Reasoning and Brain Damage: prediction and explanation in left and right hemisphere patients

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Abstract

The left and right hemispheres of the brain are generally known to be associated with different types of processing. The left hemisphere is associated with linguistic, sequential and logical processing. The right hemisphere is associated with abstract and visuospatial reasoning and creative processing. 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 these 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. Contrary to expected evidence, left hemisphere patients produced more utterances of prediction than of explanation and right hemisphere patients produced more utterances of explanation than prediction on a narrative discourse task. Linguistic processing capabilities and cognitive processing capabilities are jointly discussed as explanations for these results.

keywords

Abduction, Aphasia, Brain Damage, Categorization, Creativity, Explanation, Left Hemisphere, Prediction, Reasoning, Right Hemisphere.

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 more related with classical logical deduction (Feferman 2002), and the second is more closely related with abductive reasoning (Magnani 2002) and creative thinking. This paper shows 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 in thought is associated with the right hemisphere (Code 1987). By binding the concept of logic and deduction in reasoning with prediction of the future, it appears that left hemisphere patients, on the other hand, linguistically attend more to prediction than explanation, even though linguistic evidences of both types of reasoning are fewer than in normals. The implications of this evidence and possible linguistic and cognitive explanations for this evidence are discussed.

Related Research

Few previous studies have been done directly exploring the effect of left versus right hemisphere brain damage on explanation and prediction reasoning processes. The left hemisphere has been commonly associated with language processing and the right hemisphere with visuospatial processing and abstract reasoning. Related studies have focused on causal reasoning, theory of mind processing, metaphor interpretation, and discourse abilities.

Theory of 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). Walter Huber discusses conflicting evidence that Global and Wernicke's aphasic patients had as much difficult 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.

Walter Huber (Joanette & Brownell 1990) found that choosing a figurative meaning of an idiom is more demanding than choosing the literal meaning for normals, right hemisphere patients, 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 Stringellow (1999) worked with right hemisphere patients, 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 right hemisphere patients 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 right hemisphere patients, their ability to distinguish between lies and jokes was described as fragile and unreliable (Winner *et al.* 1998). Left hemisphere and right hemisphere responses in picture description tasks differ among patients who acquired left hemisphere brain damage early as well. 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. Hemispheric responses in picture descriptions still did show differences. Left hemisphere responses are quite descriptive with a focus on explanatory reasoning, while right hemisphere responses were quite visuospatially oriented and included both explanatory and predictive reasoning foci (Code 1987).

Brain Damage

The right hemisphere and left hemisphere are generally associated with many different communicative and cognitive processing capabilities. Much evidence of the different hemisphere roles in communication and cognition have been based on studies of brain–damaged populations.

Left hemisphere brain damage is usually associated with the term "aphasia". Aphasia is defined by the National Institute on Deafness and Other Communication Disorders (NIDCD 2004) as a communication disorder that can affect a person's ability to use and understand spoken or written words. It is not a disorder in speech production. It results from damage to the side of the brain dominant for language. For most people, this is the left side. Aphasia usually occurs suddenly and often results from a stroke or head injury, but it can also develop slowly because of a brain tumor, an infection, or dementia. Aphasia is only an acquired disability. Normal language must have been developed first in order for someone to become aphasic (Varney 1990).

Aphasia can manifest itself in many different ways. Word–finding difficulty is associated with all types of aphasia to varying degrees. Broca's aphasia, associated with a lesion in the inferior frontal gyrus of the frontal lobe, manifests itself with a difficulty in expressing language utterances. Speech for Broca's patients is usually strained, non–fluent, and lacking in grammar. Patients sometimes omit words or substitute words or phonemes. Broca's aphasics generally do not have severe spoken or written comprehension difficulties, but may have poor arithmetic skills, sequential processing difficulties, as well as difficulty in repetition (Varney 1990).

Wernicke's aphasics, associated with a lesion in the posterior left temporal lobe, generally are thought to have fluent speech which is lacking in communicative informational content and have difficulty in language comprehension. As with Broca's patients, level of severity of symptoms can vary greatly between patients. Patients may make semantic and phonemic errors, use irrelevant words, and have loose sentence structure. The ability to read and write is also often severely impaired. Wernicke's patients are often unaware of their comprehension and expressive deficits (Varney 1990).

Global aphasics exhibit symptoms of severe language deficits in numerous modalities. Global aphasia is associated with lesions in both Broca's and Wernicke's areas (Ruff & Barth 2000).

Given the differences between types and severity of aphasia, the amount of words an aphasic patient uses does not necessarily correlate with more informational content being communicated. Patients may use more paralinguistic communication strategies in order to communicate effectively or they may rely on the more intact visuospatial representation and object attribute recognition processes. Alternatively, they may be unaware of their own communicative difficulties if both language comprehension and production are lacking.

The right hemisphere, on the other hand, is associated with more cognitive processing difficulties. Patients with right hemisphere brain damage can exhibit difficulties in abstract reasoning, novel situation problem solving, organization, and orientation. Right hemisphere patients commonly misinterpret non–verbal cues and can easily lose the meaning of a message, but have fluent speech, according to the American Speech-

Language-Hearing Association (ASHA 2004). When speaking, patients may characterize pictures correctly, but then inject personal details, embellish or confabulate with a lack of sensitivity to the bizarre and emotional elements of input cues. Patients seem unable to appreciate the relations among the key points in a story or joke (Code 1987).

Reasoning

If thinking can be seen as a psychological function that involves the creation and organization of information in the mind (Sternberg 2003), 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 2003). Reasoning is not thinking – animals may be said to think, but humans are characterized by the ability of doing more sophisticated reasoning activities. They are capable not only of reacting to an external stimuli, but also to find explanations for their observations or predict possible future outcomes of their actions.

One of the main activities performed in reasoning is a process called categorization, namely the basic cognitive process of arranging things into classes or categories. Ironically, reasoning itself has proven to be difficult to categorize and as such has been the subject of categorization by philosophers, artificial intelligence researchers and other cognitive scientists. 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, 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 more related with classical logical deduction, and the second is closely related with 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*.

After a more careful analysis 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 2002):

> "*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 first 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 2002), Polya analogously introduces the idea of *plausible* reasoning in contrast with *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 have decided to create a separate category for it in order to have more insight into the differentiation between explanation and prediction.

The fact that we are not interested in inductive reasoning (i.e. the creation of a general rule from evidence) is because observing abductive 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. When linguistic structures are damaged, it 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.

Given the association of the right hemisphere with abstract reasoning and the left hemisphere with language processing, the question of possible reasoning differences between the hemispheres is interesting. With the possible lack of grammatical or syntactic structure as well as naming capabilities, left hemisphere patients' possible lack of linguistic evidence in reasoning may be attributed solely to language processing deficiencies or lack of the reasoning processes which are normally represented by these linguistic structures. Right hemisphere patients have deficiencies in visuospatial processing, have a tendency to confabulate, interject personal details, and exhibit an inability to make relations from input stimuli (Code 1987). They may still produce more linguistic evidence of reasoning, related or non–related to the task at hand. Even with these deficiencies, right hemisphere patients are still attending to reasoning. Given a picture which provides stimuli conducive to both explanatory and predictive reasoning instances in narrative description, how may the linguistic evidences of attention to these stimuli differ between the hemispheres?

If a language system is damaged with respect to syntax, grammar, and naming, it is possible that patients may not only be unable to express reasoning processes, but that reasoning processes have also been damaged. Over longer periods of time, patients may also exhibit cognitive deterioration in reasoning if the communicative ability to express these reasoning ideas is damaged and no other compensatory approaches have been developed. The first step is to compare linguistic evidence of reasoning and then hypothesize other studies to further explore the possible connection of language damage and cognitive damage or deterioration.

Methods

Differences in cognitive processing may exist between creative reasoning and logical deductive reasoning. Considering differences in linguistic production and evidences 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 picture the patients in this experiment were given (see Figure 1) provided different scenes of stimuli conducive to explanation and prediction.

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.

As seen in Figure 2, the four main scenes in the picture are: the butcher and cleaver, the woman and the cans, the boy and the eggs, and the Eskimo and igloo. Each individual scene had visuospatial triggers of items which may be connected to the main participants via a reasoning process. According to Paul Kay (Kay 1983), ideal readers of a text try to cohere lexical triggers together, combining participants and scenarios into one envisionment, 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 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 analyzing.

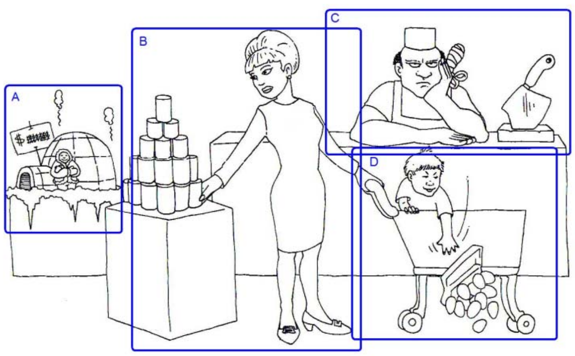

Figure 2: Four main scenes are evident in the picture. A. The Igloo, B. The Lady, C. The Butcher and D. The Kid.

In Figure 3, it is possible to see the different main visual triggers that could be connected in a narrative description.

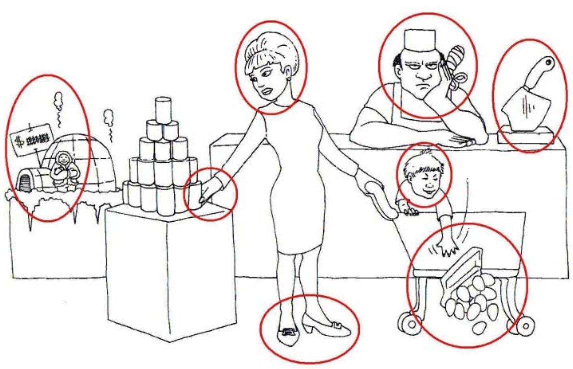

Figure 3: Some different details in the picture which patients sometimes connected by reasoning. Examples of patient utterances: Control patient: “the butcher looks like he would like the lady and baby to go home”, Right Hemisphere patient: “there’s a woman getting some cans pushing a monkey in a grocery cart”, Left Hemisphere patient: “the butcher he’s ice cold”.

The proximity and semantic relatedness of the butcher with the cleaver is probable 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 is thought to prompt the explanation that the child threw the eggs (see Figure 4).

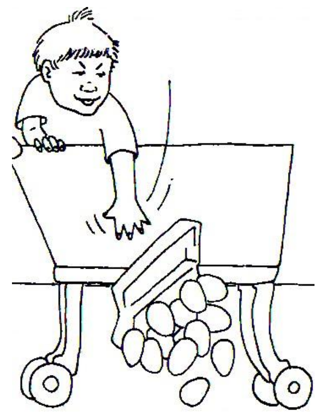

Figure 4: Close–up of scene with child and eggs. Examples of patient utterances: Control patient: “the strange looking kid dumped the eggs”, Right Hemisphere patient: “he’s going to get his bottom spanked”, Left Hemisphere patient: “playing and eggs and dropped them on the floor”.

The woman and the cans may prompt the prediction that the cans will fall when she takes the can from the bottom. The turning of the woman’s head (see Figure 5) away from attention to the child may prompt an explanatory relation between the child’s ’bad behavior’ and the woman’s inattentiveness to the situation. The butcher’s expression may be explained by his situation of his wrapped finger or the scene he is observing in front of him of the woman and child.

The Eskimo and igloo in Figure 6 may provide a challenge for observers to relate what their purpose is in the picture, or what they represent in connection with the scene. There are many triggers in this scene, of which above are given only some general 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 evidences of reasoning, we also separated out categorization. Categorization was the default placement of evidences 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 let us keep track of other linguistic evidence of reasoning as a whole.

Data Collection

Data was collected from patients in the Boston VA Hospital as part of a routine evaluation measure. Patients were given the picture in Figure 1 and asked:

Figure 5: Close–up of lady scene. Examples of patient utterances: Control patient: "this woman is weird looking", Right Hemisphere patient: "thats suppose to be a woman", Left Hemisphere patient: "the mother's looking one way".

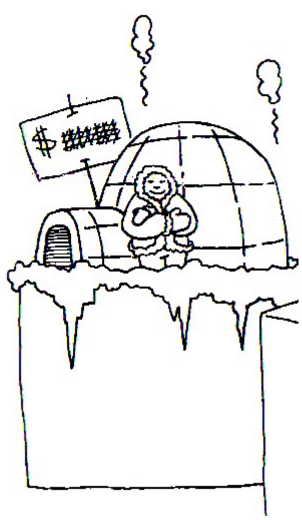

Figure 6: Close–up of igloo and Eskimo scene Examples of patient utterances – Control patient: "it looks like a display", Right Hemisphere patient: "probably a special display for ice cream", Left Hemisphere patient: "frozen food is on sale".

> "*I have a picture here. As you see, there's a lot going on. Look it over and tell me about it*".

Of the total 65 patients who were asked to describe the picture, 24 were not identified as having brain damage, 24 were identified as having left hemisphere brain damage, and 15 patients were identified as having right hemisphere brain damage. No additional patient data was collected in this measure regarding other diagnoses, such as type or severity of aphasia, exact location of infarcts or lesions, cause of brain damage, or diagnoses unrelated to brain damage.

Labeling the Data

We labeled instances of linguistic evidence of reasoning in the data as categorization, explanation, or prediction. The labeling process consisted of five distinct sessions in which we reached unanimous agreement for each label before proceeding further. General guidelines for labeling were devised and are described below in Classification Judgment Criteria.

Classification Judgment Criteria

Identifying linguistic evidence of types of reasoning poses a couple problems. The most challenging problem is that there is no established one–to–one correspondence between types of reasoning and linguistic forms. The second problem is that almost all speech is indicative of reasoning, so evidence of reasoning that is especially useful for this task needs to be separated from that which is less useful. Therefore, criteria had to be chosen to allow consistent labeling of the forms present in the data.

Only reasoning about the picture will be labeled The first criterion was intended to maintain consistency by limiting attempts at labeling to only evidence of reasoning specifically about the picture in Figure 1. Speech that falls outside of this criterion consisted of two basic categories: meta–description and tangents. Meta–description is used here to refer to language that describes or comments about the task or the drawing instead of the content of the picture, as in the examples in Table 1. Meta–description manifested itself at many levels, in sentences, phrases, and words.

1. "That's the dumbest thing I ever saw."
2. "I don't understand that."
3. ". . . looks like. . . "
4. ". . . maybe. . . "

Table 1: Examples of meta–description.

The last two examples in Table 1 are examples of linguistic tools used by the subjects to indicate their own commitment to a proposition being made. Such usage is often referred to as epistemic modality (Bybee 1985). In labeling types of reasoning, only words contributing to the proposition about the content of the picture were counted, and markers of epistemic modality were ignored.

Tangent language is used here to refer to propositions that are not directly related to the picture. This includes language that has no apparent connection to the picture as well as language that is unclear, as in the examples in Table 2.

1. "Excuse me" (no apparent connection)
2. "egles . . . of the sun" (unclear)

Table 2: Examples of tangents.

Atelic description is categorization Telicity is a characteristic that is used to label the boundedness of predicates (Krifka 1998). In the examples in Table 3, the first phrase is an example of a telic or bounded predicate. This essentially means that it necessarily has an end. When the *apple* was consumed, the *eating* was brought to an end. In contrast, the second example does not necessarily have an end. There is neither indication that *Mary* ever stopped *eating apples* nor that any one *apple* was ever entirely consumed. The second example is therefore atelic or unbounded.

1. "Mary ate an apple" (telic)
2. "Mary ate apples" (atelic)

Table 3: Examples of telicity distinction.

Telicity was used as the primary distinguishing characteristic between categorization and the other two types of reasoning. Atelic events and states were labeled as categorization, while telic ones were then further evaluated to distinguish between explanation and prediction. Atelic expressions that served as evidence of categorization include descriptive nominals such as *igloo* and *butcher* and adjectives such as *big* and *ugly*, based on the assumption that any such expression will indicate an unbounded state (*igloo–ness*, *butcher–ness*, *big–ness*, or *ugliness*). Use of descriptive nominals and pronouns made up the bulk of the evidence of reasoning. There were, in fact, so many examples of categorization in the data that evidence of certain types of categorization were ignored altogether. Categorization concerning definiteness (*the* vs. *a*), plurality (plural *–s* or lack thereof), or simple spatial relationships (*under*, *over*, etc.), for example, were ignored largely to make the labeling task more feasible. In addition, multiple instances of evidence of a single categorization were counted as only one categorization. For example, the use of *woman* followed by the use of *she* in reference to the woman would together be labeled as a single instance of categorization.

Prediction is future and explanation is past Whenever any proposition was identified as telic, the reasoning label depended upon where in time the event reaches completion. If the event ends in the past, it is labeled explanation; if it ends in the future, it is labeled prediction.

Complete process Table 4 contains examples of utterances used for illustration of the complete labeling process. In example 1, there are no tangents or meta–description. The proposition is telic because the *cutting* has an end. The completion of the *cutting* happened in the past, so this proposition is explanation. This example also contains evidence of categorization at the word level. *The*, *butcher*, *his*, and *finger* are each evidence of categorization, but *the* is ignored as it only indicates definiteness. In example 2 of Table 4, there are once again no tangents or meta–description. The proposition is telic because the *falling* has an end. The completion of the *falling* is in the future, so this proposition is prediction. There is also categorization at the word level that is not ignored, namely *lady* and *cans*. In example 3 of Table 4, there are also no tangents or meta–description. The proposition is atelic because the reaching has no clear end, and as such, is labeled categorization. *Mom* and *can* are also evidence of categorization, and definiteness(*the*), spatial relationships(*underneath*) and plurality (*–s*) are ignored.

1. "The butcher cut his finger" (Figure 9)
2. "the lady is going to make the cans fall" (Figure 7)
3. "the mom's reaching underneath the cans" (Figure 8)

Table 4: Examples of utterances used for illustration of the labeling process.

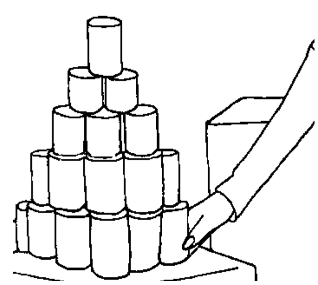

Figure 7: Close–up of the cans "about to fall" Examples of patient utterances: Control patient: "the lady is going to make the cans fall", Right Hemisphere patient: "she's about to have an accident", Left Hemisphere patient: "the can will fall in the floor".

Exceptions It is worth noting that the applicability of these judgment criteria was not without exception. The few exceptions were dealt with on a case by case basis. One illustrative example of such an exception is the distinction between *taking* and *reaching* as presented in Figure 8.

Although the phrases "taking the can" and "reaching

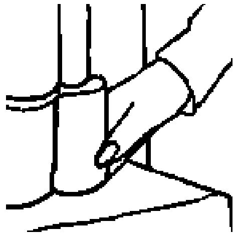

Figure 8: Close–up of "pulling, taking, reaching for. . . a can". Examples of patient utterances – Control patient: "the lady's taking a can from a counter", Right Hemisphere patient: "the woman is going to take the one off the bottom", Left Hemisphere patient: "person who is trying to get the cans".

for the can" would both be generally considered atelic, the choice to use the verb *take* instead of *reach for* indicates the speaker's expectation that *the can* will ultimately be removed, revealing a prediction. Another notable example involves description of mental processes. In the sentence "he looks like he would like the lady and the baby to go home", the *liking* has no clear end, so it is atelic. However, it is used to explain the speaker's impression of the appearance of the man in the picture and is therefore more accurately labeled as explanation as presented in Figure 9.

Figure 9: Close–up of the butcher scene. Examples of patient utterances: Control patient: "the butcher cut his thumb or his finger", Right Hemisphere patient: "he has a sore finger", Left Hemisphere patient: "he looks disgusted at the whole situation".

Results and Analysis

As we described before, the data was labeled by group (i.e. right hemisphere, left hemisphere, and controls) and individually per patient. In Tables 5, 6, and 7, the number of words uttered in the description and the instances of explanation, categorization, and prediction are counted for each patient. These results are summarized in Table 8.

These numbers provided the basis for our analysis. The sum, mean and standard deviation of the number of words, explanation, categorization, and prediction for all patients in each group are shown at the bottom of

Patient ID	Word Count.	Exp.	Cat.	Pre.
170004	87.00	5.00	9.00	3.00
170008	13.00	0.00	2.00	0.00
290004	74.00	3.00	9.00	1.00
300003	51.00	2.00	9.00	2.00
300004	46.00	1.00	10.00	1.00
400005	50.00	2.00	13.00	2.00
430003	86.00	5.00	19.00	0.00
802004	80.00	2.00	20.00	1.00
802006	28.00	1.00	10.00	0.00
811031	65.00	3.00	5.00	1.00
811042	62.00	1.00	16.00	1.00
812064	44.00	1.00	14.00	0.00
826006	70.00	2.00	22.00	0.00
826008	110.00	3.00	13.00	3.00
826019	88.00	5.00	12.00	0.00
sum	954.00	36.00	183.00	15.00
mean	63.60	2.40	12.20	1.00
std.dev.	25.47	1.59	5.47	1.07

Table 5: Right Hemisphere Patients – word count for each patient description – number of evidences of explanation (Exp.), categorization (Cat.) and prediction (Pre.) for each patient description – sum of words and types of reasoning for all right hemisphere patients – mean = average of total words and types of reasoning per patient description – std. dev. = standard deviation from mean of total words and types of reasoning per patient description.

the tables. The average number of words per patient is similar across groups, ranging from a minimum of 63.60 in right hemisphere patients to 75.38 in left hemisphere patients, with an average across groups of 71.23 and a standard deviation of 6.62, as seen in Table 9, and Figure 10.

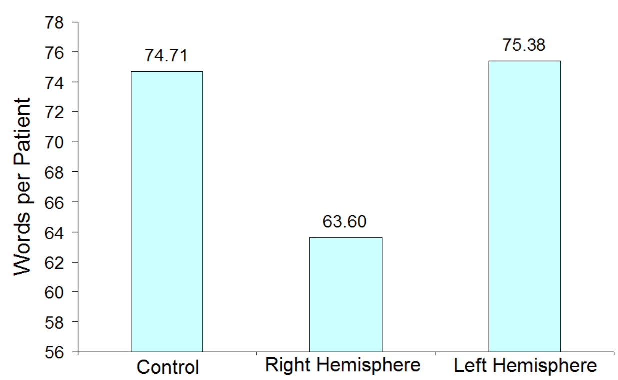

Figure 10: Average words per patient in controls, right hemisphere patients, and left hemisphere patients.

Although the average number of words was similar, the standard deviations did vary between groups. The right hemisphere and control standard deviations were similar at 25.47 and 29.62 respectively, but the left hemisphere standard deviation was more than double at 67.43. Therefore, while the total number of words per

Patient ID	Word Count.	Exp.	Cat.	Pre.
000001	90.00	3.00	17.00	4.00
044033	93.00	0.00	13.00	2.00
080007	111.00	0.00	16.00	0.00
080013	71.00	2.00	8.00	1.00
230002	366.00	1.00	35.00	3.00
480009	75.00	0.00	14.00	1.00
810018	10.00	0.00	2.00	0.00
810019	109.00	1.00	15.00	1.00
810020	76.00	0.00	18.00	2.00
811033	12.00	0.00	3.00	0.00
811034	85.00	1.00	13.00	0.00
811035	14.00	0.00	1.00	0.00
811036	23.00	1.00	4.00	0.00
811043	27.00	0.00	7.00	0.00
811044	53.00	0.00	9.00	0.00
811046	41.00	1.00	8.00	0.00
812063	40.00	0.00	3.00	0.00
813007	84.00	4.00	8.00	0.00
815050	102.00	1.00	17.00	1.00
816054	60.00	0.00	6.00	0.00
824077	62.00	2.00	13.00	1.00
824085	106.00	1.00	21.00	2.00
824086	109.00	2.00	12.00	1.00
824087	49.00	0.00	13.00	0.00
826030	32.00	0.00	11.00	0.00
826096	60.00	0.00	18.00	0.00
sum	1960.00	20.00	310.00	21.00
mean	75.38	0.77	11.92	0.81
std.dev	67.43	1.07	7.25	1.10

Table 6: Left Hemisphere Patients – word count for each patient description – number of evidences of explanation (Exp.), categorization (Cat.) and prediction (Pre.) for each patient description – sum of words and types of reasoning for all left hemisphere patients – mean = average of total words and types of reasoning per patient description – std. dev. = standard deviation from mean of total words and types of reasoning per patient description.

Patient ID	Word Count.	Exp.	Cat.	Pre.
030002	122.00	1.00	21.00	2.00
060006	57.00	2.00	16.00	4.00
070009	97.00	3.00	15.00	2.00
080001	61.00	2.00	13.00	2.00
120004	52.00	1.00	15.00	2.00
140005	108.00	1.00	23.00	1.00
180017	43.00	1.00	12.00	0.00
210002	125.00	5.00	25.00	1.00
210007	47.00	2.00	14.00	2.00
270006	46.00	3.00	17.00	0.00
270007	58.00	1.00	16.00	1.00
280026	31.00	2.00	9.00	0.00
290001	39.00	0.00	14.00	1.00
310005	76.00	1.00	23.00	0.00
390004	83.00	0.00	19.00	2.00
400001	92.00	2.00	17.00	3.00
420001	79.00	3.00	11.00	1.00
430005	61.00	1.00	18.00	2.00
450001	54.00	3.00	13.00	2.00
470008	113.00	1.00	17.00	2.00
490006	49.00	0.00	13.00	1.00
520001	112.00	2.00	17.00	2.00
811030	67.00	3.00	20.00	0.00
826095	121.00	3.00	22.00	4.00
sum	1793.00	43.00	400.00	37.00
mean	74.71	1.79	16.67	1.54
std.dev.	29.62	1.22	4.11	1.14

Table 7: Control Patients – word count for each patient description – number of evidences of explanation (Exp.), categorization (Cat.) and prediction (Pre.) for each patient description – sum of words and types of reasoning for all control patients – mean = average of total words and types of reasoning per patient description – std. dev. = standard deviation from mean of total words and types of reasoning per patient description.

	Cont.	R-H	L-H
Explanation	43.00	36.00	20.00
Categorization	400.00	183.00	310.00
Prediction	37.00	15.00	21.00
Num. of Patients	24.00	15.00	26.00
Mean per Patient	20.00	15.60	13.50

Table 8: Number of instances of explanation, categorization, and prediction reasoning in controls (Cont.), right hemisphere (R-H), and left hemisphere (L-H) patients. Mean total evidences of reasoning per patient group are shown.

	Cont.	R-H	L-H	mean	std.dev.
Num. Pat.	24.00	15.00	26.00		
Num. Words	1793.00	954.00	1960.00		
Words/Pat.	74.71	63.60	75.38	71.23	6.62
Words/Exp.	41.70	26.50	98.00	55.40	37.67
Words/Cat.	4.48	5.21	6.32	5.34	0.93
Words/Pre.	48.46	63.60	93.33	68.46	22.83
Words/Rea.	3.74	4.08	5.58	4.47	0.98

Table 9: Num. Pat. = number of patients. Num. Words = total number of words produced in descriptions per patient group. Words/Pat. = average words per patient in patient groups. Words/Exp. = density of explanations per patient. (for example: for every 25.78 words produced by a right hemisphere patients, there will be one evidence of explanatory reasoning) Words/Cat. = density of categorization.

patient was similar across groups, the left hemisphere patients had a greater variance in number of words uttered, ranging from 10 to 366 words.

Also worthy of note is that categorization is far and away the most common type of reasoning, ranging from 78% (right hemisphere) to 88% (left hemisphere) of all instances of reasoning – see Figure 11 and Table 10.

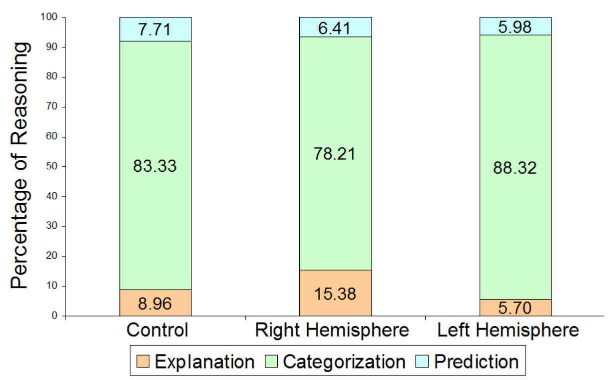

Figure 11: Percentage distribution of explanation, categorization and predication in controls, right hemisphere patients and left hemisphere patients.

This great difference remains despite the fact that many instances of categorization were deliberately ignored (see Classification Judgment Criteria).

In counting instances of explanation, left hemisphere patients had a mean of 0.77, controls 1.79, and right hemisphere patients 2.40 per patient. Left hemisphere patients therefore produced 57% fewer instances of explanation than controls and right hemisphere patients produced 25% more instances of explanation than controls. 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.

[%]	Cont.	R-H	L-H	mean	std.dev.
Exp.	8.96	15.38	5.70	10.01	4.93
Cat.	83.33	78.21	88.32	83.29	5.06
Pre.	7.71	6.41	5.98	6.70	0.90

Table 10: Percentage of types of reasoning - explanation (Exp.), categorization (Cat.), and prediction (Pre.) per patient group. mean = mean evidences of type of reasoning across patient groups. std. dev. = standard deviation from mean of evidences of type of reasoning across patient groups.

In counting categorization, left hemisphere patients had a mean of 11.92, right hemisphere patients 12.20, and control patients 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 11.

	Cont.	R-H	L-H	mean	std.dev.
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 11: Average number of instances of explanation (Exp.), categorization (Cat.), and prediction (Pre.) per patient description produced in each patient group. mean = mean of types of reasoning across patient groups. std. dev. = standard deviation from mean across patient groups.

In counting instances of prediction, left hemisphere patients had a mean of 0.81, right hemisphere 1.00, and control patients 1.54 per patient. Left hemisphere patients produced 48% fewer instances of prediction than controls and right hemisphere patients produced 36% fewer instances of prediction than controls (see Table 11).

To verify the validity of the differences in amounts between the types of reasoning, we designed a new measure called "density of reasoning", which records 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. Some of them are in fact made even more apparent when viewed in terms of density (compare Figures 12 and 13).

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, left hemisphere patients had a mean density of 98.00, control patients 41.7, and right hemisphere patients had a mean density of 26.5. For categorization, left hemisphere patients had a mean

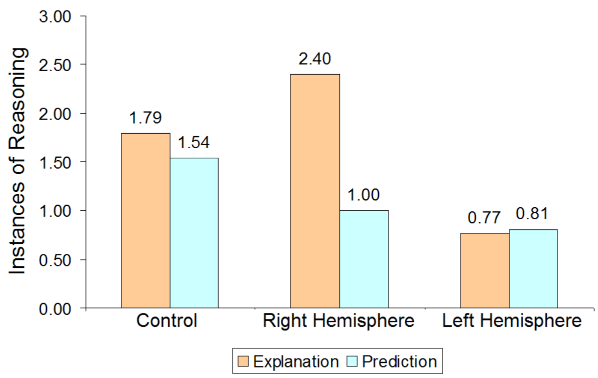

Figure 12: Average instances per patient of explanation and prediction in controls, right hemisphere patients, and left hemisphere patients.

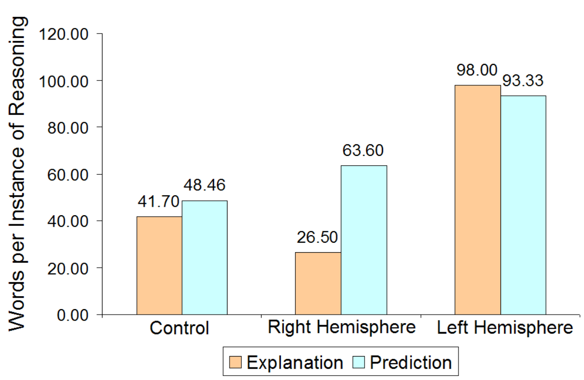

Figure 13: Average density (i.e. words per instance) of explanation and prediction in controls, right hemisphere patients, and left hemisphere patients.

density of 6.32, right hemisphere patients 5.21, and control patients 4.48. For prediction, left hemisphere patients had a mean density of 93.33, right hemisphere patients 63.6, and control patients 48.46 (see Table 9).

Discussion

As mentioned previously, the standard deviation for word count per patient in left hemisphere patients is twice that of either of the other groups (see Table 6). 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 should be considered before automatically coming to this conclusion. This paper 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.

An interesting idea generated from this research that deserves more investigation focuses on the possibility of cognitive deterioration of reasoning processes being associated with lack of ability to communicate reasoning. A longitudinal study comparing communication techniques used by aphasic speakers and the resulting effectiveness in transferring reasoning acutely after stroke or injury, followed by the effectiveness of alternative communication strategies after a rehabilitation program may provide insight into this possible connection. If patients are able to switch communicative strategies in order to effectively communicate, it is possible that evidence of reasoning may look more similar to that of controls, indicating that cognitive reasoning processes must not have been damaged in the left hemisphere. If patients are able to switch communication strategies in order to communicate and there is still a decided lack of expression of reasoning processes, this may indicate that cognitive reasoning processes may have been affected by left hemisphere brain damage.

If patients are unable to switch strategies, it may be impossible, or at least quite difficult, to further explore possible connections between reasoning processes. If comprehension is more or less intact in patients, it may be possible to construct an experiment where reasoning questions are posed about a picture and possible answers are given, only one answer actually containing reasoning instead of just general observation about the picture. A patient's choice of answers containing reasoning over general observation in response to a question that would require reasoning, may support intact reasoning processing even without any effective means of expressive communication. Lack of ability to distinguish between reasoning answers and observation answers could be possibly explained a few different ways: original reasoning process damage as a result of the stroke or injury, cognitive deterioration over time or lack of effective means of communicating reasoning, or simply an overwhelming difficulty in language comprehension in addition to expressive difficulties. In essence, it would be difficult to draw a clear conclusion relating to reasoning processes if testing were only done acutely. Comparing results obtained acutely and results farther post–stroke or injury may give insight into possible cognitive deterioration, or natural recovery in cognitive reasoning, over time.

To be able to make more specific statements about the connections between reasoning, brain damage, and language, specific left hemisphere patient information, such as type and degree of aphasia or locus of damage, is needed. For right hemisphere patients, information regarding locus of damage could also be used to support the observations made in this paper associated generally with the right hemisphere. Future studies where researchers have access to detailed information about patients should be able to shed more light on these preliminary observations from each hemisphere and what role they may play in reasoning in general as well as between types of reasoning, which may rely on separate processing mechanisms. Longitudinal studies can also shed light on possible cognitive deterioration in reasoning associated with specific areas of brain damage, as well as natural recovery in reasoning over time.

Conclusion

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. The kind of reasoning that is associated with creating new ideas and new knowledge, as described by Polya and Pierce, is exactly the kind of reasoning that patients with left hemisphere struggle with the most and at which right hemisphere patients seem to excel. This observation suggests that prominent notions about the association of the right hemisphere of the brain with creativity might need to be re–examined 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. A connection between the loss of processing of grammar and left hemisphere brain damage has already been well established in research. The possibility should not be ruled out that loss of creative reasoning processing, as opposed to other types of reasoning processes, may also be associated with left hemisphere patients. Future research needs to be done exploring the possibility of separate reasoning processes and what their relation may be to specific brain damaged populations.

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