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Praxis and Writing in a Right-Hander with Crossed Aphasia

Adam D. Falchook, MD^{1,2,4}, D. Brandon Burtis, DO^{1,2,4}, Lealani M. Acosta, MD^{1,2,4}, Liliana Salazar, BS^{1,2}, Vishnumurthy Shushrutha Hedna, MD^{1,3}, Anna Y. Khanna, MD^{1,3}, and Kenneth M. Heilman, MD^{1,2,4}

¹Department of Neurology, University of Florida, Gainesville, Florida, United States

²Center for Neuropsychological Studies, University of Florida, Gainesville, Florida, United States

³Shands at the University of Florida Stroke Program, University of Florida, Gainesville, Florida, United States

⁴Malcom Randall Veterans Affairs Medical Center, Gainesville, Florida, United States

Abstract

Studies of patients with brain lesions have demonstrated that language and praxis are mediated by dissociable networks. However, language has the capacity to influence the selection of purposeful actions. The abilities to use language and to program purposeful movements are often mediated by networks that have anatomic proximity. With hemispheric injury, the diagnosis of apraxia is often confounded by the specific influence of language impairments on the ability to select and produce transitive gestures. We report a patient who illustrates this confound. This patient is a right-handed man who developed global aphasia and neglect after a right hemispheric stroke. His right hand remained dextrous, and when asked to produce specific transitive gestures (pantomimes), he often performed normally but did make some body part as object and perseverative errors. However, he did not demonstrate the temporal or spatial errors typical of ideomotor apraxia. He also had a perseverative agraphia. Our patient's left hemisphere praxis system appeared to be intact, and the error types demonstrated during production of transitive gestures cannot be attributed to a degradation of postural and movement (praxis) programs mediated by his left hemisphere. The praxis error types are most consistent with a deficit in the ability to select the necessary praxis programs. Thus, our patient appeared to have dissociation between language and praxis programs that resulted in body part as object and perseverative errors.

Keywords

crossed aphasia; apraxia; agraphia; handedness; hemispheric specialization

Introduction

Liepmann (1905) established that apraxia is most common in people with left hemisphere damage who have aphasia. However, he also reported that, less commonly, apraxia can occur without aphasia, and aphasia can occur without apraxia. Liepmann and Mass (1907) and Liepmann (1908) posited that the laterality of the movement programs, rather than language, primarily accounted for handedness. Goodglass and Kaplan (1963) demonstrated that while apraxia is more common among aphasics than neurologically impaired people without aphasia, there was not a correlation between severity of apraxia and severity of

aphasia. They interpreted this as evidence that the systems that mediate language and praxis are distinct to a certain extent. In contrast, Goldstein (1948) wrote "...for those cases where the abstract attitude is impaired and this impairment is more or less the cause of the aphasic symptoms. Under this condition, particularly the pantomime may be disturbed severely, too." We report a right-handed man who developed a global aphasia from a right middle cerebral artery territory infarct (crossed aphasia). Our patient's performance on tests of praxis helps provide new insight into the nature of the relationship between language and praxis.

Geschwind (1975) proposed that when a person with typical brain organization is asked to pantomime how to use a specific tool, this auditory input is first decoded in the primary auditory association cortex (Wernicke's area, located in the left posterior portion of the superior temporal gyrus). To activate the motor system, this auditory information is relayed to the left sided motor association cortex (premotor cortex) by the arcuate fasciculus. From the left premotor cortex, the information can either be relayed to the left motor cortex, if the pantomime is to be performed with the right hand, or it is relayed across the anterior corpus callosum to the right premotor cortex and then to the right motor cortex if the pantomime is to be performed with the left hand. Geschwind noted that this model does not account for pantomimes performed by imitation or in response to the visual presentation of the tool (rather than in response to an auditory verbal command). To account for this, he proposed that visual information is relayed from visual association cortex to premotor areas that select and prepare the movements that produce the pantomime.

Heilman et al (1982) proposed that auditory visual or somesthetic input is relayed to the left inferior parietal lobe, and from there to the left premotor cortex. The model proposed by Heilman et al (1982) is consistent with Liepmann's hypothesis that the left parietal lobe contains movement representations that are the memories of the spatial and temporal components of learned skilled purposeful movements. Heilman et al called these representations visuokinesthetic motor engrams. The model by Heilman et al also provides a mechanism to account for how auditory or visual information can access these visuokinesthetic engrams. To support this model, Heilman et al demonstrated that people with fluent aphasia (left temporoparietal lesions) who also had apraxia were unable to recognize or discriminate between correctly and improperly performed transitive gestures (pantomimes), consistent with destruction of these left parietal visuokinesthetic engrams. People with non-fluent aphasia (left frontal lesions) and apraxia were, however, able to recognize and discriminate incorrectly performed pantomimes but not produce transitive gestures. In these people, the left parietal visuokinesthetic engrams remained intact but were disconnected from the left frontal premotor regions. These premotor regions are responsible for developing the motor programs that activate the motor cortex and allow the implementation of the movements required for the correct performance of the transitive gestures.

Johnson-Frey et al (2005) demonstrated that when healthy right-handed adults prepare to perform transitive gestures, there is increased fMRI activity in a left hemispheric network that includes the left posterior temporal cortex including the posterior middle temporal gyrus, the left anterior supramarginal gyrus, a second and more caudal left hemispheric region in the left inferior parietal lobule, the left inferior frontal gyrus, the left ventral premotor cortex, and the left dorsolateral prefrontal cortex. While some right-handed participants had bilateral parietal activation and one had unilateral right parietal activation, in the majority of participants, a left lateralized praxis network was activated regardless of the hand for which the transitive gesture was planned. This study provided converging evidence that left frontal, parietal, and temporal regions are important nodes in the networks that mediate the ability to select, prepare, and program transitive gestures.

Kalénine et al (2010) demonstrated that an impairment of the ability to recognize the pantomime of how to use a tool from among semantically related foils (pantomimes of how to use related tools) correlated most strongly with damage to the left posterior middle temporal gyrus. An impairment of the ability to recognize the pantomime of how to correctly use a tool from among spatially related foils (pantomimes in which the hand or arm posture, amplitude, or timing was incorrect) correlated most strongly with damage to the left inferior parietal lobule. Furthermore, damage to the left inferior frontal gyrus did not correlate with an impairment of the ability to recognize transitive gestures.

This study by Kalénine et al (2010) supports the model proposed by Heilman et al (1982) and provides further evidence that damage to the left inferior frontal gyrus is insufficient to impair the ability to recognize correctly performed transitive gestures. However, Grafton et al (1997) demonstrated that as compared to observation of abstract geometrical designs, when healthy adults observe tools there is increased fMRI activity in the left dorsal premotor cortex and an area of the left inferior prefrontal gyrus that is transitional between Brodmann's areas 45 and 46. Increased activity in Broca's area was present when the tools or their associated uses (actions) were silently named, but not when the tools were only observed. Grafton et al suggested that the left premotor activation during observation of tools may implicate this brain region in comprehension of the visually presented tools, and they suggested that the dorsal premotor cortex may mediate associative motor learning between the sensory representations of a tool and the movements necessary for the tool's action.

Halsband and Freund (1990) demonstrated that people with lesions of the premotor cortex have impaired associative motor learning, regardless of whether the arm movements to be learned were associated with visual, auditory, or tactile stimuli. The instruction to pantomime to verbal command may require retrieval of auditory-motor associative knowledge. Furthermore, the name of the tool may generate an image that leads to retrieval of visuokinesthetic-motor associative knowledge. In either case, retrieval of associative motor knowledge necessary for production of transitive gestures appears to require different posterior to frontal connections than those necessary for retrieval of the tool's name. Ochipa et al (1989) reported the case of a left-hander who, after a right hemisphere infarct, was able to name tools but not identify the tools by their function or perform the transitive gestures associated with the tools.

Wheaton et al (2005) demonstrated that when healthy adults perform transitive gestures or intransitive (communicative) gestures, EEG activity in the left parietal lobe preceded activity in the left frontal lobe. Greater mesial frontal activity preceded transitive as compared to intransitive gestures. This study demonstrates that while selection and preparation of transitive and intransitive gestures begins in the parietal lobe, the mesial frontal lobe plays a role in retrieval of learned skilled transitive gestures that is somewhat distinct from its role in the retrieval of over-learned intransitive gestures. The finding of increased mesial frontal activity during selection and preparation for tool use is also consistent with previously reported cases of apraxia after damage to the left supplementary motor area (Watson et al, 1986).

This case report is based on the evaluation of a right-handed man with global aphasia from a right middle cerebral artery infarct. As posited by Liepmann (1908), if this man's visuokinesthetic engrams (spatial-temporal movement representations) are lateralized to the left hemisphere, or represented in both hemispheres, we would not expect any temporal or spatial errors during the production of transitive gestures (Poizner et al, 1990). In addition, if this man's conceptual tool-action knowledge (Roy, 1983, Roy and Square 1985, Ochipa et al, 1992, Schwartz et al, 2000) is lateralized to the left hemisphere, or represented in both

hemispheres, we would also not expect any content errors (incorrect selection of a transitive gesture for a related tool). In the setting of an otherwise intact left hemisphere praxis system and global aphasia from a right hemispheric infarct, the ability to retrieve words and the ability to retrieve transitive gestures, two distinct processes, may be impaired by the same underlying disorder, such as impaired attentional disengagement. Alternatively, an impaired ability to select and prepare transitive gestures may directly result from a reduced capacity for language to influence action selection.

Case Description

The patient is a 51 year old right-handed man who awoke in this usual state of health on the day of admission to the hospital. His fiancée asked if he wanted a cup of coffee and he replied “Yes.” She left the room and returned a few minutes later to find him lying in a doorway, unable to speak or move his left side. He was brought to Shands Hospital at the University of Florida, diagnosed with an acute stroke on the basis of neurological and radiological evaluation, and intravenous tPA was administered. The patient’s son reports that the two of them had played golf three days earlier and the patient did not have any neurological problems at that time. The patient has a history of hypertension and myocardial infarction with placement of two coronary stents, and he also had a history of cervical spinal surgery. There was no history of previous strokes. Inpatient medications included a nicotine patch, ranitidine, thiamine, aspirin, subcutaneous heparin, and n-acetylcysteine. Levetiracetam was started by the emergency medical technicians because of their concern for seizures. On admission to the hospital, the patient had an EEG that showed mild depression and slowing in the right temporal region and occasional slowing on the left. There was, however, no epileptiform or subclinical seizure activity.

Whereas our patient only went to school through the eighth or ninth grade, he did not have a known learning disability and had been working as the owner of a courier business up to the day before the stroke. The patient has smoked one pack of cigarettes daily for many years and would sometimes drink alcohol on weekends. He is engaged and lives with his fiancée. There was no reported family history of neurological disease. The patient has always been right-handed, and he swings a golf club right-handed. There is no family history of left-handedness among the patient’s parents, five siblings, and three children.

When examined three days after the stroke, his vital signs were stable. The patient was sleeping but easily awakened and was in no acute distress. Heart rate and rhythm were regular with no murmurs, rubs, or gallops. His optic discs were sharp bilaterally. Visual fields could not be reliably assessed. His extraocular movements were full and there was no eye deviation. He had flattening of his left nasolabial fold. Facial sensation was symmetric. The patient could not protrude his tongue to verbal command, but he was able to protrude his tongue, which was in midline, when imitating the examiner. There was some mitgehen (facilitatory) paratonia in the right arm and leg. On the right side of his body, he had normal strength in all major muscle groups. However, on his left side, he had 2/5 strength in the muscles of the left upper extremity but no movement of the fingers and 3/5 strength in his left lower extremity. He was able to raise his left leg off the bed. Sensation to sharp tactile stimulation was intact in the right arm and bilaterally intact in his lower extremities. The patient did not consistently respond to sharp stimuli applied to his left upper extremity. Deep tendon reflexes were 2/4 in the left upper extremity at the biceps, triceps, and brachioradialis, 3/4 in all other extremities (right biceps, triceps, and brachioradialis, bilateral patella and ankles). Plantar responses were extensor (up going) on the left and flexor (down going) on the right. Finger to nose testing was intact with the right upper limb, with no evidence of ataxia or optic ataxia. With his left arm weakness, these functions could not be tested on the left side. Gait was not assessed.

Our patient remained alert and attempted to cooperate with this examination. However, his performance was prominently affected by his propensity to make perseverative responses. His speech was non-fluent and mostly consisted of over learned phrases, such as “excuse me” and “thank you.” He would also sometimes repeatedly say sequences of words, such as “see can when then.” However, on further testing of automatic speech, the patient was unable to count forwards or backwards, sing familiar songs, or say the Pledge of Allegiance (though he did bring his right hand across midline to cover his heart when he heard the term “Pledge of Allegiance”). Speech was not distorted or dysarthric. There was no evidence of jargon aphasia or production of either semantic or phonemic paraphasic errors. He was able to follow some one-step commands, such as “raise your hand” or “shut your eyes.” He was unable to point to named objects, although this was limited by stimulus-bound behavior, and he most commonly pointed to all pictures presented on the page. When objects were held side by side, he consistently pointed to the object on the right, suggestive of spatial neglect. He was unable to name colors or point to named colors. He was unable to point to named body parts and consistently pointed to his nose, although he was not initially asked to point to his nose. When requested to repeat, he was unable to repeat any sentences or words, and he consistently replied with automatic phrases, such as “excuse me.” He replied with these same over learned phrases in response to questions that could be answered with yes/no responses, when asked to name pictures from the Boston Naming Test (Kaplan et al, 1983), and when asked to read printed words.

He had a linguistic-aphasic agraphia together with perseveration. When asked to write words to dictation, he consistently wrote various combinations of the letters H, C, K, E, and Y. It appeared, however, that he had intact grapheme-motor representations for those letters he wrote, since these letters were always printed normally with no evidence of apraxic agraphia. He was able to normally write his name. He was unable to copy shapes, such as a triangle, square, and circle. Uncertain as to his task when he saw the circle, he drew three lines within the circle so that it resembled a peace sign. He was unable to hold up his index finger to verbal command, although he was able to hold up his thumb to verbal command. In addition, right-left orientation could not be clearly assessed.

When asked to imitate the examiner’s finger movements, our patient repeatedly had difficulty with this task. For example, when the examiner held up his index finger, the patient held up his index finger and pinky. However, on further testing, the patient was able to hold up his index finger appropriately when imitating the examiner. In contrast, his ability to imitate arm movements was notably better than his ability to imitate finger movements. When the examiner raised his arm up, down, or to the right; the patient was able to imitate this correctly. However, when the examiner moved his arm across the body to the left, the patient brought his arm to midline and then stopped, again suggestive of hemispatial neglect. Later in the exam, after the examiner had succeeded in getting the patient to attend to left body-centered hemispace, the patient was then able to move his right arm partially into left body-centered hemispace. The patient was unable to follow instructions to perform other tests of neglect such as the line bisection test.

Since his left upper limb was paretic we could not assess this limb for limb-kinetic apraxia. However, Hanna-Pladdy et al (2002), using a coin (nickel) rotation task, reported that right handed patients with left hemispheric infarctions are impaired when using their ipsilesional left hand. Thus, in our patient a coin rotation test was performed with his ipsilesional right hand. The patient was able to perform this task, and the time it took the patient to perform twenty 180 degree rotations of a nickel was recorded. Times for three trials were: 18.6 seconds, 17.5 seconds, and 15.6 seconds. This patient may have not understood the instructions to rotate the coin between the thumb, forefinger and middle finger, and instead

this patient sometimes used his ring finger in addition to his thumb, forefinger and middle finger to rotate the coin.

His ability to perform transitive gestures was assessed with the Brief Apraxia Screening Test (Efros et al., 2005). This test consists of twenty-three transitive gestures and one intransitive gesture, all performed to verbal command. The patient attempted all gestures with his right hand. He correctly performed 11 gestures, 10 transitive and 1 intransitive. He committed 6 body part as object errors and 4 perseverative errors. When asked to scramble eggs with a fork, he demonstrated how he would flip the eggs in a frying pan and then salted the eggs, but he did not demonstrate how to scramble eggs with a fork. For two verbal commands, he made unclassifiable errors, such as picking at his clothes. Of note, during the production of the transitive gestures, he was never observed to make the spatial or temporal errors that are typical of patients with ideomotor apraxia (Poizner et al., 1990). The patient was also consistently able to normally perform intransitive gestures, such as showing how to hitchhike and salute. The patient was able to correctly perform some facial and respiratory purposeful action to command such as kiss, blow out candles, and cough. However, his demonstration of how to drink through a straw was questionable, and he was not able to protrude his tongue to verbal command, although he was able to do so to imitation. Table 1 summarizes our patient's performance on the tests of ideomotor praxis and limb kinetic praxis.

MRI of our patient's brain (Figure 1) showed an extensive acute infarction in the right middle cerebral artery (MCA) territory. There was also injury to the brain in the territories supplied by the right anterior choroidal artery and the right recurrent artery of Heubner. There was no evidence of previous strokes or other disease of the left hemisphere. Computer tomographic angiography (CTA) was significant for dissection and occlusion of the right cervical internal carotid artery (ICA) extending to occlude the proximal right middle cerebral artery (MCA). There was focal dissection at the origin of the left ICA and 50% stenosis of the proximal left subclavian artery.

Discussion

This 51 year old right-handed man who sustained a large right hemispheric infarction developed global aphasia with spontaneous speech that primarily consisted of over-learned phrases, limited verbal comprehension, and an inability to repeat or name. In addition to this aphasia he had evidence of spatial neglect with motor (action-intentional) neglect. He had preserved dexterity with the right hand, and with his right upper limb he made no temporal or spatial errors during performance of transitive gestures. However, he made frequent body part as object (BPO) errors such that he moved the hand and arm as if his upper extremity were the tool rather than demonstrating how he would hold and use the tool. He also made perseverative errors, performance of a previously requested gesture when asked to perform a new gesture, and he demonstrated perseverative agraphia such that he only wrote combinations of the same five letters. Whereas these written letters were all normally produced, his attempts at writing were characterized by marked graphemic perseveration. Since motor perseveration severely impaired this man's ability to write, we were unable to learn if he had an impairment of phoneme to grapheme conversion, which is often associated with phonological dysfunction in the setting of global aphasia, or a degradation of his orthographic lexical representations that mediate the ability to write whole words, including irregularly spelled words, as these representations may remain relatively intact even in the setting of impaired phoneme to grapheme conversion (Roeltgen et al, 1983).

It appears that this right-handed patient had atypical right hemisphere dominance for language, and he did have typical left hemisphere dominance for praxis. Visuokinesthetic

engrams represent the memory for the temporal and spatial organization of purposeful transitive and intransitive actions including the ability to pantomime. Damage to, or disconnection from, these visuokinesthetic motor engrams has been associated with impairments of limb orientation, interjoint coordination, timing, and the integration of the temporal and spatial aspects of upper limb movements during the performance, including pantomimes, of learned skilled movements in people with left hemisphere damage (Poizner et al, 1990). Our patient was not observed to make any spatial or temporal errors, and this suggests that while our right-handed patient had atypical (right hemispheric) language dominance, the visuokinesthetic motor engrams that mediate the ability to produce learned skilled gestures were lateralized to his left hemisphere.

Dissociation of hemispheric specializations for language and praxis is not uncommon in right-handers with atypical language dominance. Alexander et al (1989) noted that only 3 of 27 right-handers with crossed aphasia from right hemisphere lesions had limb apraxia that persisted beyond the acute period after the stroke. The study by Alexander et al (1989) provides evidence that visuokinesthetic engrams are most often lateralized to the left hemisphere in right-handers and that hemispheric specialization of language, as well as visuokinesthetic movement representations, may not entirely predict handedness. Hand preference may also be influenced by hemispheric specialization for the ability to program deft (precise, independent, and coordinated) upper limb movements (Hanna-Pladdy et al, 2002; Barber et al, 2012).

The coin (nickel) rotation test requires precise and independent, but also coordinated, finger movements, and this test is used to assess dexterity-deftness (Hanna-Pladdy et al., 2002). During the coin rotation test, our patient demonstrated preserved deftness for fine finger movements made with the right hand. Liepmann (1920) proposed that limb-kinetic apraxia results from a loss of the “innervatory patterns” that mediate the ability to make precise independent finger movements. Hanna-Pladdy et al (2002) demonstrated that among right-handers, right hemisphere lesions produced a contralateral limb-kinetic apraxia (of the left hand). In contrast, left hemisphere lesions produced a bilateral limb-kinetic apraxia. This asymmetry suggests that in right-handers, the left hemisphere helps program deft movements for both hands and thus is dominant for mediation of deft movements (limb-kinetic praxis). Our patient’s preserved ability to make deft fine finger movements with his right hand suggests that the motor innervatory programs that mediate limb-kinetic praxis are lateralized to his left hemisphere. However, it is also possible that before his stroke, our patient’s motor innervatory programs that control each hand were primarily mediated by the contralateral hemisphere.

In the setting of global aphasia and an inability to repeat, name, write words, or read, our patient had a remarkably preserved ability to pantomime to verbal command. He correctly performed 11/24 gestures to verbal command, and for 6 additional verbal commands, he made BPO errors. When making these BPO errors, he appeared to have comprehended the name of the tool since he produced a gestural emblem for the tool when asked to pantomime the tool’s use. This dissociation suggests that this man’s lexical-semantic systems for tools may have been mediated by his left hemisphere. Warrington and Shallice (1984) and Warrington and McCarthy (1987) provided evidence that people can have category specific lexical-semantic impairments, and that this specificity may be related to the sensory modality that is critical in formation of this lexical-semantic network. Whereas this man’s lexical and semantic networks were primarily lateralized to his right hemisphere, his lexical-semantic networks for tools and actions appear to be lateralized to his left hemisphere (or represented in both hemispheres), and this left hemispheric lateralization may be related to lateralization of his visuokinesthetic motor representation for purposeful skilled movement to this same hemisphere.

Geschwind and Levitsky (1968) provided evidence that functional hemispheric specialization may be strongly associated with anatomical asymmetry. Thiebaut de Schotten et al (2011) have demonstrated that in healthy right-handed adults, the segment of the arcuate fasciculus that directly connects Wernicke's area to Broca's area has a greater volume in the language dominant left hemisphere. Furthermore, Makris et al (2012) demonstrated that in humans, the middle longitudinal fasciculus connects the temporal pole and superior temporal regions with the inferior parietal lobule more strongly in the left than right hemisphere. Although diffusion tensor imaging was not performed for our patient, he developed global aphasia from a right hemisphere lesion, and it is possible that our patient's arcuate fasciculus was more strongly lateralized to his right hemisphere and thus damaged by the right middle cerebral artery territory infarct. However, our patient's performance on the test of ideomotor praxis in response to verbal commands, with no temporal or spatial errors, suggests that his visuokinesthetic motor engrams are more strongly lateralized to the left hemisphere. The left superior temporal gyrus is part of a network that stores lexical representations including those for tools, and the inferior parietal lobule is part of a network that stores spatiotemporal movement representations for transitive actions. It is possible that in our patient, the middle longitudinal fasciculus, a connection between these two brain regions, may have been more strongly lateralized to the left hemisphere.

Goodglass and Kaplan (1963) studied gestural ability in 20 men with aphasia and 19 men with neurological disease but normal performance on the aphasia screening tests. The two groups were matched for age and performance IQ. Presence of BPO errors correlated with severity of gestural impairment in both groups and not with severity of aphasia in the aphasic group. However, BPO errors were more common in the aphasic group than in the control group. The results of the study by Goodglass and Kaplan suggest that BPO errors are a sign of ideomotor apraxia. However, the relationship between BPO errors and aphasia is not fully explained.

Duffy and Duffy (1989) reported that among 28 left hemisphere damaged people with aphasia, the frequency of BPO errors did not correlate with impairments of the ability to pantomime the use of a tool in response to its picture or with the ability or with the ability to imitate motor acts. The frequency of BPO errors did not correlate with severity of aphasia or differ when the left hemisphere damaged aphasic group was compared to a right hemisphere damaged group and a control group. However, Duffy and Duffy (1989) did note that there was a positive correlation between individual items that elicited BPO errors in the right hemisphere damaged group and the control group, while frequency with which individual test items elicited BPO errors in the left hemisphere damaged aphasic group did not correlate with the frequency with which each of these test items elicited BPO errors in the other two groups.

Raymer et al (1997) demonstrated that there was not a significant difference in the number of BPO errors between a left hemisphere damaged group and a control group instructed to demonstrate how to hold and use the tools. However, when healthy control participants and participants with left hemisphere damage were reinstructed not to use their hand as if it were the tool, the healthy control participants correctly modified almost all BPO errors, whereas left hemisphere damaged subjects were, for the most part, unable to correct the BPO errors. Although the left hemisphere damaged participants in the study by Raymer et al had normal auditory comprehension on the yes/no subtest from the Western Aphasia Battery (Kertesz, 1982), it is possible that these participants did not fully understand the request and thought the examiner wanted to see an emblem of the tool. Alternatively, these left hemisphere damaged participants may have comprehended the command but lost the knowledge of how to make the correct hand-arm posture necessary to produce the transitive gesture.

Our patient had preserved deftness in his right hand, and he often correctly performed transitive pantomimes to command with no evidence of temporal or spatial errors. Thus, it would appear that the BPO errors produced by our patient cannot be attributed to damage to the left hemisphere praxis system. However, it is possible that the BPO errors reflect our patient's impaired comprehension of the task and this comprehension deficit is associated with his aphasia. Partial support for this postulate comes from Wang and Goodglass (1992), who demonstrated a strong correlation between auditory comprehension and the ability to produce transitive gestures, although they did not assess the relation between language and BPO errors.

Overton and Jackson (1973) asked children between 3 and 8 years of age to pretend to use six common tools and implements. Their results were consistent with an earlier study by Kaplan (1968), who initially noted that children normally produce BPO errors that resemble those of adults with acquired aphasia. Three year old children most often performed gestures as BPO errors and uncommonly as pantomimes. The ability to perform these gestures as pantomimes increased from 4 to 6 to 8 years of age while the frequency of BPO errors decreased. Peigneux and van der Linden (1999) provided evidence that BPO errors are also more common in healthy older adults, as compared to younger adults, although there was no difference between the groups when they were subsequently re-instructed to avoid the BPO errors. These investigators suggested that the increased incidence of BPO errors in older adults could be related to an impairment of inhibitory control and an inability to inhibit the gestural emblems for tools during assessment of praxis. In children, BPO errors may result from impaired inhibitory control or be associated with language skills that have also not fully developed. Inhibitory control is mediated by the frontal lobes (Luria, 1965). Frontal lobes myelination occurs relatively late in human development (Klingberg et al, 1999), and frontal lobe white matter connections are particularly susceptible to damage with aging (Jernigan et al, 2001).

The second most common type of praxis error made by our patient was perseverative errors (4/24) such that when asked to demonstrate the use of a tool, he produced a previously requested transitive gesture. The inability to inhibit a previously produced response when the task calls for the initiation of a new type of response can lead to motor perseveration, and perseverative errors are often characteristic of frontal lobe damage (Luria, 1965). Albert and Sandson (1986) demonstrated that, when compared to non-aphasic patients with right hemisphere damage, people with aphasia are more likely to produce recurrent perseverations during a picture naming test or when asked to draw pictures to command. Albert and Sandson (1986) defined recurrent perseveration as the inability to inhibit all or part of a past response when presented with a related stimulus, and they noted that this type of perseveration was more common with left posterior (temporal-parietal) as compared to left anterior (frontal) cortical lesions. Although recurrent perseveration during a naming test could be related to impaired lexical retrieval, the group with aphasia from left hemisphere damage also produced recurrent perseverations when asked to draw pictures to command. In the setting of aphasia, either impaired comprehension of the command or a degradation of the lexical-semantic representation for the item to be drawn may have resulted in recurrent perseveration during this non-verbal drawing task, and a degradation of our patient's right hemisphere mediated lexical-semantic system may have contributed to the perseveration we observed.

Roy (1996) proposed that response selection is the step that bridges the praxis conceptual system (tool and action knowledge) with the praxis production system that is necessary to produce the pantomime. It is possible that in our patient, impaired comprehension with damage to lexical-semantic networks, or, disconnection of lexical-semantic knowledge from the praxis system may have affected his ability to select and initiate the correct pantomime

in response to a verbal command. This may have caused him to perseverate and retrieve an action representation for a previously performed gesture. It is also possible that both BPO errors and perseverative errors produced by our patient reflected an impairment of response inhibition. While aphasia or impaired response inhibition could have accounted for the two primary error types produced by our patient during assessment of ideomotor praxis, these neurological impairments do not explain why our patient with global aphasia was able to correctly produce 11/24 transitive gestures in response to verbal command.

To further understand the nature of our patient's ability to perform transitive gestures to verbal command, we examined the individual items performed correctly or incorrectly. Of the 24 items on the Brief Apraxia Screening Test, 11 begin with the word "use," for example, "use a hand saw to cut wood," while the other 13 begin with a verb more specific to the gesture such as "throw a baseball." Of the transitive gestures performed incorrectly, 10 of 13 were in response to commands that began with the word "use." In contrast, 10 of 11 gestures performed correctly were in response to commands that began with the requested action such as "sew with a needle." The one gesture performed correctly in response to a command that begins with the word "use" was "use a razor to shave your face." This is likely to be a relatively over-learned and well practiced action.

The 11 commands that began with the word "use" tended to be longer (median 10 words, mean 9 words, standard deviation 4 words) than the 13 commands that began with a verb more descriptive of the action (median 4 words, mean 6 words, standard deviation 4 words). For our patient with aphasia, longer verbal commands may have been more difficult to comprehend. Our patient demonstrated perseveration and a marked impairment of attentional disengagement. Thus, it is also possible that he was best able to comprehend the requested action when it was presented at the beginning of a sentence, such as "brush teeth." When the action was preceded by several other words, such as "use a comb to fix your hair," he may have perseverated on the initial words of the sentence with a resultant impaired ability to comprehend subsequent words that were more descriptive of the requested action. However, some transitive gestures in response to shorter commands that did not begin with the word "use" were also performed incorrectly, such as "slice bread" and "staple papers together." We were unable to find any other explanation that more consistently explained the pattern of correctly and incorrectly performed gestures.

Our patient had spatial neglect with elements of motor (action-intentional) neglect. Fiorelli et al (1991) demonstrated that some patients with motor neglect from right hemisphere lesions have reduced metabolism of the otherwise intact left hemisphere, an effect known as diaschisis. Thus, it is also possible that while our patient's left hemispheric ideomotor and limb kinetic praxis networks were intact, the function of these praxis networks was impaired by diaschisis from right hemisphere damage, and this led to an inconsistent ability to correctly select and perform transitive gestures. Our patient's EEG showed mild depression and slowing in the right temporal region and, consistent with diaschisis, occasional slowing on the left.

Our patient's performance on the test of ideomotor praxis can be interpreted as an impairment of response selection. Petrides and Pandya (2009) have proposed that Broca's area in humans, and its homologous region in other primates, could mediate retrieval from posterior cortical regions as necessary for the control of actions including tool use and gestural communication. While the left hemisphere appears to be necessary for action selection in an abstract context, such as performance of a pantomime or a sequence of meaningless movements (Kimura and Archibald, 1974; Rapcsak et al, 1993), it remains unknown how these functions relate to typical left hemispheric dominance for language. Our patient had global aphasia and an intact left hemisphere. Although aphasia may have

contributed to his impaired ability to select and perform transitive gestures, this impairment cannot be attributed to left hemisphere damage. Perseveration and impaired response inhibition could also have resulted from right frontal lobe damage.

Luria (1966) proposed an ontogeny of motor control that progresses from reflexive movements to actions in response to verbal commands and then to self-directed actions guided by inner speech. Our right-handed patient developed global aphasia after a right hemispheric infarct. The left hemisphere innervatory patterns and visuokinesthetic engrams remained intact although disconnected from the language dominant right hemisphere. This case supports Luria's proposal that the capacity for language plays an important role in the ability to select actions in the setting of a lack of environmental cues to guide behavior.

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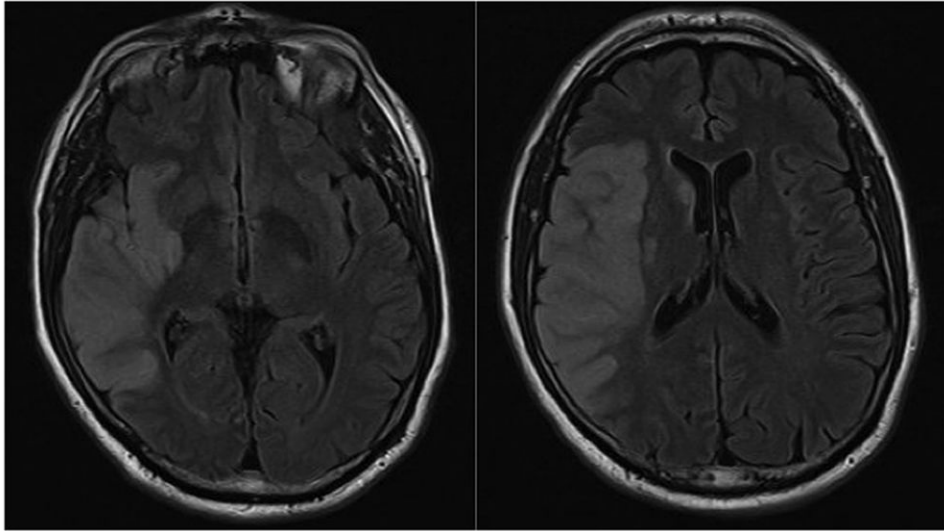


Figure 1. Magnetic resonance images demonstrate an acute infarction in the right middle cerebral artery territory.

Table 1

Tests of ideomotor praxis and limb kinetic praxis*

Brief Apraxia Screening Test (Efros et al 2005)	
Correct gestures	11/24
Body part as object errors	6/24
Perseverative errors	4/24
Unclassifiable errors	3/24
Coin rotation test**	18.6 seconds, 17.5 seconds, 15.6 seconds

* all tests were performed with the ipsilesional right hand

** Hanna-Pladdy et al (2002) reported a mean time of 15.4 seconds (SD 3.7 seconds) for coin rotation performed with the right hand by right-handers with right hemisphere damage and 22.2 seconds (SD 8.1 seconds) for coin rotation performed with the right hand by right-handers with left hemisphere damage.