Finding Evidence of Deductive and Abductive Reasoning Abilities: An Experiment with Lateral-Brain-Damage Patients

Franco Salvetti (franco.salvetti@colorado.edu)
Dept. of Computer Science
University of Colorado at Boulder
430 UCB, Boulder, CO 80309–0430, U.S.A.

Nicolas Nicolov (nicolas@umbrialistens.com)
Umbria Inc.
1655 Walnut Str.
Boulder, CO 80302, U.S.A.

Abstract

In narrative discourse, explanation can be considered abductive reasoning, described as a creative type of reasoning which generates new ideas, and prediction can be considered logical deductive reasoning. Given the well-known associations with hemisphere processing and reasoning associations, it would be expected that patients with left hemisphere brain damage would exhibit more evidence of explanation versus prediction in reasoning and patients with right hemisphere brain damage would exhibit more evidence of prediction versus explanation in reasoning. By observing actual linguistic evidence of reasoning in left and right hemisphere brain damaged patients in comparison to that of a control group, we were able to discover important differences between these groups. Contrary to assumed wisdom, patients with left hemisphere damage produced more utterances of prediction than of explanation and patients with right hemisphere damage produced more utterances of explanation than prediction on a narrative discourse task. Linguistic processing and cognitive processing are discussed as explanations for these results.

Introduction

Human beings are able to generate long chains of reasoning which produce inferences (Birnbaum, 1986). A way to categorize different kinds of reasoning is to focus on reasoning which produces prediction versus reasoning which explains observations. These two tasks are here considered cognitively different. The first is considered more closely related to classical logical deduction (Feferman, 1999), while the second to *abductive reasoning* (Magnani, 2005) and creative thinking.

Analyzing transcripts from an experiment, administered at Boston VA Hospital and fully described here, that involved patients with lateral brain damage, we have found preliminary evidence that patients affected by aphasia exhibit verbal evidence of reasoning which, compared with a control group, suggests that while capable of performing reasoning, they have less problems in producing sentences with evidence of prediction than sentences with evidence of explanation. Patients with right–hemisphere brain damage exhibit verbal evidence of reasoning which, when compared with a control group, suggests that even though abstract reasoning and the ability to make inferences may be impaired, they have fewer problems producing sentences with evidence of explanation than sentences with evidence of prediction.

By binding the concept of creativity in reasoning with explanation in the past, it appears that patients with right hemisphere brain damage attend even more to this type of reasoning than normals, even though creativity could be thought of as associated with the right hemisphere (Code, 1987). By binding the concept of logical deduction in reasoning with prediction of the future, it appears that patients with left hemisphere damage, on the other hand, linguistically attend more to prediction than explanation, even though linguistic evidence of both types of reasoning is less than among members of the control group.

The implications of this evidence and possible linguistic and cognitive explanations for this evidence are discussed.

Related Research

Several previous studies, e.g., (Geminiani & Bucciarelli, 1998), have addressed the effect of lateral brain damage on explanation and prediction reasoning processes. By and large, the left hemisphere has been more commonly associated with language processing and the right hemisphere with visuospatial processing and abstract reasoning. Related studies, e.g., (Sacco, Bucciarelli, & Adenzato, 2001), have focused on causal reasoning, theory of mind processing, metaphor interpretation, and discourse abilities.

Mind processing and simple causal reasoning were shown to be intact in a severe agrammatic aphasic patient with a large lesion in the left hemisphere who could not formulate propositions in speech or writing, make judgments as to whether a sentence is grammatical, match sentences to pictures, or identify the meaning of verbs. This patient tested in the 91st percentile on the Wisconsin card sorting test and was able to rely on the visuospatial representation and memory of the location and attributes of objects in order to communicate his responses. Grammar may therefore play a vital role in the development of cognitive processes, but once these processes are established, cognition can operate without grammar (Siegal, Varley, & Want, 2001).

The assumption that reasoning based on world knowledge is intact in severe aphasia may be questioned (Joanette & Brownell, 1990). Huber discusses conflicting evidence that Global and Wernicke's aphasic patients had as much difficulties ordering picture stories as did right hemisphere patients. Not only may visuospatial reasoning be damaged, but general impairment of reasoning or sequencing may be attributed to these common deficits. Huber (Joanette & Brownell, 1990) found that choosing a figurative meaning of an idiom is more demanding than choosing the literal meaning for normals, patients with right hemisphere damage, and aphasic patients. Idioms with close relationships between the literal and figurative meanings led to a higher probability of the literal meaning being chosen. Global and Wernicke's aphasic patients were found to have the most difficulty identifying both literal and figurative meanings of idioms when there was a remote relationship between the two. When the two meanings were close, the literal meaning was more easily accessed. Brownell and Stringfellow (Brownell & Stringfellow, 1999) worked with patients with right hemisphere damage, exploring their performance in making requests in various situations. Findings were that some patients produced less explanatory material, and others produced normal amounts but did not vary the amounts in ways that could be tied to the discourse setting. The conclusion was that the most common limiting factor for patients with right hemisphere damage when making requests was not the initial assessment of the situation, but rather using the understanding as a guide to designing appropriate utterances.

In other studies with patients with right hemisphere damage, their ability to distinguish between lies and jokes was described as fragile and unreliable (Winner, Brownell, Happe, Blum, & Pincus, 1998). Left hemisphere and right hemisphere responses in picture description tasks differ among patients who acquired left hemisphere brain damage early. The right hemisphere was shown to be able to develop an apparent speech production capability comparable to that normally associated only with the left hemisphere. Patients' responses in picture description tasks still showed differences—the responses of patients with left hemisphere damage are quite descriptive with a focus on explanatory reasoning, while the responses of patients with right hemisphere damage were quite visuospatially oriented and included both explanatory and predictive reasoning (Code, 1987).

Reasoning

If thinking can be seen as a psychological function that involves the creation and organization of information in the mind, reasoning is a set of cognitive processes by which an individual may infer a conclusion from an assortment of evidence or from statements of principles (Sternberg, 1999).

Classification of the different kinds of reasoning has produced a large number of definitions, which frequently contrast each other. The following is a list of possible kinds of reasoning which can be encountered in scientific publications: abductive, affective, algebraic, analogical, anthropic, approximate, automated, bounded, case–based, causal, circular, clinical, commonsense, consequentialist, critical, deductive, default, defeasible, demonstrative, deontic, diagnostic, equational, formal, forward, fuzzy, gifted, hierarchical, inductive, legal, logical, mathematical, metaphorical, monotonic, moral, non–monotonic, plausible, pragmatic, probabilistic, proportional, prudential, qualitative, quantitative, spatial, stereotypical, systematic, taxonomical, temporal, terminological, terrain, textual, and verbal. Our aim here in not to refine or redefine a paradigm of the possible different forms of reasoning; on the contrary, our aim is to use the broadest possible classification capable of distinguishing among the intuitively different, even if sometimes similar, reasoning activities we will encounter in our research.

Reasoning which produces *prediction* and reasoning which *explains observations* are here considered cognitively different. The first is closely related to classical logical deduction, and the second is closely related to abductive reasoning and creative thinking. Being interested in exploring possible differences between brain damaged populations in terms of creative thinking, we decided to differentiate types of reasoning by focusing on verbal evidence of reasoning in terms of *prediction* and *explanation*.

We noticed that many cases of inferences, which can be considered explanations of some observations, can be better labeled as *categorization*. For instance, when a patient claims, "There is a butcher", we are observing the results of categorization, because the butcher, which actually is a category, is chosen as the best label which can explain the observations. Although some may argue that the process of choosing "butcher" as a label is deduction and not explanation, we are here accepting the idea of *abductive reasoning* (Magnani, 2005):

> "*Abduction is the process of forming an explanatory hypothesis. It is the only logical operation which introduces any new idea.*" – Pierce

The primary difference between deduction and abduction is that deduction usually tends to predict results, such as in "All men are mortal, Socrates is a man, therefore Socrates is mortal." Abduction tends to find, among the possible *causes* of an observation, the one which is more likely, with respect to our knowledge so far, such as in "John has lung cancer, John smokes, *therefore* smoking is the cause of his cancer". The Socrates example cannot be contested; it is a logical deduction, but the second example is just one of many possible explanations of our observation. It could be that John has cancer due to some rare genetic disease. Moreover, inferences produced through abduction are defeasible because new and more accurate observations can lead to completely different and even opposite inferences. If Pierce uses abduction and deduction (Magnani, 2005), Polya analogously introduces the idea of *plausible* reasoning in contrast to *demonstrative* reasoning (Polya, 1968):

> "*Plausible reasoning is the only means by which we can acquire new knowledge. We secure our knowledge by demonstrative reasoning, but we support our conjectures by plausible reasoning. A mathematical proof is demonstrative reasoning, but the inductive evidence of the physicist, the circumstantial evidence of the lawyer, the documentary evidence of the historian, and the statistical evidence of the economist belong to plausible reasoning.*"

Considering that categorization is an instance of abductive or plausible reasoning that is so abundant in languages, as is evident, for instance, in the data that will be presented we decided to create a separate category for it in order to have more insight into the differentiation between explanation and prediction.

We are not interested in inductive reasoning (i.e., the creation of a general rule from evidence) because observing inductive reasoning during the description of a picture is not likely, whereas verbal instances of prediction, explanation and categorization are present in sufficient amounts to justify a comparison.

Language and Reasoning

Considering that it is impossible to directly access internal reasoning processes and see exactly how and where they happen, external observation of expression and confirmation of understanding can be used to validate the existence of reasoning processes. A focus on understanding reasoning is directed toward patients being able to recognize logical or justified reasoning. By focusing on spontaneous evidence of reasoning in language, more attention can be paid to how much patients choose to express reasoning about presented stimuli. Patients may choose to attend or not attend to reasoning about certain stimuli based on what given structures are available linguistically. It is equally plausible that attempts may still be made to communicate reasoning even without sound linguistic structure. The question of patient motivation and desire to communicate conceptual and linguistic structure that may be difficult varies between people in general, but may also be associated with cognitive processing variance between people. For example, aphasic patients have been shown to have difficulty with sequential processing (Joanette & Brownell, 1990). The possible connection between sequential processing and the ability to reason about explanations which precede a situation and predictions which follow can then be presented. If linguistic structures are ill-formed, this may simply be evidence of the communicative structure being damaged or it may be that underlying processes associated with reasoning and grammar have been damaged.

Figure 1: Original picture shown to patients for data collection. Patients were asked to describe what is going on. – ©1992 by R.P. Co. All rights reserved.

Methods

Differences in cognitive processing may exist between creative reasoning and logical deductive reasoning. Considering differences in linguistic production and evidence of cognition in studies of right and left hemisphere brain damage, comparing attention to and attempts at expressing these different reasoning types may give insight into a representational difference between creative reasoning processes and logical deduction processes. In order to see evidence of these two types of reasoning processes, an appropriate stimulus was needed. The most logical place to look was in regular picture stimuli as given to patients for evaluation measures. These pictures commonly exhibit situations which may be conducive to making inferences, labeling figures, and expressing coherence between possibly unrelated scenes in order to evaluate patients' language and inferential processing abilities.

The patients in this experiment were given Figure 1. It provided different scenes of stimuli conducive to explanation and prediction. As seen in Figure 2, the four main scenes in the picture are: the Eskimo and igloo, the woman and the cans, the butcher and cleaver and the boy and the eggs (frame lines and letters were not shown to patients). Each individual scene had visuospatial triggers of items which may be connected to the main participants via a reasoning process. Indeed, according to (Kay, 1983), ideal readers of a text try to cohere lexical triggers together, combining participants and scenarios into one environment, connecting actions and roles. When presented with visuospatial stimuli, it is probable that normal observers do the same in order to give a coherent narrative description. Given the expectations that readers will

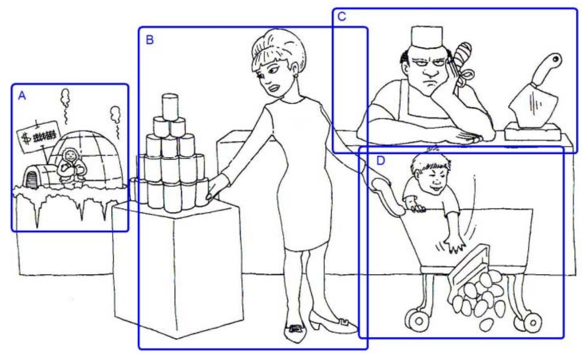

Figure 2: Four main scenes are evident in the picture: (a) the igloo; (b) the lady; (c) the butcher; and (d) the child.

use these visual triggers to facilitate making connections, we felt this picture provided strong cues to associate with the reasoning processes in which we were interested. In Figure 3, it is possible to see the different main visual triggers that could be connected in a narrative description. Examples of patient

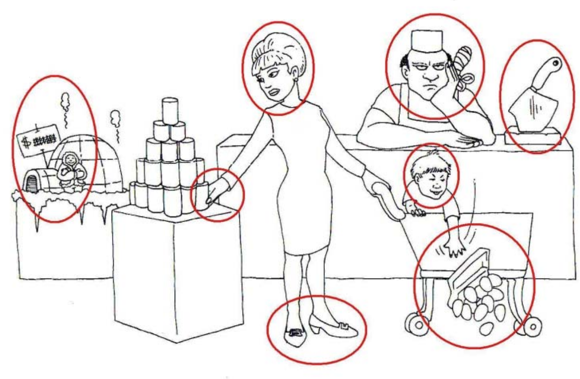

Figure 3: Details in the picture which patients sometimes connected by reasoning.

utterances: Control group patient: "the butcher looks like he would like the lady and baby to go home"; patient with right hemisphere damage: "there's a woman getting some cans pushing a monkey in a grocery cart", patient with left hemisphere damage: "the butcher he's ice cold".

The proximity and semantic relatedness of the butcher and the cleaver is likely to prompt explanatory reasoning that the butcher may have cut his finger with the cleaver. The child's facial expression along with movement lines from his hand to the eggs are likely to prompt the explanation that the child threw the eggs. Examples of patient utterances for the child scene include: Control group patient: "the strange looking kid dumped the eggs", patient with right hemisphere damage: "he's going to get his bottom spanked", patient with left hemisphere damage: "playing and eggs and dropped them on the floor".

There are many triggers in this scene, of which the ones illustrated above are examples. These triggers are conducive to observers expressing reasoning of situations prior to this picture, which is explanation, and what may happen as a result of this picture, which is prediction. To avoid confusing creative explanations and the more logical deductive predictions with other evidence of reasoning, we also separated out categorization. Categorization was the default label of evidence of reasoning regarding naming, description of states and current events, and descriptions of emotional states or theory of mind. This provides a category specific to evidence of reasoning not directly associated with making explanations or predictions from the picture stimuli, and also lets us keep track of other linguistic evidence of reasoning as a whole.

Data Collection and Quantitative Analysis

Data was collected from 65 patients in the Boston VA Hospital as part of a routine evaluation. 24 patients were not identified as having brain damage, 24 (15) were identified as having left (right) hemisphere brain damage. Patients were given a picture as in Figure 1 and asked to describe it.

We labeled instances of linguistic evidence of reasoning in the data as categorization, explanation, or prediction.

Analysis and Results

The collected data was labeled by group (i.e., right hemisphere, left hemisphere, and controls) and individually per patient. Table 1 summarizes the average number of words in the picture description per patient in each group, and the total number of instances of the different kinds of reasoning per group.

	Ctrl	R-H	L-H
Num. of patients	24	15	26
Mean word count	74.71	63.60	75.38
Explanation	43.00	36.00	20.00
Categorization	400.00	183.00	310.00
Prediction	37.00	15.00	21.00
Mean per patient	20.00	15.60	13.50

Table 1: Average number of words in descriptions, and number of instances of explanation, categorization, and prediction reasoning in control (Ctrl.), right hemisphere (R-H), and left hemisphere (L-H) patients. Mean total evidence of reasoning per patient group are shown.

Categorization is by far the most common type of reasoning, ranging from 78% (right hemisphere) to 88% (left hemisphere) of all instances of reasoning – see Figure 4 and Table 2.

Type	Ctrl	R-H	L-H	μ	σ
Explanation	8.96	15.38	5.70	10.01	4.93
Categorization	83.33	78.21	88.32	83.29	5.06
Prediction	7.71	6.41	5.98	6.70	0.90

Table 2: Percentage of types of reasoning per patient group. μ = mean evidence of type of reasoning across patient groups. σ = standard deviation from mean of evidence of type of reasoning across patient groups.

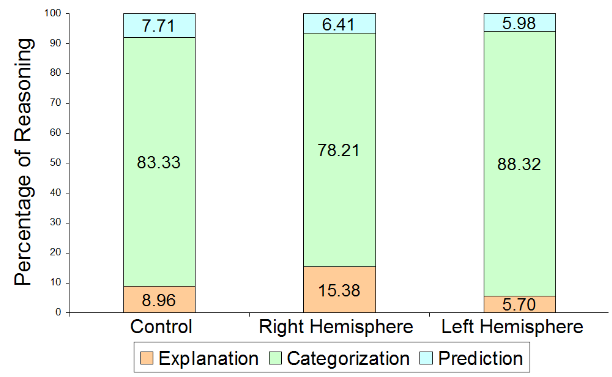

Figure 4: Percentage distribution of explanation, categorization and prediction in the control group, patients with right and left hemisphere damage.

This great difference remains despite the fact that many instances of categorization were deliberately ignored (see above). In counting instances of explanation, patients with left hemisphere damage had a mean of 0.77, control group members 1.79, and patients with right hemisphere damage 2.40 per patient. Patients with left hemisphere damage, thus, produced 57% fewer instances of explanation than control members and right hemisphere ones produced 25% more instances of explanation than control members. The fact that right hemisphere patients overall produced 25% more instances of explanation than controls and yet they also produced the lowest average of words per patient, 63.60, especially highlights the difference between right hemisphere patients, left hemisphere patients, and controls in producing utterances of explanation. In counting categorization, left hemisphere patients had a mean of 11.92, right hmisphere 12.20, and control ones 16.67 per patient. Left hemisphere patients therefore produced 28% fewer instances of categorization than controls and right hemisphere patients produced 27% fewer instances of categorization than controls (see Table 3). Considering instances of prediction per patient, mem-

	Ctrl	R-H	L-H	μ	σ
Exp./Pat.	1.79	2.40	0.77	1.65	0.82
Cat./Pat.	16.67	12.20	11.92	13.60	2.66
Pre./Pat.	1.54	1.00	0.81	1.12	0.38

Table 3: Average number of instances of explanation (Exp.), categorization (Cat.), and prediction (Pre.) per patient description produced in each patient group. μ = mean of types of reasoning across groups. σ = standard deviation from mean across groups.

bers of the control group had a mean of 1.54 examples per patient, patients with right (left) hemisphere damage – 1.00 (0.81). Patients with right (left) hemisphere damage produced 36% (48%) fewer instances of prediction than control group members. To verify the validity of the differences in amounts between the types of reasoning, we designed a new measure called "density of reasoning", which represents the average number of words between instances of reasoning to be used in connection with and in comparison to measurements of instances per patient. The differences in reasoning instances per patient are very similar to the differences in respective densities of reasoning. This becomes even more apparent when looking at the densities (compare Figures 5 and 6).

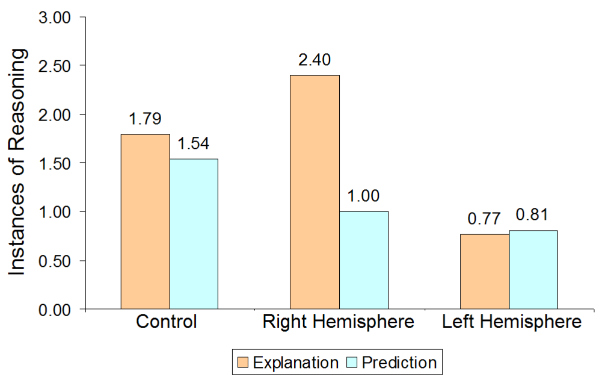

Figure 5: Average instances of explanation and prediction per patient in control group, and patients with right (left) hemisphere damage.

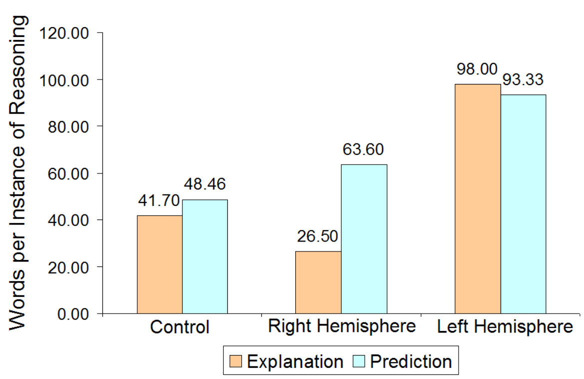

Figure 6: Average density (words per instance) of explanation and prediction in control group, and patients with right (left) hemisphere damage.

In examining these figures, note that for density, low numbers indicate higher density, so if the differences are the same, the graphs should look like mirror images of each other. For explanation, members of the control group had a mean density of 41.7 and patients with right (left) hemisphere damage – 26.5 (98.0). For categorization, mean density was 4.48 for control, 5.21 for right and 6.32 for left hemisphere, For prediction, mean densities were 48.46, 63.60 and 93.33 respectively.

Discussion

The standard deviation for word count per patient in patients with left hemisphere damage (67.43) is twice that of either of the other groups (25.47 for right; 29.62 for control). This large variance in number of words per patient may be attributed to the fact that patients in the left hemisphere group were not distinguished by degree or type of aphasia. The general label of 'left hemisphere' describes the specific hemisphere of brain damage, but does not differentiate between fluent and non–fluent aphasia, mild, moderate, and severe aphasia or Broca's and Wernicke's aphasia. The diagnosis 'aphasia' therefore has quite broad ways of being described, differing in reference to both linguistic expression and comprehension with each of these more specific labels.

Generally, the measures of instances of reasoning indicate that the control patients produce the most evidence of reasoning, followed by right hemisphere patients, with left hemisphere patients producing the least evidence of reasoning. The only exception to this generalization is the fact that the right hemisphere patients produced more explanation than did the control patients. There are a few hypotheses that could account for this observation. Right hemisphere patients, with their possible tendencies to inject personal details or tangents in narrative descriptions (Code, 1987), may have done so without our noticing that the explanation was not directly related to the picture, although we tried to exclude any reasoning that could not be directly connected with the picture. Alternatively, right hemisphere patients could be making abnormally high amounts of explanation, regardless of whether or not the reasoning is logical and justified (we did not exclude instances that may be considered less than sound judgment), as compared with controls. Given that explanation is here considered creative reasoning, it is interesting to note that patients with right hemisphere brain damage actually produced more evidence of creative reasoning than controls, whereas the right hemisphere is normally associated with creative processing, such as in interpreting metaphor. Left hemisphere patients, with possible damage to their expression of language, may possibly have less access than controls to the grammatical structures associated with explanation in speech. Alternatively, what may appear on the surface as mere lack of grammatical structure may instead be evidence of damage to the abductive or plausible reasoning process of introducing new ideas or thoughts, here considered a creative process.

While in this paper a distinction has been made between explanation, prediction, and categorization, it is possible that these processes in the brain are the same. While the tendency for both controls and right hemisphere patients was to have most reasoning focused on categorization, less focus on explanation, and the least focus on prediction, left hemisphere patients broke this pattern with slightly more focus on prediction and less focus on explanation. This distinction possibly can be accounted for by lack of the grammatical structures required to specifically produce explanation in left hemisphere patients. While this is the usual conclusion drawn in reference to cognitive processes with left hemisphere patients, other hypotheses may be considered.

Our annotation of the transcripts suggests that these differences may also be evidence of damage to reasoning processes, particularly distinctions between abductive and deductive reasoning processes.

A study that allows patients to use other strategies of communication, like gesture and drawing, would possibly be able to distinguish between any change in different reasoning patterns of left hemisphere patients as compared with controls and lead to a stronger indication, or lack of indication, of cognitive reasoning associations with the left hemisphere.

The distinction also has been seen here that left hemisphere patients, in general, have fewer utterances of explanation, prediction, and categorization overall than controls and right hemisphere patients. Although right hemisphere patients did follow the pattern of left hemisphere patients and had fewer utterances of prediction and categorization than controls, right hemisphere patients broke this pattern with more utterances of explanation than controls. Since explanation has been associated with abductive reasoning, here supported as a creative type of reasoning, original expectations that this reasoning would have fewer representations is not supported. The idea that creative processes are considered to be damaged in right hemisphere patients, evidenced by lack of ability to interpret metaphor and make inferences between input stimuli, does not support the connection of abduction to the supposed creative processes of metaphor interpretation and making inferences. It does still suggest that there may be a distinction between types of reasoning, possibly being associated with different processing areas of the brain. A study with more specific information as to the location of right hemisphere lesions in patients could shed light on possible correlations between different types of reasoning and the right hemisphere.

Conclusions

By observing actual linguistic evidence of reasoning in left and right hemisphere brain damaged patients in comparison to that of a control group, we were able to discover important differences between these groups. We believe that the discovered differences are relevant and can stand scrutiny, since:

1. the size of the sample was relatively large, and suitable for further statistical analysis of the data, e.g., bootstrapping of the results for each class of patient.
2. the patients group was carefully assembled so as to *minimize variations due to external factors.* The participants had been selected by the staff of Boston VA Hospital to create a sample as homogeneous as possible both from the point of view of the particular type of brain damage, which was certified and unilateral, and of other relevant parameters such as age, gender and years in school. In particular, control patients were selected among fellow in-patients. Finally, professional staff administered the tests.
3. the test did not require vis-a-vis similar experiments, e.g., (Geminiani & Bucciarelli, 1998), particular memory skill to be answered, and only limited verbal skills.
4. the annotators were given precise guidelines on how to evaluate utterances w.r.t. the criteria discussed above.

Let us now reconsider that reasoning associated with creating new ideas and new knowledge, as described by Polya and Pierce, is the kind of reasoning that patients with left hemisphere struggle with the most and with which right hemisphere patients seem to have little problem. The results of analysis, if confirmed, suggests that prominent notions about the association of the right hemisphere of the brain with creativity might need to be re-examined or qualified to clarify inconsistencies between philosophical and psychological notions of creativity. The results also show that aphasic patients consistently perform fewer linguistic instances of reasoning than controls and right hemisphere patients others.

Future research needs to be done exploring the possibility of separate reasoning processes and what their relation may be to specific brain-damaged populations. Also, in the follow-up of this work we intended to relate our findings to the literature on neuroimaging of reasoning activity, and to experiments on brain-damaged patients that involved skills such as memory (Geminiani & Bucciarelli, 1998) and metaphor.

Acknowledgments. We are deeply indebted to Anna Clark and Stephen Lewis. Thanks to Monica Bucciarelli, Jim Martin, Gail Ramsberger, Lise Men, Clayton Lewis, and Carolyn Rickard.

References

Birnbaum, L. (1986). Integrated processing in planning and understanding. *Research Report 489, New Haven: Computer Science Dept., Yale Univeristy*.

Brownell, H., & Stringfellow, A. (1999). Making requests: Illustrations of how right-hemisphere brain damage can affect discourse production. *Brain and Language*, *68*, 442–465.

Code, C. (1987). *Language Aphasia and the Right Hemisphere*. Chichester: John Wiley & Sons Ltd.

Feferman, S. (1999). Logic, logics and logicism. *Notre Dame Journal of Formal Logic*, *40*, 31-54.

Geminiani, G. C., & Bucciarelli, M. (1998). Deductive Reasoning in Right-Brain Damaged. In *Proc. of the XXth Conf. of the Cognitive Science Society* (p. 386-391).

Joanette, Y., & Brownell, H. H. (1990). *Discourse Ability and Brain Damage: Theoretical and Empirical Perspectives*. New York: Springer-Verlag.

Kay, P. (1983). Three Properties of the Ideal Reader. In R. Freedle & R. Duran (Eds.), *Cognitive and Linguistic Analyses of Test Performance* (pp. 208–224). Norwood, NJ: Ablex.

Magnani, L. (2005). An Abductive Theory of Scientific Reasoning. *Semiotica*, *153*(1/4), 261-286.

Polya, G. (1968). *Mathematics and Plausible Reasoning, Volume II: Patterns of plausible inference and analogy*. Princeton, New Jersey: Princeton University Press.

Sacco, K., Bucciarelli, M., & Adenzato, M. (2001). Mental models and the meaning of connectives: A study on children,adolescents and adults. In *Proc. of the XXIIIth Conf. of the Cognitive Science Society* (p. 875-880).

Siegal, M., Varley, R., & Want, S. C. (2001). Mind over Grammar: Reasoning in aphasia and development. *Trends in Cognitive Science*, *5*(7), 296-301.

Sternberg, R. J. (1999). *Pathways to psychology* (2nd ed.). Wadsworth Publishing, CA.

Winner, E., Brownell, H., Happe, F., Blum, A., & Pincus, D. (1998). Distinguishing Lies from Jokes: Theory of Mind Deficits and Discourse Interpretation in Right Hemisphere Brain-Damaged Patients. *Brain and Language*, *62*, 89–106.