Drawing-from-Memory in Constructional Apraxia: Effects of Focal Cortical Lesions on Performance

Simon M. McCrea[*,1] and Debbi L. Chomiak[2]

[1]Department of Psychology, St. Thomas More College, University of Saskatchewan, Saskatoon, Saskatchewan, S7N 0W6, Canada

[2]Department of Psychology, University of New Brunswick, Fredericton, New Brunswick, E3B 5A3, Canada

Abstract: Constructional apraxia is impairment in activities such as building, assembling, and drawing. In this paper data is presented on the performance of left and right hemisphere single focal contiguous stroke lesion participants on drawing tasks of houses, trees, and persons. In this study, 41 participants completed a comprehensive neuropsychological battery including the House-Tree-Person Drawing Task. The drawings were then rated as exhibiting signs of neurological impairment or non-impairment by three evaluators that were blinded to the medical condition of the patient. The neuropsychological evaluator did not rate the drawings. There was 72% agreement between the three evaluators of the 123 drawings in their dichotomous ratings of constructional apraxia drawings. Both a group mean and case series analysis was used to examine the data and some patterns of concordance with a detailed cognitive neuropsychological model of constructional apraxia was found.

Keywords: Constructional apraxia, free-drawing, unilateral cortical lesions, stroke, visual imagery, lexicosemantics, cognitive neuropsychology.

INTRODUCTION

The purpose of this research study was to examine the plausibility of a previously described theoretical model of the neuropsychological basis of free-drawing related constructional apraxia [1]. There have been few previously published all-encompassing theoretical accounts of the neurological basis of the important disorder of constructional apraxia. Constructional apraxia (CA) has been described as a cortical disorder that is manifested in "*formative activities such as assembling, building, and drawing in which the spatial form of the product proves to be unsuccessful, without there being an apraxia for individual movements*" [2]. Where published models of CA could be found these were incorporated into the drawing-from-memory model of [1]. None of these previous theories provided convergent methods of validity using different levels of analysis such as neurological, cognitive systems or case-series analysis.

The research on which the current model of CA was deduced was based on the most widely agreed upon published theories as well as contemporary empirical data depicting the functional architecture associated with CA. Our model is specific to free-drawing or, more specifically, drawing-from-memory rather than line-by-line copying modes of drawing. It is hypothesized that conventionally construed constructional apraxia, (as for instance measured with the Rey Complex Figure Test or Clock-Drawing tasks), is not the same as drawing-from-memory which involves different cognitive and brain systems. In fact, it is advanced that the differences between conventionally construed CA and drawing-from-memory may be so varied as to make the former entirely inadequate for understanding CA in its myriad of naturally occurring clinical forms. It is advanced that plausible neuroanatomical correlates for aspects of the model will be able to be elaborated upon with a sample of forty-one participants studied with a comprehensive battery of neuropsychological tasks.

This study is among the first to examine free-drawing related CA in consecutively referred clinical neurological samples. In this paper we will present a quantitative analysis of variables such as main effects of gender, handedness, age, education, hemispheric localization of lesion, and interactions of various neuropsychological and demographic variables involved in constructional apraxia. Examination of across group main effects will be followed by an in-depth examination of seven subjects with unilateral cortical contiguous stroke and lesion resections presenting with constructional apraxia. This will be followed by a further investigation and comparison of six unilateral cortical contiguous stroke and lesion resection patients without constructional apraxia. Consideration of dissociations in performance should allow for a better understanding and elaboration of the model depicted in Figure **1**.

*Address correspondence to this author at the Department of Psychology, St. Thomas More College, University of Saskatchewan, Saskatoon, Saskatchewan, S7N 0W6, Canada; Tel: 306-966-4535; Fax: 306-966-8904; E-mail: simon.mccrea@usask.ca

E-ISSN: 2313-1047/15

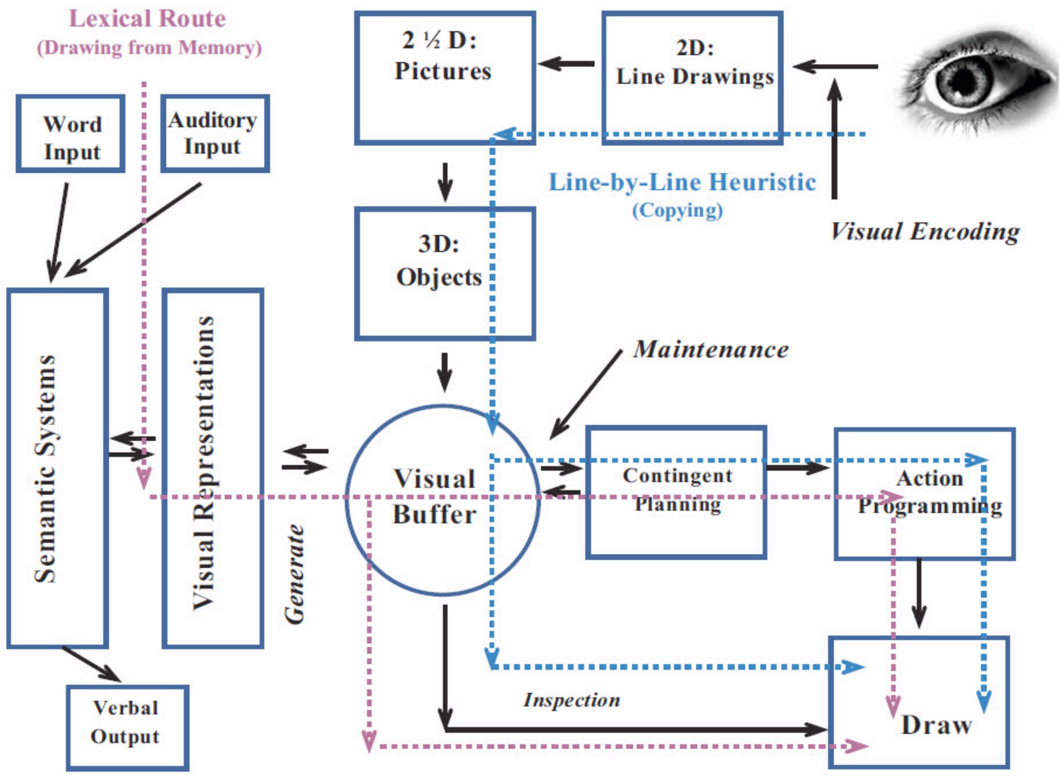

Figure 1: Contemporary model of constructional apraxia-related free drawing incorporating the lexical and line-by-line heuristic routes. Cognitive neuropsychological model illustrating Grossi's (1991) lexical route involved in drawing from memory (purple) and line-by-line heuristic used in copying from a model (blue). Adapted with permission from Figure 4 on page 69 of McCrea (2014) American Journal of Psychiatry and Neuroscience [1].

METHOD

Sample Demographics

In this study 41 participants with: (i) focal singular contiguous cortical stroke lesions, (ii) mixed multiple cortical or subcortical lesions, or (iii) general adult clinical cases were referred for comprehensive neuropsychological evaluations. Participants were recruited into the study over a 1 year period at the Wascana Rehabilitation Centre in Regina, Saskatchewan, Canada. Ethical approval was granted by Research and Performance Support of the Regina Qu'Appelle Health Region in 2010. All participants were informed about the potential inclusion of their data into neuropsychological studies and signed an informed consent form prior to participation. Participants were assured that any data included in such studies would be de-identified to safeguard research participant's confidentiality and anonymity. This research study adhered to the principles declared in the Canadian Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans as well as with the principles stated in the Declaration of Helsinki [3].

The sample consisted of 28 men and 13 women and thus there was a disproportionate sampling of the sexes [χ^2= 22.5, $p < 0.0001$]. Every effort was made to have proportional representation of the sexes. However, men outnumber women in acute stroke units and brain injury centers at younger ages. Reasons for the disproportionate sampling have previously been shown to be due to a number of interacting factors. Men have an elevated risk of cerebrovascular accident at all ages [4]. At the relatively younger ages of stroke participants recruited into this study, testable stroke participants are often male. This is because younger female stroke participants tend to have poorer prognosis due a selection effect of stroke severity and etiology [5]. Often with poorer prognosis come attendant evaluative practicality issues, such as aphasic language comprehension difficulties or motor impairments. Similarly, it has been long known that younger men have disproportionately higher rates of acquired brain injury [6]. The elevated rates of men with stroke and acquired brain injury would in all likelihood largely account for this discrepancy between the sexes.

Six of 41 participants were left-handed constituting 14% of the sample, whereas Hardyck and Petrinovich's (1977) review suggest that approximately 10% of the general population is left-handed [7]. A chi-square test found this difference non-significant (p = 0.23). This result suggests that handedness in participants will not likely skew expected distributions of test scores in the sample so as to confound the results and generalizability of the findings – (see Table **1**). The mean age of the sample was 42 years (SD = 15), and there was no difference in age between the normal and impaired groups [F(1,39) = 0.83, p = 0.37]. The precise operational definition of what constitutes "the impaired" (constructionally apraxic) versus "normal" (non-constructionally apraxic) groups will be defined shortly. The group as a whole was less educated than the general population (mean = 10 years, SD= 5.8), however there was no difference in education levels between the normal and impaired groups [F(1,39) = 0.08, p = 0.78].

Table 1: Demographics Related to Sex, Handedness, Age and Education

Drawing group	M	F	Handedness		Age		Education	
			RT	LT	Mean	SD	Mean	SD
Normal	16	10	22	4	44	15	10	6.3
Impaired	12	3	13	2	39	17	11	5.0
Total	28	13	35	6	42	15	10	5.8

The mean number of months post-injury that participants were evaluated was 16 months (SD = 22). The number of months post-injury in which normal and impaired participants were tested was not significantly different [F(1,33) = 3.58, p = 0.70]. At 16 months post-injury, participants would have been expected to have experienced near maximal levels of functional recovery [6].

This duration post-injury that patients were evaluated at may be optimal in developing first approximations of the neural correlates of constructional praxis since previous studies have often tested CA patients in the post-acute phase or only on the neurological ward [8]. At these short durations of several weeks to months post-injury, impairments on neuropsychological tasks may be due to indirect effects of the lesion (e.g., general cognitive slowing or diaschisis) rather than being a function of specific localized modular damage [9]. The premorbid FSIQ as estimated using the Advanced Clinical Solutions Test of Premorbid Functioning [10] was in the average range for the group as a whole (mean = 102, SD = 13). Importantly, there were no differences in premorbid levels of general intelligence between the normal and impaired groups [F(1,39) = 1.72, p = 0.20]. Only 24% (10 out of 41 participants) had Glasgow Coma Scale (GCS) scores available [11].

Of these ten participants, six were involved in motor vehicle accidents. Nine participants in our total sample of 41 participants in this study were involved in motor vehicle accidents. There were no significant differences in the average GCS scores between the drawing impaired and non-impaired groups [F(1,8) = 0.29, p = 0.61]. Given the paucity of GCS information with this diverse sample it was hypothesized that use of specific covariance procedures involving premorbid ability, demographics, and other neuropsychological test measures would constitute a more valid index of severity of injury.

Constructional Apraxia Rating System

Participants with single focal continguous stroke lesion of an ischemic or hemorrhagic nature or neuro-surgical resections in the left or right hemisphere were the primary focus of the investigation, as suggested by lesion characterization experts [12]. Participants were determined to belong to a neurologically impaired or normal group by a combination of two rating systems which were subsequently demonstrated to show near equivalence. In the first rating system, (*Unanimous Rating System)* those participants demonstrating complete agreement across three trained raters on at least one drawing [(1) house, (1) tree, (1) person] were classed as impaired regardless of the status of the other two drawings in the set of 3. Again, there are 41 participants with three drawings each for a total of 123 drawings. The 123 drawings were first randomized and then rated blindly by three raters. These evaluators did not administer any neuropsychological tests to the participants and thus were not biased by experimenter expectancy effects [13]. Previous studies have included novice raters who did not have any detailed neuropsychological knowledge of CA and yet subsequently satisfactorily scored participants' drawings [14]. Sixteen participants were classified as impaired using the first rating system.

In the second rating system, *(Threshold Rating System)* those participants who scored above critical cutoff were deemed impaired (e.g., ≥ 12 on an 18 point scale). In the second rating system each house, tree, and person drawing was either dichotomously rated by three raters as either normal (1 point) or impaired (2 points) providing for a total of 9 possible ratings collapsed across individual participants. Therefore, a minimum possible score for an individual subject was 9 and a maximum was 18. Importantly, using the second rating system, 15 participants were classed as impaired. *Using both rating systems together 14 participants in common were classed as impaired.* One subject from the first classification system was deleted because this person did not complete essential neuropsychological tests and a second subject was deleted from the first unanimous rating system because one of the drawings in a set was unscorable.

One new subject was added to the second Threshold Rating System's impaired group. This additional subject, who had a right cerebellar lesion, demonstrated no unanimous impairment across an individual drawings but did show significant levels of cumulative impairment across all drawings (score = 14/18). Finally, one subject was deleted from the Threshold Rating System group because of a non-relevant nonverbal learning disability. There was 93% agreement between the Unanimous and Threshold Rating Systems categorization of impaired and normal participants. Henceforth the second Threshold Rating System was used as it was subsequently found to provide the most robust measure of overall sensitivity to constructional apraxia in its diverse forms. Additionally, the second Threshold Rating System had a degree of specificity to all three drawing tasks in comparison to the first Unanimous Rating System that did not have this property. Importantly, the neuropsychological examiner of the 41 individual patients did not perform any of the constructional apraxia ratings and these were performed by two volunteer clinical psychologists and a graduate student in clinical psychology (e.g., DLC).

Neuropsychological Measures

In this study, we used a well-known drawing task to study constructional apraxia. The house-tree-person drawing task has been implemented in clinical and experimental psychology for over 100 years [15]. This drawing task has unique advantages compared to other drawing tasks widely used in clinical neuropsychology. For example, the Rey Complex Figure Test [6], which is widely used test of visuoconstructional ability, is semantically impoverished but has a structural description that is complex. In comparison, a line drawing of a house, tree or a person also have comparably complex structural descriptions, but also a rich array of semantic associates in addition. Quantitative analysis of the semantic characteristics of these three words and concepts of houses, trees and persons is also possible.

The widely used psycholinguistic variables of familiarity, concreteness and imageability can be determined for words of a wide variety of languages [16]. Familiarity represents printed frequency indices of large compilations of words usually derived from electronic sources. These variables have ranges from 100-700 with a mean of 500 and a standard deviation of 100. Concreteness and imageability also have the same parameters. The respective ratings for the house, tree and person were derived from the MRC Psycholinguistic searchable internet lexical database freely available at the School of Psychology at the University of Western Australia in Perth. (http://websites.psychology.uwa.edu.au/school/MRCDatabase/uwa_mrc.htm).

In this study, we used the ratings of neuropsychological impairment, or lack thereof, in the drawings of 41 participants using the house-tree-person drawing test [17,18]. We used the rating system of Reynolds and Hickman (2004) [17] for the Draw-A-Person: IQ normed for children, adolescents and adults [17]. The instructions for the Draw-A-Person: IQ of Reynolds and Hickman was modified for the trees and houses drawings (e.g., See Appendix 1). The *familiarity*, *concreteness and imageability* ratings of: houses (600, 608, 606), trees (613, 604, 622), and persons (620, 562, 562) demonstrated a high degree of concordance. None of these values for each of the three variables were significantly different across the three types of ratings.

Although developed over 100 years ago, these drawings tests were obviously constructed without these psycholinguistic variables in mind. Yet through trial and error, and use by skilled clinicians and subsequent refinements, the house-tree-person drawing test has yielded a large array of clinical data and utility when used in conjunction with other measures [18-23].

In the present study, participants were assessed using the Wechsler Adult Intelligence Scale – Fourth Edition (WAIS-IV) [24], Wechsler Memory Scale - Fourth Edition (WMS-IV) [25], and the ACS Social Perception Battery [26]. These core batteries were supplemented by tests of attention, verbal and nonverbal executive function, motor and sensory functions as well as tests of personality and mood. A description of the Wascana Rehabilitation Centre's

Table 2: Description of Individual Cases' Lesion, Etiology and Demographics. Cases 1A to 15A consist of participants with constructional apraxia in their drawings according to the cumulative score across the three raters. Cases 1B to 26B consist of participants with normal drawings. Lat. = laterality of lesion (left, right); RT = right; A/P or Ant./Pos.= anterior or posterior lesion; Hand = handedness (left or right); Educ = years of education; MVA = motor vehicle accident; DAP:IQ = Draw-A-Person IQ [17]; pos. = posterior; inf = inferior; Rating = Threshold Rating System - three drawing set pooled; TL = temporal lobe; mid = middle, SPL = superior parietal lobule, AG = angular gyrus.

Case	Lesion and Etiology	Lat.	A/P	Sex	Age	Hand	Educ	Rating	DAP:IQ
1A	RT ant TL, insula and basal ganglia	Right	Ant.	M	56	Right	16	15	92
2A	RT basal ganglia and insula stroke	Right	Ant.	M	64	Left	14	18	59
3A	RT pos mid TG and AG and pos SPL	Right	Pos.	M	35	Right	12	12	102
4A	Right temporoparietal resection	Right	Pos.	M	40	Left	14	16	107
5A	Right temporoparietal stroke	Right	Pos.	M	56	Right	16	17	95
6A	Left pos. temporal lobe stroke	Left	Pos.	F	41	Right	12	14	101
7A	Left temporoparietal stroke	Left	Pos.	F	56	Right	13	15	66
8A	MVA and diffuse injury	-	-	M	16	Right	10	12	116
9A	MVA and diffuse injury	-	-	M	50	Right	10	12	99
10A	RT. superior cerebellar stroke	-	-	M	57	Right	16	14	95
11A	Assault and diffuse injury	-	-	F	17	Right	10	15	106
12A	MVA and diffuse injury	-	-	M	17	Right	11	15	92
13A	MVA and diffuse injury	-	-	M	16	Right	10	15	75
14A	Bilateral thalamic infarcts	-	-	M	28	Right	17	16	81
15A	Cardiac arrest and global anoxia	-	-	M	50	Right	14	17	95
1B	Left frontal lobe stroke	Left	Ant.	F	56	Right	14	10	106
2B	Left inferior frontal lobe stroke	Left	Ant.	M	64	Right	17	11	120
3B	Left parietal lobe stroke	Left	Pos.	F	47	Left	16	9	109
4B	Left inferior temporal lobe stroke	Left	Pos.	F	63	Right	12	11	92
5B	RT ant inf TL and RT orbital gyrus	Right	Ant.	F	35	Right	17	9	90
6B	RT inferior and middle frontal gyrus	Right	Ant.	M	55	Right	16	10	99
7B	Fall and diffuse contusions	-	-	M	46	Right	9	-	-
8B	West Nile virus encephalitis	-	-	M	47	Right	19	9	116
9B	Personality Disorder	-	-	M	31	Right	13	9	112
10B	MVA and diffuse injury	-	-	M	18	Right	12	9	116
11B	MVA and diffuse injury	-	-	M	37	Right	18	9	105
12B	Assault and diffuse injury	-	-	M	26	Left	10	9	113
13B	Right pos. thalamic infarct	-	-	M	23	Right	16	9	102
14B	Fall and diffuse injury	-	-	M	61	Right	19	9	125
15B	MVA and diffuse injury	-	-	F	24	Right	12	9	97
16B	Fall and diffuse injury	-	-	F	50	Left	12	9	104
17B	Personality Disorder	-	-	M	24	Right	12	9	106
18B	MVA and diffuse injury	-	-	F	62	Left	14	10	107
19B	Fall and diffuse injury	-	-	M	46	Right	20	10	95
20B	Central pontine myelinosis	-	-	F	57	Right	16	10	76
21B	Chronic alcoholism	-	-	M	51	Right	12	10	84
22B	Cardiac arrest and global anoxia	-	-	M	60	Right	18	11	91
23B	Chronic alcoholism	-	-	M	49	Right	12	11	90
24B	Concussion	-	-	M	57	Right	12	11	89
25B	MVA and concussion	-	-	F	54	Right	12	12	81
26B	Nonverbal learning disability	-	-	F	18	Right	12	12	92

Department of Neuropsychology's Standard Neuropsychological Battery is detailed elsewhere [27].

Case Series Sample

A group average comparison approach was implemented to analyze differences between drawing-normal and drawing-impaired participants. Using this method, analysis of dissociations between participants' performances on specific tests could then be carried out in the context of the patients' different lesion topographies [27]. This approach could conceivably be used to develop a first approximation of the neural correlates of CA associated with free-drawing especially if undertaken in conjunction with an examination of a succession of case-series.

The strength of the dissociation of performances paradigm lies in its use of inferences regarding the "*configuration of signs*" rather than isolated test signs in pointing towards specific neuropsychological syndromes [28]. When brain lesions are large enough and of sufficient severity to cause cortical neurological disorders such as CA and non-CA neuropsychological syndromes, an *impaired/normal* analysis of errors in performance should enable determination of some of the essential neural systems involved [9, 12, 27, 28].

Importantly, although the "impaired" and "normal groups" are categorized qualitatively in this way, nearly all non-CA participants with brain injuries demonstrated at least one type of neuropsychological deficit other than CA. This is an important point since this finding implies that there was enough statistical power to produce a diversity of effects which is important in any neuropsychological study. Further, the use of an over-arching neuropsychological theoretical orientation about the mechanisms, interactions, and functional aspects of coordinated brain systems can obviate the need for large samples when determining the neural correlates of performance on newly developed neuropsychological tests [28-32]. Participants with unambiguous constructional apraxia using the Threshold Rating System and with singular, focal, and contiguous lesions were first identified. Seven participants were identified in this manner. Six participants with lesions that were singular, focal, and contiguous without constructional apraxia were also identified.

Eight participants with constructional apraxia without lesions that were clearly able to be classified as singular, focal, and contiguous were also included to provide a better first approximation of the range of variance associated with CA. Finally, 20 additional control participants without CA and without lesions that were clearly discernible as singular, focal, and contiguous were included. Importantly the non-CA participants all had some form of neuropsychological disorder (21/26 = 84%). Only five participants (two personality disorder participants, two persons with alcoholism, and one subject with nonverbal learning disability) did not have brain-lesion related neuropsychological disorders. These five participants were included nonetheless to accentuate the normal range that one might find in an unselected sample of neuropsychological patients recruited in rehabilitation settings.

The anterior-lesioned group consisted of participants for whom the center of mass of the lesion was anterior to the central sulcus with at least 75% of the lesion extending within the frontal lobes. The posterior-lesioned group was comprised of participants for whom the center of mass of the lesion extended within the parietal-temporal-occipital lobes. With the posterior group, 75% of the lesion was required to extend within the posterior cortices. Left and right hemisphere lesioned participants were similarly categorized as involving only one hemisphere or another.

All participants' lesions were correlated with written summaries of the neuroradiologist's reports. Visual inspection of the full neuroimaging data sets with lesion visualization software [33] in conjunction with a standard CT/MRI atlas [34] was also completed. Only participants with single, focal, and contiguous topographical lesions extent-wise were included in the case series analysis. In summary, 8 of 15 or 53% of CA participants did not fit into an exclusive laterality (left hemisphere/right hemisphere) by anterior-posterior (2 x 2) designation group.

There were six participants with single focal contiguous lesions in a laterality (left hemisphere/right hemisphere) by anterior-posterior (2 x 2) grouping who did not demonstrate CA. These non-CA participants could then be compared with one another and to the CA group to determine brain areas not likely to be involved in constructional apraxia. Hence two groups were formed. The constructional apraxia (CA) or non-constructional apraxia (non-CA) groups, each with singular focal contiguous stroke lesions, provide the basis for single dissociation characterization [28, 29].

Again, it is important to reiterate that participants with specific focal lesions were examined with dichotomous ratings on their free-drawings for the presence or absence of CA. A dichotomous rating system might facilitate the identification of the most salient features of the drawings in order to determine categorization into the CA or non-CA groups. Such a dichotomous rating scale might also obviate the need for drawing evaluators with detailed artistic or neuropsychological knowledge [23]. Participants with focal lesions of comparable size/severity, and who manifest other non-CA neuropsychological syndromes, yet present without CA, would suggest that a particular brain region is probably not involved in free-drawing related constructional apraxia. The focus of our investigation, however, was to examine the effects of a series of single specific neuroanatomically localized lesions in the brain.

Patterns of Dissociations in Case-Series

A cross-tabulation chi-square analysis of the nominal variables of etiology crossed with impaired/ non-impaired status (diffuse injury in motor vehicle accident: n = 16 cases; cortical stroke: n = 14; general neuropsychology: n = 4; subcortical lesion: n = 3; personality disorder: n = 2; concussion: n = 2) was non-significant [χ^2 (5) = 4.84, p = 0.44]. A chi-square analysis of the nominal variables of anterior/posterior (anterior, posterior, neither anterior nor posterior) and impaired/non-impaired status was similarly non-significant [χ^2 (2) = 3.73, p = 0.16]. A chi-square analysis of the nominal variable of left/right (left hemisphere, right hemisphere, neither hemisphere) and impaired/non-impaired status was also non-significant [χ^2 (2) = 3.73, p = 0.16]. Again, ANOVA of the continuous variables of age, education in years, and months post-injury at the time of neuro-psychological evaluation were similarly non-significant across groups. The results of the analysis of nominal and continuous variables suggested that drawing-impaired and drawing-normal subject groups are directly comparable after examination of potential confounds (Table **3**).

In the drawing impaired group, (2/7) 28% of participants had frontotemporal/subcortical lesions and both of these two participants had right anterior lesions (1A, 2A). The mean global impairment rating for the two right frontotemporal/subcortical participants was 16.5/18. Both participants had right insula and right basal ganglia damage and therefore their lesions could not be construed as strictly frontal in etiology. Moreover posterior-ventral aspects of the right frontal lobe were damaged in both cases but not superior or anterior prefrontal regions. In the drawing impaired group (5/7) 72% of participants had posterior lesions. Three of five CA participants had right posterior lesions and the average global impairment rating was 15/18 (3A, 4A, 5A). One of the right posterior participants had right parietal damage and this patient's global impairment rating was 12.0/18 (3A). The mean of the global impairment rating for the other two right posterior lesion participants (both with right temporoparietal lesions) was 16.5/18 (4A, 5A).

The mean global impairment rating for the two CA left posterior participants with inferior (left posterior temporal lobe) and superior lesions (left temporal lobe) was 14.5/18. There were no participants among the single stroke lesion group that had left frontal lesions and accompanying CA. In fact the opposite pattern was observed. Two participants with large left anterior-superior (1B) and left anterior-inferior (2B) lesions did not demonstrate CA (mean rating = 10.5/18) suggestive of a single dissociation. This preliminary frequency analysis points to the involvement of both the right and left temporoparietal regions and the right insula and right basal ganglia in free drawing-related constructional apraxia.

There appeared to be some sex-related differences in the manifestations of constructional apraxia at least at the case series level of analysis. One patient that had left parietal and left supramarginal gyrus damage was unimpaired; however, this patient was a strongly left-handed female (3B) with very superior visual

Table 3: Laterality, Rostral-Caudal Lesion Site, and Etiology. Normal = non-constructionally apraxic participants; Impaired = constructionally apraxic participants; L = left hemisphere, R = right hemisphere; A = lesion anterior to the central sulcus; P = lesion posterior to the central sulcus; 1 = motor vehicle accident and diffuse injury; 2 = stroke; 3 = general neuropsychology participants; 4 = subcortical etiology; 5 = personality disorder; 6 = concussion.

Drawing group	Laterality			Rostral-Caudal			Etiology					
	L	R	-	A	P	-	1	2	3	4	5	6
Normal	4	2	20	4	2	20	9	7	4	2	2	2
Impaired	2	5	8	2	5	8	7	7	-	1	-	-
Total	6	7	28	6	7	28	16	14	4	3	2	2

memory abilities (e.g., WMS-IV Visual Memory Index = 145). Another exception was a female patient who did not have CA with a left-only inferiomedial occipital lesion (4B). Another unimpaired female patient had a right anterior temporal lobe lesion and accompanying right orbital gyrus lesion without right basal ganglia lesioning (5B).

The remaining male subject had extensive right inferior, middle, and superior frontal gyral lesions (6B) without there being substantial right basal ganglia or insular involvement as in the case of two CA participants (1A, 2A). The intact drawings of these two anterior frontal participants (5B, 6B) suggest that as with the left frontal regions, the right superior frontal cortical regions are unlikely to be involved in either (1) a pure constructional apraxia, (2) non-dysexecutive type or primary type of constructional apraxia. Additionally, there were two participants without cortical lesions who demonstrated constructional apraxia. Subject 10A, who had a large right superior cerebellar lesion, and subject 14A who had bilateral thalamic lesions, both demonstrated clear evidence of constructional apraxia.

RESULTS

Group Main Effects and Interactions

The drawing impaired and drawing-normal groups were compared in terms of obtained Full-Scale IQ (FSIQ) after brain injury, with no significant difference found between the two groups [$F(1,39) = 2.10$, $p=0.16$]. There was, however, a significant difference on the Verbal Comprehension Index between the impaired (mean = 77) and non-CA groups (mean = 95) [$F(1,33) = 7.51$, $p < 0.01$]. A multivariate analysis of covariance (MANCOVA) with age, gender, education, post-injury duration, and premorbid IQ as covariates was conducted on the 15 WAIS-IV subtests. There was an overall significant main effect of gender: Wilks $\lambda = 0.24$, [$F(1,14) = 2.54$, $p < 0.04$]; duration post-injury: Wilks $\lambda = 0.23$, [$F(1,14) = 2.72$, $p < 0.03$] and premorbid IQ: Wilks $\lambda = 0.06$, [$F(1,14) = 13.21$, $p < 0.0001$]. Thus, a between-groups examination of the strength of main effects of constructional apraxia covaried for these covariates could then be examined at the subtest level. MANCOVA showed that the Comprehension subtest [$F(1,30) = 4.37$, $p = 0.04$], Matrix Reasoning [$F(1,30) = 4.16$, $p < 0.05$], Visual Puzzles [$F(1,30) = 4.24$, $p = 0.04$] and Letter-Number Sequencing [$F(1,30) = 6.02$, $p = 0.02$] were the only subtests remaining significant. Scores on these four WAIS-IV subtests for the CA group were all below the subtest scores of the unimpaired group.

The association of CA with impaired performance on Raven's Progressive Matrices is an old finding [35]. This association alludes to the large-scale networks that are likely dependent upon fluid intelligence with which to coordinate and integrate distal modules involved in CA [36]. The absence of significant differences in FSIQ between the two groups in the context of significant differences in subtest scores suggests that these WAIS-IV subtests are measuring componential aspects of performance associated with free-drawing rather than a general intellectual decline associated with CA [37]. Previous studies have found that drawing-impaired participants perform poorly on Matrices and Block Design tasks [38].

Our new findings add to the literature by identifying an association between CA and impairments on the Verbal Comprehension Index and the WAIS-IV subtests of Comprehension, Visual Puzzles, and Letter-Number Sequencing. Collectively, these results point to a previously undefined verbal factor that is mediating the effects of CA with free-drawing. It is possible that this verbal factor is a verbal concept formation factor rather than a generalized verbal comprehension factor. The lack of significant between-group differences for Block Design [$F(1,30) = 0.16$, $p = 0.69$] perhaps highlights the essential differences between free-drawing, which appears to require access to verbal representations, and copying nonverbal designs such as the Rey Complex Figure, which donot.

Differences on the Comprehension subtest were associated with CA, but the same could not be said for Similarities, Vocabulary and Information subtests, which argues against an interpretation that the CA participants did not verbally understand the task. First, all participants included in the study had sufficient language comprehension abilities to complete a full neuropsychological evaluation. None of the participants had receptive aphasia so severe that it would render them untestable, although some participants in the study did have left posterior lesions. Second, it is important to recognize that on the WAIS-IV Comprehension subtest examinees answer questions based on their understanding of general principles and social situations. The Comprehension subtest assesses knowledge, judgment and verbal concept formation, and low scores may reflect social ineptitude (e.g., understanding of indirect requests) [39] which sometimes occurs with right hemisphere injury [40]. Given these findings, the WAIS-IV Comprehension subtest may not be evaluating language comprehension per se in our study to the same extent as does the

Wide Range Achievement Test – Fourth Edition (WRAT-4) [41] Sentence Comprehension subtest.

Moreover 71% of participants in the CA group had lesions that were specifically located within the right hemisphere. Tellingly, at the group level there were no impairments on any of the verbal executive function tasks [see ref. 27]. The Cancellation and Coding subtests of the WAIS-IV were similarly unimpaired in the CA group ($p > 0.15$). Neither was visual search impaired in these groups on the Ruff 2 and 7 Selective Attention Test [42]. Auditory attention as assessed by the Brief Test of Attention was similarly unimpaired [43] –all p's > 0.15. Qualitative analysis of errors on the visual attention tests did not reveal a disproportionate number of omissions or commissions in the left visual field of the response booklets.

Similarly, a qualitative observation of the performances' of the three participants with right posterior lesions in a drawing-impaired group did not favor a visual neglect-related interpretation for CA [39]. Two of the most severely impaired CA participants on the Visual Puzzles subtest had left posterior lesions (e.g., subject 6A with a left posterior temporal lobe lesion and Visual Puzzles subtest age scaled score of 2 and subject 7A with a left temporoparietal lesion and Visual Puzzles subtest age scaled score of 4). The mean aged scaled score of the remaining five right hemisphere lesioned CA participants was 6.5 on Visual Puzzles. Only the Trail-Making Test Part B executive function test was impaired in the CA group [$F(1,29) = 8.61$, $p = 0.006$]. In an effort to understand the hypothetical nature of these executive and verbal impairments, a detailed analysis of the three motor subtests of Grip Strength, Finger Tapping, and Grooved Pegboard was undertaken [44].

ANOVA of these three motor tests showed that only right hand Grooved Pegboard scores were significantly different across CA and non-CA participants. However, analysis of covariance ANCOVA with Grip Strength (right hand), Finger Tapping (right hand), drawing ability, age, sex, educational level, months post-injury and premorbid intelligence still yielded a high significant main effect of group [Grooved Pegboard: $F(1,22) = 17.6$, $p < 0.0001$]. However, when the WAIS-IV Verbal Comprehension Index was next added as covariate, the group main effect was no longer significant [$F(1,15) = 4.71$, $p > 0.10$], suggesting that network impairments involving the coordinated interaction between semantic and motor systems in the left hemisphere could be mediating the CA in free-drawing.

Cross-modal matching of congruent facial expression and voice intonation provides further insight into the origins of the WAIS-IV Verbal Comprehension Index deficit in CA subjects.

Both Prosody Face Matching [$F(1,22) = 20.7$, $p < 0.0001$] and Prosody Pairs Matching [$F(1,22) = 10.8$, $p=0.0001$] of the Wechsler Advanced Clinical Solutions battery demonstrated a significant main effect of group [45]. CA subjects were more impaired at cross-modality matching of affective cues. Both the Prosody Face Matching and Prosody Pairs Matching tasks involve cross-modal matching of auditory (voice) and visual (facial affect) cues. Such cross modal matching has been previously shown to involve the right temporoparietal junction involved in social knowledge construction [46] and three of seven CA participants indeed demonstrated damage to this area.

There were no differences in naming the affect of a set of visually presented faces [$F(1,22) = 1.23$, $p=0.28$], perhaps not surprising since face recognition is almost exclusively a function of the integrity of the ventrally located right fusiform gyrus [47] which was intact in the CA group. A MANCOVA of the WMS-IV showed that covariate of obtained FSIQ was significant Wilks $\lambda = 0.55$, $F(1,22) = 2.58$, $p = 0.04$] across CA groups. Subsequent main effect comparisons showed that only the Visual Immediate Memory Index was significant [$F(1,28) = 4.12$, $p < 0.05$)]. The Visual Immediate Memory Index of the WMS-IV is comprised of the subtest of Designs I and Visual Reproductions I. Analysis of covariance with FSIQ as covariate still revealed a highly significant main effect of Designs I [$F(1,38) = 8.81$, $p = 0.005$] and Visual Reproductions I [$F(1,38) = 8.67$, $p = 0.005$]. Designs I and Visual Reproductions I scores were significantly impaired in CA subjects.

On the WRAT-4 Spelling subtests the CA group (mean = 85, SD =14) and non-CA group (mean = 102, SD =12) were significantly different [$F(1,35) = 13.6$, $p < 0.001$]. Analysis of covariance with FSIQ as covariate still revealed a highly significant main effect of the WRAT-4 Spelling subtest [$F(1,34) = 12.0$, $p = 0.001$]. Notably, there were no differences on the WRAT-4 Sentence Comprehension subtest with FSIQ as covariate, which argues against the supposition that the impaired (CA group) did not linguistically understand the tasks. This poorer performance of the drawing impaired group on the Spelling subtest could imply common damage to mechanisms associated with both phonological processing and access to visual imagery through semantics. On the WRAT-4 Subject 6A with a left posterior temporal lobe stroke (standard score = 50, z = -2.50, p = 0.006) and subject 7A with a left temporoparietal stroke performed the poorest (standard score = 66, z = -1.36, p = 0.08). This finding is not a new one, although it is a replication using complex real nameable drawings and is thus unique in this respect. Left posterior lesions have been previously shown to cause deficits in both visual imagery, as well as phonological decoding skills [37].

Inter-rater concordance analysis was conducted for the complete set of 41 participants for a total of 123 drawings. The three scalers were blinded to the name, identities, demographic information or neuropsychological status of the participants. All that the evaluators or raters saw was a page with a drawing on it in randomized order. The scalers were instructed to read three articles on features of drawings demonstrating signs of brain damage [21,22,48]. Previous reviews have shown that indications of organic impairment in drawing from memory can be detected by raters with a high degree of concordance. These studies have also shown that organic symptoms in drawings may be easier to code, more salient, and possess better construct validity than personality-related variables [21, 22, 48]. Other psychological variables with a presumed concurrent validity using the house-tree-person drawing test include IQ. Recent studies show that the inter-rater reliability of Draw-a-Person estimates of IQ and obtained IQ from conventional intelligence tests could range as high as 0.83 at least in adults [23].

In the present study, the evaluators were informed about the base rates of drawing related CA in consecutive samples of unselected clinical neuropsychology referrals. These raters were informed that the base rates of CA have been shown to range from anywhere between 15-40% depending to some extent of the severity of the brain injuries [14,49]. The mean percentage of CA participants would be expected to be approximately 27%. This would mean that approximately 33 of 123 drawings would potentially have a high probability of having symptoms or signs of CA.

All patients included in this study were either admitted to an in-patient rehabilitation hospital or had a neuropsychological referral by a neurologist. Evaluator A scored 80 percent agreement with evaluator B ($r = 0.60$, $p < 0.0001$, $N = 123$ ratings) and 85% agreement with evaluator C ($r = 0.65$, $p < 0.0001$, $N = 123$ ratings). Evaluators B and C scored 76 percent agreement with each other ($r = 0.50$, $p < 0.0001$, $N = 123$ ratings). All of

Table 4: Categorization of the House-Tree-Person Drawing Impairments. Unanimity of agreement = 1 or 2; 1 = unanimous agreement that the drawing is not impaired across the three evaluators of the drawings, 2 = unanimous agreement that the drawing is impaired and exhibits signs of constructional apraxia across the three evaluators. Note that unanimous agreement requires identical ratings for each of the three raters for 1 of 3 of the particular types of drawing. Also average (Avg.) ratings can range from 3 (no impairment) to 6 (total impairment). Average ratings are the sum of the mean ratings for a particular house, tree and person drawing across the three evaluators.

Case	Lesion and Etiology	Avg.	House	Tree	Person
8A	MVA and diffuse injury	4.00	*2.00*	1.00	1.00
9A	MVA and diffuse injury	4.00	*2.00*	1.00	1.00
3A	Right parietal lobe resection	4.00	1.00	*2.00*	1.00
6A	Left posterior temporal lobe stroke	4.67	1.33	*2.00*	1.33
11A	Assault and diffuse injury	5.00	1.33	1.67	*2.00*
12A	MVA and diffuse injury	5.00	*2.00*	*2.00*	1.00
13A	MVA and diffuse injury	5.00	1.00	*2.00*	*2.00*
7A	Left temporoparietal stroke	5.00	1.67	1.33	*2.00*
1A	Right frontotemporal stroke	5.00	1.33	1.67	*2.00*
14A	Bilateral thalamic infarcts	5.33	1.67	1.67	*2.00*
4A	Right temporoparietal resection	5.33	*2.00*	*2.00*	1.33
15A	Cardiac arrest and global anoxia	5.67	1.67	*2.00*	*2.00*
5A	Right temporoparietal stroke	5.67	*2.00*	*2.00*	1.67
2A	Right basal ganglia and right insula	6.00	*2.00*	*2.00*	*2.00*

the three raters were all blinded to the medical condition of the patients. The 123 drawings were put in random order before ratings began. The task was to dichotomously sort the drawings into impaired or unimpaired categories. When complete agreement was examined between the three set of raters using both normal and impaired drawings, the level of agreement was 72%.

Based on Table **4**, there were 14 participants with at least one drawing that was unanimously rated as impaired. However, there were 21 drawings that were rated as impaired overall. These 21 impaired drawings were approximately equally distributed across the three categories of House, Tree, and Person. This means that across 123 drawings in the total set, 17 percent of drawings would be rated as impaired. Hence, the level of our objectively assessed base rates of CA was on the low end of the predicted range of previous estimates [14, 49]. Our sample included a small proportion of general clinical psychology out-participants and this may explain the relatively low frequency of constructional apraxia. However these general clinical referrals only constituted 12% of the overall sample and an alternative hypothesis could be that free-drawing related CA is rarer in frequency compared to regular constructional apraxia due to the hypothesized specificity of the lesions that would give rise to this behavior.

Another correlational analysis was undertaken between the house, tree, and person individual cumulative ratings pooled across the three raters, and the (i) global rating of impairment pooled across the three sets of drawings and the three raters (Threshold Rating System) and (ii) the Draw-A-Person IQ – (see Table **5**). The global rating involving pooled ratings across the three raters and across the three types of drawings was highly significantly related with the individual ratings (mean correlation = 0.791). The same was not true for the DAP: IQ, where the relationship with the house drawings was non-significant but the person and tree drawings were again highly significant. One parallel is that a house is a nonliving object whereas trees and persons are living entities and this might explain this finding. Finally, the Threshold Rating System appeared to capture the essence of the CA better than the DAP:IQ which is perhaps not surprising since there is substantial evidence that persons and bodies have separable neural encoding schemes within the brain [39].

Table 5: Correlations between Individual House, Tree, Person Drawing Ratings and the Threshold Rating System and Draw-A-Person: IQ. Individualized house, tree and person ratings thus vary between 3 (rated as unimpaired (1) on the drawing by all three raters) and 6 (rated as impaired (2) on the drawing by all three raters). Threshold Rating System varies between 9 (rated as unimpaired (1) on all three drawings for a subject by all three participants) to 18 (rated as impaired (2) on all three drawings for a subject by all three participants).

	House			
Tree	r = 0.522 p < 0.0001	**Tree**		
Person	r = 0.275 p = 0.086	r = 0.511 p = 0.001	**Person**	
Threshold Rating System	r = 0.748 p < 0.0001	r = 0.868 p = 0.0001	r = 0.758 p < 0.0001	**Threshold Rating System**
DAP:IQ	r = -0.194 p = 0.225	r = -0.406 p = 0.008	r = -0.605 p < 0.0001	r = -0.503 p = 0.001

In order to better understand the findings of the Verbal Comprehension Index scores correlation with right hand/left hemisphere manual dexterity effects on CA a further correlational analysis was undertaken. The Verbal Comprehension Index (VCI) was significantly correlated with the DAP: IQ (r = 0.372, p = 0.02). However, deficits in verbal comprehension appear to be unlikely to be able to explain the poor performance of the CA groups since the Threshold Rating System of CA and DAP-IQ appear to be measuring the same construct (r = - 0.503, p = 0.001). DAP: IQ was also significantly correlated with Visual Reproductions I (r = 0.323, p = 0.03) but not with Designs I of the WMS-IV. The main difference between Visual Reproductions I and Designs I is the motor programming component in Visual Reproductions I and the spatial location memory component in the Designs I. DAP: IQ was also significantly correlated with the Trail-Making Test: Part B (r = 0.408, p =0.02) which suggests that DAP: IQ has specific motor programming component. Finally, DAP: IQ was correlated with the Spelling subtest of the WRAT-4 (r = 0.344, p = 0.03) although it was not correlated with Word Reading (p = 0.37), Sentence Comprehension (p = 0.10) or the Math subtest (p = 0.19) perhaps alluding to the dual reliance on the neural correlates of visual imagery and phonological decoding [37] in these two correlated tasks.

DISCUSSION

There was 72% overall agreement between the three evaluators when the 123 drawings were randomized and the scorers were asked to dichotomously sort the drawings into neurological intact and impaired categories. DAP-IQ was non-significantly related to the house drawings however it was correlated with the person and tree drawings. The living/non-living distinction between objects may be relevant here [39]. The Threshold Rating System captured the essence of CA better than the DAP:IQ. There is substantial evidence that human bodies have dedicated neural encoding schemes within the brain [6,9,28,39]. Scores on Comprehension, Matrix Reasoning, Visual Puzzles and Letter-Number Sequencing subtests were all below the subtest scores of the unimpaired group. The association of CA with impaired performance on Raven's Progressive Matrices has been described before [35], and alludes to the large-scale brain networks involved in the inherent connectivity associated constructional apraxia [36].

The absence of significant differences in FSIQ between the two groups in the context of significant differences in subtest scores suggests that these WAIS-IV subtests are measuring componential aspects of performance associated with free-drawing rather than a general intellectual decline [37]. Previous studies have found that drawing-impaired participants perform poorly on Matrix Tests and Block Design [38]. However, performance on Block Design did not predict impairment status on the CA tasks in this study. These results point to a previously undefined lexical-semantic factor that is mediating the effects of CA with drawing-from-memory. The lack of significant between-group differences for Block Design perhaps highlights the essential differences between free-drawing, which appears to require access to verbal representations, and copying nonverbal designs such as the Rey Complex Figure, which appear not to, by comparison.

The Comprehension subtest assesses knowledge, judgment and verbal concept formation, and low scores may also reflect social ineptitude (e.g., understanding of indirect requests) [39] which sometimes occurs with right hemisphere injury [40]. Moreover 71% of participants in the CA group had lesions that were specifically located within the right hemisphere. Both Prosody Face Matching and Prosody Pairs Matching of the Advanced Clinical Solutions Social Perception battery demonstrated a significant main effect of group [45]. These results may provide some of the best leads as to the origins of the WAIS-IV Comprehension subtest results. Both the Prosody Face Matching and Prosody Pairs Matching tasks involve cross-modal matching of auditory (voice) and visual (facial affect) cues. Such cross modal matching tasks have been previously shown to involve the right temporoparietal junction involved in social knowledge construction [46] and three of seven CA participants indeed demonstrated damage to this area.

There were no impairments on tests of executive function (except for the Trail-Making Test: Part B). Similarly, there was no impairments in visual search, auditory attention or visual neglect associated with CA. Verbal Comprehension Index (VCI) scores were moderately correlated with the DAP: IQ. However, deficits in VCI appear to be unable to entirely explain the poor performance of the CA groups since the Threshold Rating System of constructional apraxia and DAP: IQ were also correlated. The advantage of the Threshold Rating System is that because it is common across several types of semantic stimuli (i.e, houses, trees and persons) it should theoretically be able to distinguish common elements of the semantic and motor networks associated with constructional apraxia. Thus the Threshold Rating System should be associated with task-independent and common features of drawing-from-memory.

DAP: IQ was also significantly correlated with Visual Reproductions I but not with Designs I of the WMS-IV. The main difference between Visual Reproductions I and Designs I is the motor programming component in Visual Reproductions I and the spatial location memory component in the Designs I. The DAP: IQ and Trail-Making Test correlation suggests that DAP: IQ has specific motor programming component. Collectively these findings suggest that DAP-IQ measures both semantic memory and visuomotor memory programming (see Figure **1**).

DAP: IQ was also correlated with the Spelling subtest of the WRAT-4. This is suggestive of dual reliance on the neural correlates of visual imagery and phonological decoding [37]. These lexicosemantic and visual imagery interfaces are presumed to occur within the left posterior cortex (see Figure 5 on page 71 of Ref. [1]).

There is additional evidence of where these two semantic and motor systems may interact in the human brain based on in-depth analysis of the case series. Visual puzzles is presumed to exemplify the type of task that would neurally instantiate much of the visual imagery network depicted in Figure **1**. Two of the most severely impaired CA participants on the Visual Puzzles subtest had left posterior lesions (e.g., subject

6A with a left posterior temporal lobe lesion and Visual Puzzles subtest age scaled score of 2 and subject 7A with a left temporoparietal lesion and Visual Puzzles subtest age scaled score of 4). The mean aged scaled score of the remaining five right hemisphere lesioned CA participants was 6.5 on Visual Puzzles. Recall that only the Trail-Making Test Part B executive function test was impaired in the CA group. In an effort to understand the hypothetical nature of these executive, motor or verbal impairments, a detailed analysis of the three motor subtests of Grip Strength, Finger Tapping, and Grooved Pegboard was undertaken [44].

ANOVA of these three motor tests showed that only right hand Grooved Pegboard scores were significantly different across CA and non-CA participants. However, analysis of covariance ANCOVA with Grip Strength (right hand), Finger Tapping (right hand), drawing ability, age, sex, educational level, month's post-injury and premorbid intelligence still yielded a high significant main effect of group ($p < 0.0001$). However, when the WAIS-IV Verbal Comprehension Index was next added as covariate, the group main effect was no longer significant, suggesting that network impairments involving the coordinated interaction between semantic and motor systems in the left hemisphere could be mediating the CA in free-drawing. This would be congruent with the hypothesis that the deficits are (i) semantic, (ii) motor programming in nature, but not primarily (iii) dysexecutive or "frontal" in origin. Rather lesions within the left posterior cortex might be expected to produce damage to conduits to motor programming centers in the left hemisphere.

There were no differences in naming the affect of a set of visually presented faces perhaps not surprising since face recognition is almost exclusively a function of the integrity of the ventrally located right fusiform gyrus [47] which was intact in the CA group. A MANCOVA of the WMS-IV showed that covariate of obtained FSIQ was significant across constructional apraxia groups. Subsequent ANCOVA with FSIQ as covariate still revealed a highly significant main effect of Designs I and Visual Reproductions I (both p's < 0.005). What this means is that is irrespective of general ability spatial location memory and visuoconstructive motor memory play an important role in constructional praxis as lower scores on each of these indicators yielded a higher probability of a subject as being classified as constructionally apraxic.

The CA group (mean = 85, SD =14) and non-CA group (mean = 102, SD =12) were significantly different on the WRAT-4 Spelling subtest ($p < 0.001$). Analysis of covariance with FSIQ as covariate still revealed a highly significant main effect of the WRAT-4 Spelling subtest. Notably, there were no differences on the WRAT-4 Sentence Comprehension subtest with FSIQ as covariate, which argues against the hypothesis that the impaired (CA group) did not linguistically understand the task. This poorer performance of the drawing impaired group on the Spelling subtest could imply common damage to model-based mechanisms associated with both phonological processing and access to visual imagery through semantics (See Figure **1**). For instance, subject 6A with a left posterior temporal lobe stroke (standard score = 50, $z = -2.50$, $p = 0.006$) and subject 7A with a left temporoparietal stroke performed the poorest on the WRAT-4 Spelling subtest (standard score = 66, $z = -1.36$, $p = 0.08$). This finding is not a new one, although it is unique in that in this study complex real drawings of nameable objects were used. Left posterior lesions have been previously shown to cause deficits in both visual imagery, as well as phonological decoding skills [37].

In the drawing impaired group 28% of participants had frontotemporal/subcortical lesions and both of these two participants had right anterior lesions. The mean global impairment rating for the two right frontotemporal/subcortical participants was 16.5/18. Both participants had right insular damage and right basal ganglia damage and therefore their lesions could not be construed as strictly frontal in etiology. Moreover posterior-ventral aspects of the right frontal lobe were damaged but not superior or anterior prefrontal regions. These frontal lesions might be expected to result in a dysexecutive type of CA. In the drawing impaired group (5/7) 72% of participants had posterior lesions. Three of five CA participants had right posterior lesions and the average global impairment rating was 15/18. One of the right posterior participants had right parietal damage and this patient's global impairment rating was 12.0/18. The mean of the global impairment rating for the other two right posterior lesion participants (both with right temporoparietal lesions) was 16.5/18. These right parietal and right temporoparietal lesions would be expected to cause damage to the visual buffer and/or damage to aspects of the generate function involved in metrical coordinate transformations of aspects of the drawn image.

The mean global impairment rating for the two CA left posterior participants with inferior (left posterior temporal lobe) and superior lesions (left temporal lobe) was 14.5/18. Lesions in the vincinity of the left inferior occipitotemporal lobe would be expected to result in damage to visual representational capacity to conjure up images. There were no participants among the single stroke lesion group that had left frontal lesions and accompanying CA. In fact the opposite pattern was observed. Two participants with large left anterior-superior and left anterior-inferior lesions did not demonstrate CA (mean rating = 10.5/18) suggestive of a single dissociation. This preliminary frequency analysis points to the involvement of both the right and left temporoparietal regions and the right insula and right basal ganglia in free drawing-related constructional apraxia.

There appeared to be some sex-related differences in the manifestations of constructional apraxia at least at the case series level of analysis. One patient that had left parietal and left supramarginal gyrus damage was unimpaired. According to Figure **1** this patient should have demonstrated constructional apraxia. However, this patient was a strongly left-handed female (3B) with very superior visual memory abilities (e.g., WMS-IV Visual Memory Index = 145). Another exception was a female patient who did not have CA with a left-only inferiomedial occipital lesion (4B). Another unimpaired female patient had a right anterior temporal lobe lesion and accompanying right orbital gyrus lesion without impingement into right basal ganglia (5B).

The remaining male subject had extensive right inferior, middle, and superior frontal gyral lesions (6B) without there being substantial right basal ganglia or insular involvement as in the case of two CA participants (1A, 2A). The intact drawings of these two anterior frontal participants (5B,6B) suggest that as with the left frontal regions, the right superior frontal cortical regions are unlikely to be involved in either (1) a pure constructional apraxia, (2) non-dysexecutive type, (3) primary type of constructional apraxia or (4) posterior classical constructional apraxia.

Additionally, there were two participants without cortical lesions who demonstrated constructional apraxia. Subject 10A, who had a large right superior cerebellar lesion. This subject might expect to manifest constructional apraxia as a consequence of damage to frontocerebral networks involved in motor coordination (39) and subject 14A who had bilateral thalamic lesions. Right thalamic lesions have previously been shown to result in constructional apraxia [50]. Both 10A and 14A had clear evidence of constructional apraxia. Thirty-three and thirty-four percent of constructional apraxia and non-CA subjects had diffuse injury; respectively. This percentage difference was non-significant and perhaps alludes to the centrality of posterior syndromes as opposed to frontal and diffuse lesions that might be expected in a dysexecutive model of constructional apraxia [39]. Future studies of constructional apraxia would benefit from incorporating multiple research strategies including lesion analyses of individual patients and case series, computerized experimental design using accuracy and reaction time data, structural and functional neuroimaging as well as hierarchical statistical modeling of brain network interactions.

ACKNOWLEDGEMENTS

This research was approved by the Research and Performance Support institutional review committee of the Regina Qu'Appelle Health Region at the Wascana Rehabilitation Centre in Regina, Canada. This research was completed in the summer of 2012. All research participants provided their informed written consent in accordance with the Declaration of Helsinki. This study was conducted in accordance with the principles of the *Canadian Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans* [3]. We thank the research participants for their involvement with our study. The authors of this study report no conflict of interest.

Appendix 1.

INSTRUCTIONS FOR DRAWING A PERSON

"I want you to draw a picture of yourself. Be sure to draw your whole body, not just your head, and draw how you look from the front, not from the side. Do not draw a cartoon or stick figure. Draw the very best picture of yourself that you can. Take your time and work carefully. Go ahead." Verbatim instructions from Reynolds and Hickman, 2004 manual [17].

INSTRUCTIONS FOR DRAWING A HOUSE: ADAPTED INSTRUCTIONAL SET [17].

"I would like you to do some more drawings. I want you to draw a picture of a House. Be sure to draw the whole House. Do not draw a cartoon or stick figure. Draw the very best picture of a House that you can. Take your time and work carefully. Go ahead."

INSTRUCTIONS FOR DRAWING A TREE: ADAPTED INSTRUCTIONAL SET [17].

"I would like you to draw one more drawing. I want you to draw a picture of a Tree. Be sure to draw the whole Tree. Do not draw a cartoon or stick figure. Draw the very best picture of a Tree that you can. Take your time and work carefully. Go ahead."

REFERENCES

[1] McCrea SM. A neuropsychological model of free-drawing from memory in constructional apraxia: A theoretical review. Am J Psychiatr Neurosci. 2014; 2(5): 60-75. doi: 10.11648/j.ajpn.20140205.11

[2] Benson DF, Barton MI. Disturbances in constructional ability. Cortex 1970; 6: 19-46. http://dx.doi.org/10.1016/S0010-9452(70)80034-X

[3] Canadian Institutes of Health Research, Natural Sciences and Engineering Research Council of Canada, and Social Sciences and Humanities Research Council of Canada, Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans, December 2010.

[4] Braun CM, Montour-Proulx I, Daigneault S, *et al.* Prevalence, and intellectual outcome of unilateral focal cortical brain damage as a function of age, sex and aetiology. Behav Neurol. 2001; 13: 105–16. http://dx.doi.org/10.1155/2002/634764

[5] Roquer J, *et al.* Sex differences in first-ever acute stroke. Stroke. 2003; 34: 1581–5. http://dx.doi.org/10.1161/01.STR.0000078562.82918.F6

[6] Lezak MD. Neuropsychological assessment - Third edition. New York: Oxford University Press 1995.

[7] Hardyck C, Petrinovich LF. Left-handedness. Psychol Bull 1977; 84: 385–404. http://dx.doi.org/10.1037/0033-2909.84.3.385

[8] Roncato S, Sartori G, Masterson J, Rumiati R. Constructional apraxia: An information processing approach. Cogn Neuropsychol 1987; 4: 113-29. http://dx.doi.org/10.1080/02643298708252037

[9] Vallar G. The methodological foundations of neuropsychology. In: Denes G, Pizzamiglio, L, Eds. Handbook of clinical and experimental neuropsychology. East Sussex, UK: Psychology Press 1999; pp. 95-131.

[10] Pearson. Test of premorbid functioning: Advanced clinical solutions for use with WAIS-IV and WMS-IV. San Antonio: Pearson Education, 2009.

[11] Teasdale G, Jennett B. Assessment of coma and impaired consciousness: A practical scale. Lancet 1974; 81-3. http://dx.doi.org/10.1016/S0140-6736(74)91639-0

[12] Damasio H, Damasio AR. Lesion analysis in neuropsychology. New York: Oxford University Press 1989.

[13] Rosenthal, R, Fode, KL. Psychology of the scientist: V. Three experiments in experimenter bias. Psychological Reports. 1963; 12: 491-511. http://dx.doi.org/10.2466/pr0.1963.12.2.491

[14] Gainotti G. Constructional apraxia. In: Frederiks JAM, Ed. Handbook of clinical neurology – Volume 1. Amsterdam: Elsevier 1985; pp. 491-506.

[15] Goodenough F. Measurement of intelligence by drawings. New York: World Books 1926.

[16] Paivio A Mental representations: a dual coding approach. Oxford. England: Oxford University Press 1986.

[17] Reynolds CR, Hickman JA. DAP: IQ: Draw-A-Person intellectual ability test for children, adolescents and adults. Austin, TX: ProEd 2004.

[18] Buck JN. The House-Tree-Person technique: Revised Manual. Beverly Hills, CA: Western Psychological Services 1966.

[19] Swenson CH. Empirical evaluations of human figure drawings 1957-1966. Psychol Bull 1968; 70: 20-44. http://dx.doi.org/10.1037/h0026011

[20] Kahill S. Human figure drawings in adults: An update of the empirical evidence 1967-1982. Can Psychol 1984; 25: 269-92. http://dx.doi.org/10.1037/h0080846

[21] Ogdon DP. Psychological signs, symptoms, and syndromes. Los Angeles: Western Psychological Services 2001.

[22] Ogdon DP. Psychodiagnostics and personality assessment: A handbook - third edition. Los Angeles: Western Psychological Services 2004.

[23] Williams TO *et al.* The reliability of scores for the Draw-a-Person intellectual ability test for children, adolescents and adults. J Psychoeduc Assess 2006; 24:137-44. http://dx.doi.org/10.1177/0734282905285249

[24] Wechsler D. Wechsler Adult Intelligence Scale – Fourth edition. San Antonio, TX: Psychological Corporation 2008.

[25] Wechsler D. Wechsler Memory Scale – Fourth edition: Technical and Interpretive Manual. San Antonio, TX: Psychological Corporation 2009.

[26] NCS Pearson. Advanced clinical solutions for WAIS-IV and WMS-IV: Administration and scoring manual. San Antonio, TX: Psychological Corporation 2009.

[27] McCrea SM, Robinson TP. Visual puzzles, figure weights and cancellation: Some preliminary hypotheses on the functional and neural substrates of these three new WAIS-IV subtests. ISRN Neurol 2011; Article ID 123173, 19 pages, doi: 10.5402/2011/123173.

[28] Kolb B, Whishaw IQ. Fundamentals of human neuropsychology – Fourth edition. New York: W.H. Freeman and Company 1996.

[29] McCarthy RA, Warrington EK. Cognitive neuropsychology: A clinical introduction. San Diego, CA: Academic Press 1990.

[30] Russell EW. A reference method for constructing neuropsychological test batteries. J Clin Exp Neuropsychol 1987; 9: 376-392. http://dx.doi.org/10.1080/01688638708405058

[31] Robertson LC, Knight RT, Rafal R, Shimamura AP. Cognitive neuropsychology is more than single-case studies. J Exp Psychol Learn Mem Cogn 1993; 19:710-7. http://dx.doi.org/10.1037/0278-7393.19.3.710

[32] Yin RK. Case study research: Design and methods – Second Edition. London, UK: Sage Publications 1994.

[33] Philips Healthcare. [Philips iSite Enterprise]. Andover, MA, United States of America.

[34] Kretschmann HJ, Weinrich W, Eds. Cranial neuroimaging and clinical neuroanatomy: Atlas of MR imaging and computed tomography: Third edition. New York: Thieme 2001.

[35] Costa LD, Vaughn HG. Performance of participants with lateralized cerebral lesions. 1:Verbal and perceptual tests. J Nerv Ment Dis 1962; 134: 162-68. http://dx.doi.org/10.1097/00005053-196202000-00007

[36] Glascher J, Rudrauf D, Colom R, *et al.* Distributed neural system for general intelligence revealed by lesion mapping. P Natl Acad Sci USA 2010; 107: 4705-9. http://dx.doi.org/10.1073/pnas.0910397107

[37] Trojano L, Grossi D. A critical review of mental imagery defects. Brain Cogn 1994; 24:213-43. http://dx.doi.org/10.1006/brcg.1994.1012

[38] Kirk A, Kertesz A. Hemispheric contributions to drawing. Neuropsychologia 1989; 27: 881-6. http://dx.doi.org/10.1016/0028-3932(89)90011-0

[39] Lezak MD, Howieson DB, Loring DW. Neuropsychological assessment – Fourth Edition. New York. Oxford University Press 2004.

[40] Brownell H, Martino G. Deficits in inference and social cognition: The effects of right hemisphere brain damage on discourse. In: Beeman M, Chiarello C, Eds. Right hemisphere language comprehension: Perspective from cognitive neuroscience. Mahwah, NJ: Lawrence Erlbaum Associates 1998; 309-328.

[41] Wilkinson GS, Robertson GJ. WRAT4: Wide Range Achievement Test – Professional manual. Lutz, FL: Psychological Assessment Resources Inc 2006.

[42] Schretlen D. Brief Test of Attention: Professional Manual. Odessa, FL: Psychological Assessment Resources Inc 1997.

[43] Schretlen D. Brief Test of Attention: Professional Manual. Odessa, FL: Psychological Assessment Resources Inc 1997.

[44] Strauss E, Sherman EMS, Spreen O. A compendium of neuropsychological tests: Administration, norms, commentary. New York: Oxford University Press 2006.

[45] NCS Pearson. Advanced clinical solutions for WAIS-IV and WMS-IV: Administration and scoring manual. San Antonio, TX: Psychological Corporation 2009.

[46] Stemmer B. Neuropragmatics: disorders and neural systems. In Stemmer B, Whitaker HA, Eds. Handbook of the neuroscience of language. New York: Academic Press 2008; pp. 175–87. http://dx.doi.org/10.1016/B978-0-08-045352-1.00017-3

[47] Farah MJ. Visual agnosia – Second edition. Cambridge, MA: MIT Press 2004.

[48] Hammer EF. Advances in projective drawing interpretation. Springfield, IL: Charles C. Thomas Publishers 1997.

[49] Dupuy D and Godefroy O. Disorders of visuoconstructive ability. In: Godefroy O, Bogousslavsky J, Eds. The Behavioral and Cognitive Neurology of Stroke. Cambridge, MA: Cambridge University Press 2007; pp. 254-68. http://dx.doi.org/10.1017/CBO9780511544880.013

[50] Perren F, Clarke S and Bogousslavsky J. The syndrome of combined polar and paramedian thalamis infarction. Archives of Neurology. 205; 62(8): 1212-16.

Received on 23-10-2014 Accepted on 13-02-2015 Published on 31-07-2015

DOI: http://dx.doi.org/10.12974/2313-1047.2015.02.01.1