pipe under the sink, which burst and quickly flooded his room. Shortly thereafter, the on-call resident and a member of the physical plant shut off the main valve supplying water to the entire facility. It was several hours before the water supply was restored.

During the time period that the water supply to the entire facility was shut off, toilets and showers were not

functional, potable water was supplied by bottled water, and hand-washing was maintained through a combination of using the drinking water for hand washing and using antimicrobial hand gel.

The incident described above resulted in potential safety risk and inconvenience for the facility, an inefficiency which may have resulted from undiagnosed cognitive motor dysfunction and may have been preventable with more accurate assessment and device management. However, such practice is not yet standard in SCI/TBI survivors. A more thorough and formal assessment of the patient, including limb apraxia, may have identified the inappropriateness of the device for this patient. There is a lack of knowledge about the ability (or inability) of dual diagnosis patients to either operate a power wheelchair or appropriately assist caregivers. There is no such standardized assessment, let alone investigations in this area. We hope this publication may inspire such tools.

4.2. Potential impact of subtypes of apraxia in SCI/TBI

Assessment of conceptual and ideational apraxia is especially important in patients with SCI/TBI. Risk of ideational apraxia, as contrasted with other types of conceptual apraxia and ideomotor apraxia, may be highest in people with TBI (1). SCI patients also frequently must perform three types of tasks that non-motorically impaired person do not routinely perform. These three tasks are first, to be able to state their movement needs and limitations; second, to supervise other people's use of tools; and third, or perform a task in a novel way. Intact action semantics becomes pivotal for their daily living.

Identifying limb apraxia in SCI/TBI and providing prognostic information requires that we have the appropriate instruments for the task. These are instruments that will allow for screening upstream of the elemental motor deficit. In this review, we wished to learn what methods of assessing limb apraxia may be available, feasible, and psychometrically developed so as to be useful for limb apraxia diagnosis in SCI/TBI patients. The aim of this review was to identify outcome measures for limb apraxia and to evaluate their psychometric properties. The inherent limit in extrapolating laboratory phenomena to real-world complex environments exists in all the instruments we review. The positive predictive value of praxis assessments for real-world functional dependence has not yet been established.

5. IDENTIFICATION OF APRAXIA ASSESSMENTS

We conducted a search of the scientific literature on current testing methods of limb apraxia using PubMed, Medline, PsychInfo and key search words linked by Boolean logic (ideomotor limb apraxia, conceptual limb apraxia, apraxia and spinal cord injury). We examined the text and references of several textbooks as well as the references of articles selected in the literature review process for information on assessment and treatment of limb apraxia, and inquired about test instruments to researchers in the field.

When we identified a test, we attempted to contact the researcher or testing company to acquire the test, determine how the test was standardized, whether or not it had been used in SCI/TBI patients, and investigate possible advantages and disadvantages of using each test. In an effort to assess the frequency with which the instruments we identified are being used, we searched the Mental Measurements Yearbook, an Ovid database of reviews on testing batteries used in medicine. We used the “Web of Science” website in order to record the number of citations for each instrument identified. This is included as an indication of the influence of the instrument on other researchers in the field of apraxia. We reviewed the list of tests with three experts in this area to ensure that all key instruments had been identified.

5.1. Properties of the apraxia assessments

The compilation of apraxia assessment instruments shown in Table 1 underscores three key items: data on young controls, psychometric development of the tests, and gesture generation aspects of the available apraxia assessment instruments. Because one primary goal of this publication was to identify which tests may be of use in SCI patients who cannot move their upper extremities (or other patients with limitation of upper extremity function), we have included information about which tests were motoric (requiring movement), non-motoric (do not require movement) or have both motoric and non-motoric components. In many patients with motor deficits the examiner cannot directly assess gesture production or imitation to evaluate gesture to command.

Seventeen tests require, in part, that patients being tested generate movements or tool use pantomimes to verbal command. However, subtests found in four papers, the *tool selection task* and *alternative tool selection task* in Ochipa, the *Postural Knowledge test* in Mozaz, the *Gesture Reception* and *tool selection task* of the Florida Apraxia Battery (FAB), and the gesture recognition task in Smania, required verbal rather than gestural responses (15-17). These either tested gesture recognition or other aspects of action semantics such as action planning, for example the ability to select the appropriate tool for a partially completed task (1, 15-17). Nineteen limb apraxia tests were identified (see Table 1). Three are used clinically as part of standardized clinical test batteries. These are the tests published by Kertesz, Dabul, and by Goodglass and Kaplan. The remaining tests are experimental measures.

5.1.1. Application of existing apraxia assessments to the SCI/TBI population

Instruments to assess apraxia have not been studied in the SCI or TBI population so normative data for these patients do not exist. Application of current test instruments to these populations can be assessed by whether the test is motoric or non-motoric. As can be seen in Table 1, most apraxia assessments require generation of movement on the part of the subject and therefore these tests, or the motoric component of these tests, would be inappropriate instruments to assess apraxia in the context of

spinal cord injury that impairs movement of the upper extremities.

While recognizing the importance of assessing gesture to command in an apraxia assessment, there is a need to have an ability to assess apraxia in persons with a movement disorder. Data for patients with SCI/TBI or persons with a movement disorder could not be identified for any of the seventeen tests for limb apraxia. There is a need for data within populations that have movement limitations including SCI.

5.1.2. Apraxia assessment and gesture generation

In people with SCI who have limb weakness unrelated to a brain injury, identifying limb apraxia by asking patients to make gestures may increase likelihood that examiners will make false-positive or false-negative assessment errors. Eight of the tests evaluated limb apraxia solely by asking subjects to generate gestures to command. They included the Western Aphasia Battery, Boston Diagnostic Aphasia Exam, Imitating Gestures, Apraxia Battery for Adults-II, Screening Praxis Test, Limb Apraxia Test, Florida Action Recall Test and Kaufman Hand Movement Test (18-25). The Florida Action Recall Test and the Test of Ideational Praxis require the subject to generate movement pantomimes (4, 25). However, their stimuli might also be used to assess praxic associations by subject verbal response.

5.1.3. Apraxia assessment without gesture generation

Some of the assessment tools which do not require gesturing on the part of the patient will be described in detail as they can be used to assess patients, such as those with SCI/TBI who have limitations in motor function of their upper extremities. Ochipa's conceptual praxis test, Smania's gesture recognition test, and the conceptual subtests of the Florida Apraxia Battery, and the *Postural Knowledge Test* do not require movement (1, 15-17). All four of these include tasks assessing action concepts. We could not locate published data reporting standard results for these modified tasks. Their standard scoring is based on the subject's understanding of tool movement concepts. Since production errors do not result in loss of points, these tests may also be appropriate for use in people with SCI/TBI who have sufficient movement ability to make recognizable gestures.

5.2. Normative data in young persons

Since SCI primarily affects young adults, it would be useful to know for which tests normative data are available for healthy controls under 40 years of age (13). This is of particular importance given that apraxia is commonly associated with diseases such as stroke or dementia which are more common in elderly populations and thus, these tests are more commonly administered to elderly populations. Data on young healthy controls were identified for only two tests, the Apraxia Battery for Adults-II and the Florida Action Recall Test (4, 18). Interrater reliability was available for six tests: the Western Aphasia Battery, conceptual praxis test in Ochipa, FLART, the Limb Apraxia Test and the Kaufman Hand Movement Test, and the Test of Ideational Praxis (4, 15, 19, 20-22).

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Table 1. Apraxia assessment tests

Test Name and Author	Testing Time	Motoric /Non-Motoric	Population Details	Reliability	Scoring	Availability and Times Cited	Subtests' Description	Reference
FLART Schwartz 2000	13 mins	motoric	12 with AD (73.67 yrs) 21 normals (71.95 yrs)	interrater reliability: 0.82 for AD, 0.95 for CT ADL data available also	3 raters, 2/3 blind to diagnosis of subject concept conveyed by pantomime scored, production errors did not result in loss of points <32/45 correct = apraxic	sample items available through paper 11	45 drawings of objects or scenes implying action, subject; must imagine proper tool to apply and pantomime its use; e.g. picture of bread and butter implies use of spreading knife	(4)
Conceptual praxis test Ochipa 1992		both	32 with AD 32 normals		binary pass/fail for tool selection task; scoring not delineated for other tests	75	3 subtests: tool object action, tool-object associative, mechanical knowledge	(15)
Postural Knowledge and Gesture Pantomime Production Mozaz 2002	20 items for each of 2 tests	both	20 elderly normals (77.75 yrs)		producing gestures was more difficult for normals than recognizing them	yes, basic sketch in paper 1	2 tests: postural knowledge test and gesture pantomime production 20 test and 4 training cartoons; 10 depicting intransitive action, 10 transitive action; subj. had to choose accurate gesture from 3 pictures	(16)
Gesture recognition test and tool use test Smania 2000	24 items totally	both	13 with LHD		gesture recognition: 1-10, one point for each correct tool/obj test: score: 1-14, <14 = apraxia, correct 2 pts, hesitation 1 pt, wrong 0	some items available in paper 4	Ad hoc test 5 transitive, 5 intransitive gesture recognition trials	(17)
ABA-II Dabul 2000	20 mins	motoric	40 with apraxia (33-93 yrs) 49 normals (30-90 yrs)		speech and language pathologists must score only cutoff scores indicate apraxia, no total score	yes, commercially 60	6 subtests: Subtest III assesses oral and limb apraxia, limb apraxia section consists of 10 oral directions requiring mvmt of limbs, similar to DeRenzi task	(18)
Kaufman Hand Movement Test 1983	75 items	motoric		interrater reliability 0.99	21 point multidimensional scale like PICA	0	21 items on test, variable combos for 3 hand positions – fist, palm, side	(21)
Test of Ideational Praxis (TIP) May-Benson and Cermak, 2007		motoric	80 children ages 5-8	Interrater reliability 0.85 (coefficient alpha=0.74)	total number of actions the child performed that demonstrated recognition of object affordances is recorded	Yes, in text of publication 0	Child is given objects and instructed to “show me everything you can do with this object” for single items and to “show me everything you can do with these two things together” for multiple items	(22)
Imitating Gestures DeRenzi 19802		motoric	100 with LHD (55.9yrs), 80 with RHD (55.7yrs) 100 normals (52.6 yrs)		0,1,2,3 (based on # of trials needed) max score: 72 apraxic score: < 62	yes, through paper 243	2 subtests: -Movement Imitation Test (24 items) -intransitive gestures only -Demonstration of Use Test	(23)
Screening Praxis Test Kokmen 1998	5-10 minutes 55 items	motoric	87 with AD or PD 81 normals		total score 110 0 if cannot do it, 1 if cannot complete, 2 if completes action	2	7 subtests: Oral/Facial, Upper Extremity, Lower Extremity, Axial, Sequential, Imitation, Use of Actual Objects	(25)
TULIA Vanbellingen 2010	20 min	motoric	84 LHD, 49 RHD	Construct validity shows high correlation (r=0.82 with DeRenzi test)	6 point scoring method for each item; score range 0-240	In German 0	48 items on 6 subtests for imitation and pantomime of non-symbolic intransitive and transitive gestures	(30, 31)

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FAB and FAST-R Rothi, 1997	FAB long FAST-R 20mins	both			detailed system; includes multiple error types 15/30 cutoff score for FAST-R	FAST-R – yes FAB – no 11	4 subtests: Gesture Reception, Gesture Production, Praxis Imitation, Action Semantics	(32)
Limb Apraxia Test Duffy RJ and Duffy JR 1990	long 80-250 items	motoric	77 with LHD 30 normals	interrater reliability: 0.96 internal reliability: 0.94	21 point multidimensional scale like PICA	2	8 subtests: each has 10 items imitated limb movements	(33)
FABERS Power 2010	2 hrs	both	16 healthy controls	90 percent interrater agreement	Max score 255 over 5 subtests	Yes, in appendix of publication 0	5 subtests: pantomime reception, verbal semantics, action semantics, transitive and intransitive pantomime expression, meaningless imitation errors	(34)
Deftness tests Hanna-Pladdy, 2002		motoric	13 with LHD (58.5 yrs), 13 with RHD (63.4 yrs) 60 controls (58.9yrs)		score for a test is time required to complete task except for hand held tapping test, score is mean no. of taps in 5 10 sec trials	Yes, in text of publication 2	4 deftness tests: 1) finger tapping test (assesses speed of open looped movements (mvmts)), 2) grooved pegboard test (assesses closed loop precision of proximal mvmts), 3) coin rotation task (assesses closed loop precision of distal limb mvmts), 4) hand held tapping test	(35)
Neumann and Kotchoubey, 2004	3-4 hrs for total neuro-psych assessment, 30-90 minutes for Event-Related Potentials (ERP)	Non-motoric	ERP was applied to 98 adult patients with extremely severe diffuse brain damage	ERP tests yielded effects identical with those observed in healthy controls and all effects were significant at the 0.05-0.10 level	The active hemisphere in the task is compared to the contralateral hemisphere at symmetrical sites via EEG measurements.	5	Patient is asked to imagine fast hand movements as EEG is recorded at the sites above the hand motor areas	(36)
Zwinkels 2004		both	100 patients with first stroke admitted to rehab	As indicated by percentages of agreement, Cohen's kappa and intraclass correlation coefficients, percentages of agreement for the separate items 60 percent	Gesture imitation, 3 points if correct, 2 points if imprecise or involves body part as object, 1 point if weak resemblance to correct gesture, 0 for incorrect or not recognizable gesture	Yes, in text of publication 8	Two subtests: 1) evaluates use of objects thereby assessing ideational Apraxia. Three sets of objects are presented to the patients with the instruction, "Show me how you would use...". 2) assessment of ability to imitate gestures, aiming at ideomotor Apraxia. Six gestured are demonstrated by the tester and the patient is asked to imitate the gesture	(37)
Schwartz 2002		Motoric	45 RHD, 30 LHD, 25 TBI		Scores frequently observed errors in following instructions and accomplishment of necessary steps	Commercially available 70	Naturalistic Action Test differentiates between commission errors and omission errors. Uses array of common objects to perform household tasks.	(38)

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WAB Kertesz 1982	50-70 mins	motoric	365 with aphasia 161 normal (62.8yrs)	interrater reliability: 0.99 (p. 69 of Kertesz text)	praxis exam: 20 commands given; 3 for acceptable, 2 for imitation only, 1 for approx. performance	yes, commercially 757	17 subtests: major tests include Spontaneous Speech, Comprehension, Repetition, Naming, Reading, Writing, Praxis, Drawing, Calculation, Block design, Raven's matrices	(19, 39, 40)
BDAE Goodglass and Kaplan 1983	75-150 mins	both	242 with aphasia 147 normals	alternate forms, test-retest and interrater reliability: not available	must be interpreted by a trained speech language pathologist, 2 pts for correct answer, 1 for hesitation, 0 for wrong	yes, commercially 221	12 subtests; limb apraxia relevant one is Auditory Comprehension, includes: Commands, Complex Ideational Material, Word Discrimination, Visual Confrontation Naming	(24, 40)

Note. WAB = Western Aphasia Battery; BDAE = Boston Diagnostic Aphasia Exam; ABA-II = Apraxia Battery for Adults; FAB = Florida Apraxia Battery; FAST-R = Florida Apraxia Screening Test-Revised; FLART= Florida Action Recall Test; AD = Alzheimer's Disease; PD = Parkinson's Disease; LHD = Left Hemisphere Damage; RHD = Right Hemisphere Damage; ADL = activities of daily living, EEG=electroencephalogram, TBI= Traumatic brain injury, TULIA = Test of Upper Limb Apraxia, FABERS = Florida Apraxia Battery-Extended and Revised Sydney

5.3. Psychometric development of apraxia instruments

Psychometric development of the tests of limb apraxia, in general, are incomplete. Data on experimental cohort sizes could be identified for all tests except for the Florida Apraxia Battery and Florida Apraxia Screening Test-Revised (1). Data on average age of subjects were available for the Western Aphasia Battery, Florida Action Recall Test (FLART), Apraxia Battery for Adults (ABA-II), DeRenzi's Imitating Gestures test, Postural Knowledge and Gesture Pantomime Production Test and Test of Ideational Praxis(1, 18, 19, 24). Validity with respect to activities of daily living was available only for the FLART(4). Of the seventeen tests, four are potentially available to a clinician by purchase or in published articles: the Western Aphasia Battery, Boston Diagnostic Aphasia Exam, Apraxia Battery for Adults-II (ABA) and Florida Apraxia Screening Test-Revised (FAST-R) of the Florida Apraxia Battery (FAB) (1, 18, 19, 24). We were unable to find commercially available sources for the other nine tests (see Table 1).

5.4. Conceptual apraxia

The conceptual praxis test in Ochipa includes three subsections: the first tests *tool-object action relationships*, in which subjects must demonstrate use of an object, the second tests *tool-object associative relationships*, and the third tests *mechanical knowledge*, in which subjects must select the crucial attribute of a tool by selecting an alternative when the tool normally used for the task is not present, and must devise tools that provide the desired mechanical advantage to a problem by solving a mechanical puzzle (15). The two subtests in this instrument that do not require the patient to generate movements, the *tool selection task* and *alternative tool selection task*, assess *tool object associative knowledge* and *mechanical knowledge*. In these subtests, the subject is presented with twelve partially completed tasks, e.g. a nail that is partially driven into a board. In the *tool selection task*, twelve pictures of corresponding tools were presented and subjects were required to choose the correct tool out of five options on a given trial (*tool-object associations*). In the *alternative*

tool selection task, the tool normally used for a partly-completed task is not present, and the subject must in twenty test trials identify an appropriate alternative tool to complete the task, from five options. One such task requires the subject to complete the task shown in a cartoon of a nail partially driven into a board. In this test, a subject would be expected to choose a tool other than a hammer when presented with options like a brick, wrench, screwdriver, saw, scissors, etc. The best choice, in the absence of a hammer, is then picked by the subject.

The Postural Knowledge Test features twenty test and four training cartoons, with ten cartoons depicting intransitive actions (actions not requiring an object, e.g. waving a hand) and ten depicting transitive actions (actions requiring an object or tool such as hammering a nail) (16). The subject must identify the cartoon correctly depicting an action from two other foils, e.g. for the transitive writing cartoon, the subject views a cartoon of a woman with a paper and pencil in front of her on a table, the subject is then shown three cartoons depicting the forearm and hand in various postures and must choose the one correctly displaying the posture for writing (16).

The Florida Apraxia Battery includes four subtests: *Gesture reception*, *Gesture production*, *Praxis Imitation*, and *Action Semantics*. The first and last of these subtests do not require the subject to make movements. The Florida Apraxia Screening Test Revised (FAST-R), included in this Battery, is a widely used thirty-item gesture to command test, which requires movement production. The three *Gesture reception* subtests include *Gesture Naming* in which the subject must verbally identify a gesture pantomimed by the examiner, *Gesture Decision* in which the subject must determine whether or not the examiner's pantomimed gesture is accurately performed, and *Gesture recognition* in which the subject must determine which one out of three gestures correctly depicts a pantomime of tool use or other skilled purposive action. The *Action Semantics* subtest of the FAB is a typical tool selection task, much like the tool selection task in Ochipa.'s

conceptual praxis test, in which subjects view pictures of objects representing incomplete actions and must choose the correct tool from three choices to match the pictured action (15).

Conceptual apraxia involves a different stage of dysfunctional cognitive information processing than does ideomotor apraxia, and that specific experimental measures may assess the praxis output system. Conceptual praxis tests may not be the best choice for patients with ideomotor apraxia as those tests do not tap into the functional locus of the lesion, in the output praxis system. For example, a patient who is able to correctly identify a toothbrush when asked to name the object can demonstrate an impairment of conceptual knowledge related to tool use if he attempts to eat with his toothbrush instead of a spoon (25). Internal representations may integrate both conceptual (semantic) aspects and motor preparatory procedures/planning in ideomotor apraxia. A cognitive neuropsychological model of limb praxis incorporates input (auditory/verbal, visual/object, and visual/gestural), analysis of these inputs, input through each respective input lexicon which contributes to semantics (action) which produces output lexicon and production of motor system response (25).

6. PERSPECTIVE

A first step toward developing optimal methods of limb praxis assessment in people with SCI/TBI is accomplished herein by identifying the testing methods currently available. Administration of these tests may not be feasible given constraints of staff availability. A typical hospital setting does not allow for testing which takes more than about an hour. The inpatient setting is often a busy environment with high ambient noise which may be distracting for a task requiring concentration and abstract thinking. Interruption for necessary activities such as medication administration, toileting, therapy, and feeding are all barriers to time-intensive testing. Several tests are not readily available, limiting clinical feasibility. The quality of psychometric development of several of the available limb apraxia tests is concerning because tests may not all have a scoring method with demonstrated interrater reliability among a variety of clinicians at different levels of training.

Poeck wrote in 1986, "Unlike aphasia, no standardized battery of tasks is available for the clinical evaluation of motor apraxia. The diagnosis is made mainly on the basis of personal experience and intuition. There is no paper on record where the selection of suitable items has been achieved out of a large pool of items on the basis of patient and control groups" (26, 27).

Twenty years later, as can be seen from the collection of tests identified, there remains a lack of consensus on a standard set of requirements for limb apraxia testing. Commonly used instruments to assess apraxia are inadequate to assess persons who have difficulty moving their limbs. This deficit in limb apraxia assessment particularly affects people with TBI and SCI.

Four instruments with subtests requiring only verbal responses may be most appropriate for further development in SCI/TBI. Ochipa's conceptual praxis test, Smania's gesture recognition test, the conceptual subtests of the Florida Apraxia Battery, and the *Postural Knowledge Test* may be suitable for further development in assessing people with SCI/TBI (1, 15, 16, 17).

It is unclear which of the four tests above may be the most feasible for assessing limb praxis in subjects with SCI/TBI. An appropriate testing instrument must be accurate, reliable, have discriminative ability, responsiveness, and be feasible to administer in the clinical setting. Examiners may not be able to reliably distinguish between pathologic errors related to cognitive motor abnormality and pathologic errors related to weakness alone.

The Florida Apraxia Battery (FAB), though comprehensive with over eight subtests, may take too much time to complete to be useful in a clinical setting. Smania's gesture recognition task seems promising as it isolates the pivotal subtest of the FAB, the gesture recognition subtest. However, as an ad hoc test it lacks normative data, as does the *Postural Knowledge Test*. The *tool selection task* and *alternative tool selection task*, in which the crucial attribute of the tool must be identified, might be appropriate tests to administer even to subjects who cannot generate much movement (1, 15, 16, 17).

Validity is also important, although this has already been demonstrated for a number of the scales in question. Because we were interested in using an instrument to assess improvement in apraxia, we were less interested in how initial scores predicted functional disability, than in how change relates to functional change. Thus, reliability of a measure and particularly test-retest reliability was particularly important. We were unable to find any instruments validated to detect functional change.

Whether or not an ideal instrument for assessing limb apraxia in SCI/TBI would include any subject-generated movements is difficult to state with confidence. Many subjects with ideomotor limb apraxia may perform normally on conceptual praxis tasks that do not require subjects to generate movements, despite being at risk for functional impairment (16). This is due to the fact that good performance on tests requiring subjects to generate movements; requires intact gesture input, representation and output for successful completion; and is thus also sensitive to significant input and output abnormalities. Conceptual praxis tasks may also be easier than tasks requiring movement generation (16). As it is not known how common ideomotor versus conceptual and ideational limb apraxia may be in SCI/TBI patients, it is problematic to select a measure that reliably identifies only conceptual and ideational disorders.

As a means of enhancing administration of motoric tests to patients with partial paresis, motoric tasks like gesture to command could be included and scored in a manner similar to the Florida Action Recall Test, which tests for understanding of concept by scoring the concept conveyed by the pantomime, so that "production errors are

counted as a correct response as long as the concept was interpretable and deemed correct" (4). Alternatively, one could score parts of movements based upon individual patterns of intact motor abilities, e.g. if a patient is injured at the spinal cord cervical myotome seven, one could ask him to pantomime a task like hammering a nail, but judge performance solely based on the movement and orientation of the shoulder and elbow movement.

A last possibility for assessment of praxis in SCI/TBI involves using tests traditionally used for assessing creativity (e.g. the Duncker candle task) and the Alternate Uses Test or AUT (28, 29). These tasks require subjects to suggest alternate uses for combinations of objects, toward a novel purpose (e.g. using a matchbox as a base for a candle holder). An advantage to using these tasks, traditionally used in the past for vocational assessment, is that normative data are available for young healthy subject performance. This would assess the clinically relevant need for spinal cord injured persons to conceptualize and implement novel movement strategies.

An additional limitation of assessing apraxia is that many of the tests are administered in a laboratory setting rather than in the patient's own home environment. There is an inherent limit in all such tests. Namely, these test results must be regarded as an observation made in a laboratory setting and cannot be assumed to be an exact correlate to the patients' function at home. Performance in the lab may not match performance at home and attention should be given to this critical topic in future research. Since the study did not actually assess ADLs, further work needs to be done to clarify the relationship between the laboratory testing, ADL impairment, and functional problems with eating that affect caregivers' and patients' lives.

6.1. Importance of apraxia screening in SCI/TBI

People with SCI/TBI are in need of apraxia screening for three main reasons. First, a co-occurring traumatic brain injury may damage brain action networks. Secondly, the impact of limb apraxia is expected to be much greater in SCI subjects, because they typically use complex assistive devices, must learn novel use of tools, and may need to supervise others in these functions. Finally, aging people with SCI are at age-appropriate risk for disorders associated with limb apraxia such as stroke, and neurodegenerative Alzheimer and Parkinson disease (2). Detecting limb apraxia in people with SCI may save considerable time and money for patients and insurance care providers. Device return, abandonment, and reassignment are common problems, which may be reduced by identifying subjects at risk for device adjustment failure. Accidents related to improper assistive device use also occur. Limb apraxia assessment may identify those patients requiring assistive devices and instruments with lesser ability to independently navigate and safely operate these instruments. We do not propose an assessment for apraxia to be used exclusively for persons with SCI/TBI. Rather, an assessment for apraxia which does not include the classic generation of movement portion of the apraxia assessment, may be of great utility in patients with limitation of voluntary upper extremity movement. SCI/TBI is but one example of these patients.

Underdiagnosis and lack of assessment of apraxia has clinical consequences to the patient including but not limited to limitation of function and impairment of interaction with one's environment.

Difficulties in interaction with one's environment can lead to errors in operating machinery or directing care. These types of activities rely on complex, interrelated brain domains. One of the challenges in evaluating the cognitive domain supporting complex environmental functions is in pinpointing the exact brain domains responsible for error. For a TBI patient to be taught a new procedure, multiple cognitive resources that could be damaged must be enlisted, including language, planning, imagery, inhibition of distraction, declarative memory, working memory, initiation, overcoming fatigue, and so forth. Impairment in any of these would disrupt problem solving using new tools. In this paper we examine the role of apraxia assessment in patients with SCI. This emphasis on apraxia in this paper does not imply the absence of other contributory neuropsychological impairments toward failure to acquire a new skill.

Further research investigating appropriate testing approaches, and developing norms for such tests applicable to young people, are needed. Methods are deficient to test for apraxia in young adults, the population disproportionately affected by TBI and SCI. Although the incidence of SCI and TBI affects young adults disproportionately, the prevalence of the SCI/TBI population includes aging patients who are susceptible to all disorders of senescence which includes apraxia as a sequelae. The young SCI/TBI population is uniquely susceptible to apraxia due to the intracranial injury that can occur at the same time as the SCI/TBI injury. As they enter the ranks of aging persons, they will enter a second phase of susceptibility with their age-matched peers.

Although the focus of this paper is on improving assessment methods for people with SCI/TBI, developing tests of greater clinical feasibility for this group may well generate information of benefit to all patient groups vulnerable to developing limb apraxia.

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Abbreviations: SCI: spinal cord injury; TBI: traumatic brain injury; SCI/TBI: coexisting spinal cord injury and traumatic brain injury; ADLs: activities of daily living; NSCISC: National Spinal Cord Injury Statistical Center; WAB: Western Aphasia Battery; BDAE : Boston Diagnostic Aphasia Exam; ABA-II : Apraxia Battery for Adults; FAB : Florida Apraxia Battery; FAST-R = Florida Apraxia Screening Test-Revised; FLART: Florida Action Recall Test; AD : Alzheimer's Disease; PD : Parkinson's Disease; LHD : Left Hemisphere Damage; RHD : Right

Hemisphere Damage; ADL : activities of daily living, EEG:electroencephalogram, TBI: Traumatic brain injury, TULIA : Test of Upper Limb Apraxia, FABERS : Florida Apraxia Battery-Extended and Revised Sydney; AUT: alternate uses test

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