

## **Human memory, cerebral hemispheres, and limbic system: A new approach.**

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**Abstract:** This paper presents an integrative approach to human memory in context of brain asymmetry. According to the results of psychophysiological investigations it is suggested that the right hemisphere functioning is closely associated with the limbic system. Their close association leads to formation of polysemantic context. Polysemantic context is determined by multiple interconnections among its elements, whereas each concrete element bears the stamp of the whole context. This context sustains episodic, personal, and emotionally laden memories. The left hemisphere functioning leads to formation of monosemantic context, which is responsible for maintenance of semantic memories. This distinction in terms of general organization of material by hemispheres rises a number of explanation of such phenomena as memory disturbances among aged persons, the influence of emotions on memory, and confabulations.

### **The right and the left hemispheres: The problem of context.**

Since the first investigations performed by Sperry, Gazzaniga and their associates (Sperry, Gazzaniga, & Bogen, 1969; Gazzaniga, 1970) there was an ever increasing number of studies that focused on brain asymmetry. The first theoretical conceptualizations suggested that the left and the right hemispheres process qualitatively different information (Sperry, Gazzaniga, & Bogen, 1969; Gazzaniga, 1970). In particular, the left hemisphere was thought to be involved in processing of verbal material, signs, and symbols, whereas the right hemisphere was thought to be involved in handling non-verbal material, images, melodies, and spatial information.

However, the results of other studies refute this point of view. Really, in split brain subjects the right hemisphere is able to process verbal constructions, if they are not too complicated (Ellis, Young, & Andersen, 1988). EEG activity of the right hemisphere predominates during reading stories, while EEG activity of the left hemisphere predominates during reading textbooks in science (Ornstein, Herron, Johnstone, Swencionis, 1979). Although all melodies belong to non-verbal information, right ear (e. g. the left hemisphere) is superior to the left ear in perception of dichotically presented melodies if they differ only in rhythm (Gordon, 1978).

Split brain subjects are able to report their dreams (Hoppe, 1977), although dream is a visual experience. The left hemisphere is superior to the right one in perception of faces with some outstanding features (such as very long nose) (Parkin & Williamson, 1987). Deaf and dumb language signs are non-verbal. However, they are damaged by the left hemisphere strokes (Bellugi, Poizner, & Klima, 1983).

According to another approach the human hemispheres differ in terms of information processing (Gordon, 1978). That is, the left hemisphere is involved in sequential information processing, whether verbal or non-verbal. The function of the right

hemisphere is single-stage, parallel processing of many elements of information as a single whole. However, this point of view can not account for the findings according to which the left hemisphere is also able to grasp a series of data simultaneously, and as rapidly as the right hemisphere does (Polich, 1982).

Yet another point of view (Goldberg & Costa, 1981) stresses that the left hemisphere is responsible for the maintenance of familiar forms of behavior, whereas the right hemisphere's specialization includes the detection of novel and unexpected events. However even this approach cannot account for all existing data. Really, it cannot explain the advantage of the left hemisphere in identification of strange faces, nor the advantage of the right hemisphere in identification of normal faces with which the subject is familiar (Parkin & Williamson, 1987).

In order to explain the diversity of results in the field it was suggested (Rotenberg, 1979; Rotenberg & Arshavsky, 1991) that in the most general form, the difference between the two fundamental and most important strategies of thinking (which are customarily associated with functions of the left and right hemispheres of the human brain), is reduced to the opposite modes of organizing the contextual connection between elements of information.

Left-hemispheric or formal, logical thinking organizes any sign material (whether symbolic or iconic) so as to create a strictly ordered and unambiguously understood context. Its formation requires the active choice out of innumerable, real and potential connections between the multiform objects and phenomena of few definite connections which would not create internal contradictions. This choice would be the one most natural to facilitate a sequential analysis. A strategy of thinking of this type makes it possible to build a pragmatically convenient, but simplified model of reality.

This model is based on probability forecasting and a search for concrete cause-and-effect relations. It is precisely for this model that the vector-time orientation exists. In contrast, the function of right-hemispheric or image thinking is to simultaneously "capture" an infinite number of connections and the formation, due to this capture, of an integral but ambiguous context. In this context the whole is not determined by its components, since all specific features of the whole are determined only by interconnections between these parts. On the contrary, any concrete element of such a context bears a determining stamp of the whole. Perception at each concrete moment is brought in line with the entire past experience, with the already shaped picture of the world, and with impacts to such a capture the status of thinking.

Individual facets of images interact with each other on many semantic planes simultaneously. Examples of such contextual connections are the connections between images in sleep dreams. The advantages of this strategy of thinking manifest themselves only when the information itself is complex, internally contradictory and basically irreducible to an unambiguous context. In this case some of the existing connections, from the positions of formal logic, can be perceived as mutually exclusive and, accordingly, many of them remain unrealized, forming the basis for intuition and creative realization.

Thus, the right hemisphere (and only the right hemisphere) functions according to the holographic model and to the model of neural networks with parallel connections. In this case overlap and crosstalk are a main advantages of the right hemisphere thinking, which provide the creation of the polysemantic context and the combination of two or more concepts in a unitary pattern. The complicated interaction between

concepts only exists for the linear monosemantic left-hemisphere system.

This is especially true if all these concepts are encoded by the same units of the system and an overlap appears. For this reason, only in a linear system the encoding of information must be successive and not parallel. Contrary to this, the parallel system for the encoding of information represented simultaneously in many units is a mechanism of a polysemantic context. The combination of different concepts, each represented in every unit of the holographic system, can be seen as illustrative of the proposition that the holographic system of the right hemisphere includes not the separate concept, but rather the holistic and mosaic picture of the world. Each separate concept is only a small component of this picture. This is why every newly perceived component is integrated in the mosaic picture together with all the other components.

The process, therefore, is one of integration and not of inference. On the contrary, left hemisphere mechanisms bring about the distinguishing and structuring of some pragmatic monosemantic results extracted from the polysemantic mosaic. It is apparent that the declared differences are most similar to the differences between the iconic and the symbolic systems of representation. The main distinction is that we emphasize the arrangement of contextual relations rather than the consequitiveness or simultaneity of the synthesis (Rotenberg, 1993; Schore, 1997).

Research provides increasingly abundant evidence that the ability to arrange a polysemantic context is a specific, immanent function of the right human hemisphere and need not be further amplified by the brainstem reticular formation. Particularly, in healthy subjects tested under normal conditions, the left hemisphere is always more active than the right, as revealed by the frequency and the amplitude of the alpha-rhythm, or by the alpha-index.

The intensity and uniqueness of daydream images show a positive correlation with the alpha-index (Kripke & Sonnenschein, 1978). Vivid mental visualization does not decrease EEG synchronization for persons who have well-developed image thinking (De Pascalis & Palumbo, 1986; Rotenberg & Arshavsky, 1991). In meditation, which corresponds to the right hemisphere pattern of thinking (Ornstein, 1972), alpha waves have a high amplitude and become generalized. When a person with a high creative potential succeeds in solving a problem that calls for imaginative and creative handling, his alpha-rhythm is very distinct, especially in the right hemisphere (Martindale, 1975).

The left hemisphere data-processing pattern, contrary to that of the right hemisphere, requires higher cerebral activity - for the sole reason that it attempts to arrange the information available and distinguish the few relevant links in a multitude of irrelevant relations.

Western culture assumes that an activity should always have a purpose; a known goal should be accomplished. However, activity of the right hemisphere, in creation of the polysemantic context, involves no statistical predictions and sets no cause-and-effect relations. The right hemisphere is responsible for predictions that extend beyond the actual statistics and thus come close to the experience brought about by insight. Its mechanism is yet to be identified.

Right-hemisphere predictions may be kaleidoscopic in nature: many versions of the future are simultaneously presented with their probabilities being very close to each

other. As a result, the occurrence of an event, unlikely from the perspective of past experience, has the same weight as a product of reasoning.

### **Interrelationship between the right hemisphere and the limbic system.**

Limbic system was introduced by Broca (1878). This system includes such brain structures as hippocampal cortex and allayed structures (parahippocampal and entorhinal cortices), amygdala, fornix, septum, thalamus and hypothalamus. This portion of human brain became a focus of intensive research (e.g. Isaacson, 1982). The increasing number of structures was included in this concept. Following this development LeDoux (1987, 1989) introduced a term "limbic forebrain". In contrast, Macchi (1989) suggested that "limbic system" should be differentiated from "associated structures". The limbic system structures were implied in mechanism of emotions (Papez, 1937) and transmission of information from short into long term memory (Scoville & Milner, 1957).

In the recent years there is an ever increasing amount of evidence suggesting that the limbic system and the right hemisphere are interrelated and that they function in close cooperation. In particular, they are closely associated in processing and storage of memories (see review by Nadel & Moscovitch, 1997; Markowitsch, 1995). In line with this suggestion Tranel and Hyman (1990) reported that in a 23-year old patient there was a significant defect in visual, non-verbal memory following bilateral amygdala damage.

There is evidence for a greater interconnection between the limbic system and right hemisphere than the left hemisphere (Joseph, 1982; Tucker, 1991; Liotti & Tucker, 1995).

The formation of polysemantic contexts depends not only on the right hemisphere (Rotenberg, 1993; Rotenberg & Arshavsky, 1991), but also on the hippocampal formation. In particular, it was found that the hippocampus is involved in provision of context information (Kinsbourne & Wood, 1975; O'Keefe & Nadel, 1978; De Renzi & Lucchelli, 1993).

Emotions are closely associated with the right hemisphere (Joseph, 1982, 1988; Liotti & Tucker, 1995; Rotenberg, 1993). Emotions are essentially polysemantic and multidimensional. Words can only name emotions, but they can not convey the essence of emotional experience in its wholeness and subtlety. The words fail. Emotions, incessantly, transform themselves one into another. This continuous transformation is the essence of the personal experience.

Only polysemantic context, formed by the right hemisphere, can sustain emotional experience in its uniqueness, inner complexity, and elusiveness. On the other hand, emotions, as was initially hypothesized by Papez (1937), are closely related also to limbic system. The involvement of these two systems in emotional processing led to a hypothesis about their close cooperation (Joseph, 1982; Liotti & Tucker, 1995).

Really, patients who suffer right hemisphere damage are less facially expressive than the patients who suffer the left hemisphere damage (Borod, 1992) and have an impaired recognition of facial expression of emotions (Bowers, Bauers, Coslett, & Heilman, 1985). The expression of emotions is more intense on the left side of the face (e.g., Borod & Caron, 1980). The right hemisphere is faster and more accurate than the left hemisphere in discriminating facial expressions of emotions (Ley &

Bryden, 1979; Strauss & Moscovitch, 1981) and more efficient in processing emotional words (Graves, Landis, & Goodglass, 1981).

Another piece of evidence supports the close relationship between the limbic system and emotions (Gloor, 1960; Green, 1958; Joseph, 1982; Kaada, 1967). Emotional arousal may be elicited by stimulation of different limbic structures (Gloor, 1960; Green, 1958; Kaada, 1967; Ursin & Kaada, 1960). In particular, such limbic structure as amygdala is involved in enhancement of pleasure, consummatory behavior, fear, sadness, affection, and happiness (e.g., Isaacson, 1982), aggression (Mark & Ervin, 1970), and the inhibition of emotional activity (Penfield, 1954).

Spatial ability and visual processing are functions of the right hemisphere. In particular, the right hemisphere is concerned with spatial orientation of perceived stimuli, analysis of the body's position in space, conceptualization of form of the stimuli, figure-ground dichotomy, depth, distance, direction, shape, orientation, perspective, visual closure, body image, and many other visual functions (for review see Joseph, 1988).

Conversely, right hemisphere damage produces deficits in judging what object is closer, inability to recognize objects, friends, pets, or even one's own face (Levine, 1978). However, it is also known that lesions to inferior temporal lobe and amygdaloid complex produce severe and long-lasting recognition loss (Mishkin, 1978; Zola-Morgan, Squire, & Mishkin, 1982) or visual memory loss (Tranel & Hyman, 1990). Therefore, it seems that the right hemisphere and the limbic system closely cooperate also in different aspects of visual processing.

In summary, the right hemisphere and the limbic system are closely associated not only morphologically, but also in cooperative processing of emotional, spatial, and visual information.

### **Episodic and semantic memory.**

Human memory could be subdivided into declarative memory and procedural one (Tulving, 1972, 1991). The declarative memory refers primarily to episodic memory and semantic one. The episodic memory comprises of knowledge about personal events, episodes, and facts. These facts are related to one's self, they form a part of immediate experience, and they are memorized consciously. The more specific subtype of episodic memory deals with autobiographic memories. This memory subtype may be further subdivided into experiential information (i.e. when, where, and what personal event did occur) and personal semantics. This memory type comprises such memories as the date of one's marriage, the place of one's birth, etc) (Cermak & O'Connor, 1983; Kopelman, Wilson, & Baddeley, 1990).

The semantic memory is more factual in its essence. It refers to the objective facts of the external world. It is impersonal. This kind of knowledge can be studied from books. It refers to such facts as the capital of USA, the details of public events, or the date of the beginning of World War II. The procedural memory refers to acquisition of skills and general semantic knowledge. This kind of memories is learned without conscious awareness.

### **Memory in the context of the limbic system - right hemisphere interaction.**

Referring to this memory subdivision Nadel and Moscovitch (1997) called the

"standard model" the model that explains acquisition of declarative memories in terms of brain structures that are involved in encoding, storage, and retrieval of memories.

According to the standard model it was suggested that consolidation of short-term memory occurs in the hippocampal formation. This short-memory consolidation is completed within seconds or, at most, tens of minutes (Moscovitch, 1995). That is, the hippocampus, or even the whole medial temporal cortex (Nadel & Moscovitch, 1997), is viewed as a temporary memory system, used until long term consolidation of memories in neocortex and other structures is completed.

As reviewed by Squire and Alvarez (1995) the model explains a temporally graded retrograde amnesia. Temporally graded retrograde amnesia refers to memory loss for a particular time span (such as 10 years or even more) preceding the brain damage that caused the amnesia. According to the standard model the graded nature of memory loss appears to imply that after some period of time (such as 10 years) memories are transferred into neocortex and medial temporal cortex lesions no longer lead to memory loss. According to these authors another piece of evidence comes from the fact that the severity of retrograde amnesia is correlated with the severity of anterograde amnesia.

Anterograde amnesia refers to impaired ability to encode new memories following the brain damage. The standard model refers to subdivision into semantic and episodic memory. However the standard model, in its neuropsychological formulation, fails to differentiate between semantic and episodic memory structurally. Really, Squire and Alvarez (1995) argued that retrograde amnesia equivalently affects semantic and episodic memories, since both types of memory rely on temporal lobe functions. However, the following results cast some doubt regarding the adequacy of the model in accounting for episodic memory.

Rempel-Clower, Zola, Squire, and Amaral (1996) demonstrated that patients with large hippocampal lesions display no discernible gradient for the most recent three decades and have very little or no autobiographical memory for events occurred before 1950. In terms of the standard model these findings imply the consolidation process of episodic memories that is almost life-long!

A bulk of studies suggested that the amount of medial temporal lobe damage is strongly associated with the extent of retrograde amnesia for autobiographical memories (reviewed by Nadel & Moscovitch, 1997).

It was reported that hippocampus complex damage leads to substantial, ungraded loss of autobiographical memories (Cermak & O'Connor, 1983; Damasio, Eslinger, Damasio, Van Hoesen, 1985) or graded loss for 15 years of memories of autobiographical episodes (Scoville & Milner, 1957), graded loss of personal semantics, and personalities, leaving general semantics intact (Cermak & O'Connor, 1983; Damasio et al., 1985; Scoville & Milner, 1957).

Warrington and McCarthy (1988) reported findings about a testee's semantic memory for words that came to use during the period for which he has lost all his autobiographic memories. He could give a detailed definition of every word, while being absolutely amnesic for personal events that occurred during the period the words were introduced. Similar results were reported by Verfaellie, Reiss, and Roth (1995) in a group of non-Korsakoff amnesic patients.

General semantic memories that have importance for self-concept, such as terms related to one's profession, seems to be stored in episodic memory (Snowden, Griffiths, & Neary, 1994). The evidence for this proposition was reported in a number of studies (Beatty, Salmon, Bernstein, & Butters, 1987; Rempel-Clower, et al., 1996; Victor & Agamanolis, 1990), that found that medial temporal lesions led to loss of terms related to the subjects' profession.

To conclude: autobiographical memories, as well as knowledge that is a part of self-image, are closely associated with interacting limbic system and the right hemisphere. Therefore, when the limbic system is damaged the loss of these memories is extended, substantial, and ungraded. Does it mean that consolidation of episodic memory is life-long or that the mechanism of this memory type is different from the one proposed by the standard model?

To answer this question Nadel and Moscovitch (1997) proposed a multiple trace theory. According to it the hippocampus and the neocortex interact continuously in storage and retrieval of episodic memories throughout our life. Unlike episodic memories, semantic memories are learned after some period of time and represented outside of the hippocampus or the medial temporal lobe. In other words, the standard model accounts for semantic memory, while the multiple trace model refers to episodic memory.

The continuous interaction between the hippocampus and the neocortex leads to formation of multiple traces in the hippocampal complex and the neocortex. Thus, more remote memories are associated with a greater number of traces. This increase in number of traces and accesses to them leads to better retrieval. Conversely, any damage to the hippocampal formation adversely affects encoding, retention, and retrieval of episodic memories. However, older memories that are multiply represented would withstand the damage and would be accessible for retrieval. This would explain very flat graded amnesia for episodic events. The same explanation accounts for similarity of amnesia for events and knowledge that essentially refer to oneself to amnesia for episodic events.

However, this hypothesis produces the following contradictions. First, according to the multiple trace model the hippocampal lesion would stop the process of formation of new traces. However, this would not detrimentally affect retrieval of existing traces. Only complete destruction of hippocampus would ban access to episodic memories. That is, the hippocampal lesions would, probably, make retrieval process difficult, but in no way impossible, as is emphasized by ungraded amnesia for personal events reported in the studies.

Second, the multiple trace hypothesis views the memorizing process for episodic memories as a continuous addition of new traces to the old ones. Every new personal experience, interpersonal encounter, or professionally relevant fact are infinitely multiplied in our memory. This process would lead to redundant representation of memories and a quick satiation of long-term memory. We assume that memory capacities are limited.

Thus, according to multiple representation model episodic memory would be filled up by multiple representations of the same traces. It would turn inefficient in representation of new experiences, since no free place for them would be left. However, it is exactly the opposite of what is the case. Every new experience

enriches our life and inner world, and gives new meanings to old events. It drives us for new experiences. It makes them more vivid and emphasizes what is essential for them. It is a kind of curiosity for life, openness to experience (McCrae, 1994), or an ability to learn from one's experience (Bion, 1962) that makes our life what it is. In short, new experiences do not lead to the closure of long-term memory, as might be expected according to multiple trace theory.

On the contrary, they make memorizing process easier. In line with this suggestion Webster (1994) found that subjects who are high on the scale of Openness to Experience tend to reminisce more frequently than the subjects who are low in this characteristic. That is, people who are open to experience have more accessible memories of their remote past.

We believe that it would be more adequate to define our episodic memory in terms of multiple contexts instead of multiple traces. Accordingly, the hippocampus and the right hemisphere interact continuously. The close association between the limbic system and the right hemisphere in memory processing was already hypothesized (e.g. Markowitsch, 1995).

However, this interaction does not lead to formation of multiple traces. Instead, it leads to incessant interactions among our episodic memories. According to this model connections are less capacity consuming than particular memories. In addition, incessant interaction among different memories enriches every episodic memory. Therefore interconnections among different memories becomes part of particular memories. For these reasons this way of memory storage is less capacity demanding than the one proposed by multiple representation model.

The hippocampus-right hemisphere interaction leads to continuous formation of polysemantic contexts, comprised of episodic memories. Thus, according to our theory, right hemisphere is a seat of polysemantic context. However, the formation of a particular context depends on the interaction of the right hemisphere with the hippocampus. It is our contention that the essence of episodic memories is their dependence on multidimensional context.

Simply stated, polysemantic context and episodic memory are one. No episodic memory could be encoded, stored or retrieved outside of polysemantic context. This incessant flow of personal memories becomes a bedrock of personal experience. For the same reason the stream of consciousness is a continuous flow of memories, feelings, and thoughts. This aspect of the personal experience simply reflects the involvement of the right hemisphere in the continuous formation of polysemantic contexts.

A context-bound quality of our memories has already been emphasized by the theory of Neural Darwinism (Edelman, 1987). According to it memory is not a permanent record that reflect one's past experience. On the contrary, personal memories are dynamic reconstructions. These reconstructions are context-bound and they change as the context changes. However, the theory of Neural Darwinism does not specify the essence of this context. According to our suggestion the context comprised of episodic memories is essentially polysemantic and multidimensional. Only this kind of context can maintain the multiplicity of meaning of every single memory. Really, memories that comprise polysemantic context bear the stamp of the whole context. Therefore, changes in the polysemantic context transform meaning of particular memories and enrich them.

According to the proposed approach personal memories continuously reconstruct themselves. This process of reconstructive transformations of memories, as well as their context-bound quality, are well documented both experimentally (Bartlett, 1932; Bower, 1981; Conway & Ross, 1984; Isen, 1987; Loftus & Loftus, 1980; Neisser, 1967;) and clinically (Schafer, 1981; Spence, 1982). The notion that the change of meaning of personal memories is a heart of psychotherapy becomes increasingly accepted (Schafer, 1981; Spence, 1982). During psychotherapy some memories become meaningful, while the meanings of others become more tolerable, integrated with the rest of personality, and multiple. The multiplicity of meanings of personal experiences may be also an achievement of psychotherapy.

It seems that the relationship of the hippocampus to the right hemisphere in the case of episodic memories demonstrates a more general peculiarity of the hippocampus-right hemisphere relationship. It is this interrelation that enables maintenance of episodic memories. Or, to put it more accurately, it is this peculiarity of functioning of the hippocampus and the right hemisphere that makes episodic memories episodic ones.

It is only due to their cooperation that a possibility of polysemantic context is created. And only due to these incessantly changing polysemantic contexts that personal memories exist. In fact, the hippocampus is responsible for the emotional components of memory, whereas episodic memory has an emotional significance for the person. At the same time, as we have stressed, emotions by themselves are polysemantic and this feature is related to the right hemisphere.

### **Memory and cerebral hemispheres.**

The above approach can help us to understand the distinction between "image" memory and logic memory. The latter, (associated with the left hemisphere) can be modeled by a set of closed or open chains: each link typically connects to two links at most - the ones next to it up and down the chain; the chains are only coupled to each other via a few interlinks.

Any missing link (due to an organic lesion) will then cause the entire chain to be interrupted and some stored information will be lost. Thus, a patient with a small left-sided infarction in the area of the anterior perforating arteries, showed considerable verbal memory and learning deficits (Markowitsch, Cramon, Hoffman, Sick, & Kinzler, 1990). It seems that left hemisphere monosemantic context is particularly vulnerable to brain damage. Essentially, left hemisphere lesions interfere with formation of monosemantic context and impairs access to particular memories encoded in this context.

By contrast, formation of polysemantic context by the right hemisphere enables multiple accesses to the memories encoded into it. Therefore, polysemantic context is less vulnerable to brain damage. The gap in the context can be partially offset by other interlinks that may make up a bypass using somewhat dissimilar, though essentially relevant information, in other parts of memory storage. It would be interesting to verify this self-restorative ability of right hemisphere by comparing left-hemisphere damaged subjects with right-hemisphere damaged subjects. in their ability to complete polysemantic contexts.

By contrast, image memory rests on a large number of intertwining and interconnecting links set in a multidimensional space. Each link may interplay with many others at a time, and a complex network of intertwining and partly overlapping links is thus generated. Naturally, the more reference points there are the less significant each of them becomes. (John, Tang, Brill, Young, & Ono, 1986).

In this case one or even several missing links will not make the whole structure collapse and fall into disarray because the system uses other links and a myriad of their relations to survive. Image memory thus gains important advantages in terms of "costs" required to absorb and store information as well as of effective memory capacity and data loss probability. Luria's (1968) "A small book about Large Memory" describes a testee endowed with incredible mnemonic capabilities.

The testee could memorize a very long series of figures or words at a glance. To do this, he would visualize a real picture, for example, the arrangement of houses along a street in Moscow, and then attach the figures read to him to the houses just as beads are threaded on a string. When asked to repeat the series, even after a long time, he would make a mental trip along the same road and "take the figures off the houses" so vivid in his mind. This trick appears to require an involved mental picture of the street as a whole, if only not to get confused over the sequence of figures. The testee remembers a lot of diverse facts or, what is more, rather uniform items. Bearing this in mind, we have to assume, that each image he employed displayed a unique distinction, due specifically to a great number of various relations between its components and between the image and his perception of the rest of the world.

It is noteworthy that not only did the testee have no subjective problems in putting facts into memory but he actually suffered due to memorizing involuntarily everything he encountered.

In light of our concept that polysemantic relations are an essential element of image-thinking and image memory, we see as being remarkable the results of tests where the subject is hypnotized and instructed to reproduce specific information. The results of tests tend to be more successful when the subject created a mental picture of interacting images rather than of individual ones (Begg, 1978). Subjects who exhibit higher mnemonic capabilities in a hypnotic state report discerning a greater number of inner and often queer relations between image elements.

Subjects do not have to make an effort to relate images: the process seems to go on by itself (Crawford & Allen, 1983). Empirical evidence thus proves image-memory as well as image-thinking to be both less costly to the brain.

It has also been demonstrated (Otmachova, 1984) that the intensity of the alpha-rhythm remains unchanged when one tries to remember music, whereas a similar test with letters or figures results in a significantly decreased alpha-index in the left hemisphere. Such decreased alpha index reflects an additional stimulation of the brain hemisphere from the brain stem reticular formation.

Our suggestion concerning human memory is also in agreement with the studies of memory functions performed on persons with either hemisphere injured (Bragina & Dobrochotova, 1981). The interference was shown to play a secondary role in recalling an earlier encoded item if the right hemisphere was injured. The success of imprinting seems to depend on whether new data can be incorporated into the image context.

Once the process succeeds, the new engram coupled to many others is rather persistent. However, the process that fetches an engram from memory relies greatly on the functional capability of the unimpaired left hemisphere. A severe and widespread organic lesion of the right hemisphere may, however, impede the "coupling" proper. The close relationship between the right hemisphere and limbic system makes the right hemisphere vulnerable and very sensitive to limbic system lesions. These lesions impair the right hemisphere functioning and, in general, formation of the polysemantic context.

This dependency of the right hemisphere on the limbic system forms the main limitation of the right hemisphere. A lesion to the left hemisphere primarily impairs the function of engram retrieval. Probably, the most evident effect of such impairment is the interference, observed when the period between imprinting and retrieval is taken up by intellectual activities. Here the process of retrieving the desired data is in effect that of detecting a signal in a noisy environment and interfering data represent "noise".

The latter process calls for the ability to arrange data in a logical manner as well as to focus on a definite goal; to develop and maintain a rigorously ordered system. All these functions are performed by the left hemisphere.

In summary, each type of memory has its advantages and limitations. The right hemispheric image memory is more flexible and spontaneous and can retain an engram for a longer period. However, in a normal mind, left hemispheric processes must be strongly involved if the engram has to be properly and consciously retrieved. These processes are also dominant when a person needs to memorize ordered and well arranged material.

Image memory is identical to episodic memory that registers events of the subject's private life rather than learned, formal knowledge unrelated to his personal experience - semantic memory (Tulving, 1972). It would be interesting to investigate this hypothesis using priming paradigm with different kinds of stimuli presented sub- or supraliminally. If our reasoning is right stimuli that involve left hemisphere should be primed supraliminally. On the other hand right hemisphere is responsible for subliminally presented stimuli.

Being part and parcel of one's personal baggage, episodic memories are more emotionally laden, impressionistic, and experiential than knowledge-like semantic memories. They have a strong self-reference and they have more interconnections than semantic memories have. Therefore it seems reasonable to hypothesize that right hemisphere is a seat of episodic memory. There are some clinical data which confirm this relationship.

A patient with a parieto-occipital damage on the right side had preserved his ability for semantic learning, but was unable to remember any single event from his earlier life and was unable to relate semantic learning to his personal level (Tulving, Hayman, & MacDonald, 1991). Patients with right hemisphere damage have more difficulty in recalling emotional than non-emotional stories (Wechsler, 1973).

Accordingly, the left hemisphere seems to be involved in more formal learning and processing of semantic memories. As was already mentioned above, a patient with a small left-sided infarction in the area of the anterior perforating arteries showed

considerable verbal memory and learning deficits (Markowitsch, et al., 1990). Similarly, the left hemisphere pathology adversely affects semantically based functions, including semantic memory (McKenna & Parry, 1994).

It would be intriguing to verify this relationship in future studies. For example, is there any relationship among site of the damage, disturbances in self schema, and recall of personal, episodic memories? In addition, is impairment in emotional processing following right hemisphere damage accompanied by difficulties in recall of personal memories as opposed to semantic knowledge?

### **Memory disturbance among the aged persons.**

Memory disturbances is one of the most common complaints in aged persons, and this problem is discussed in the literature from various points of view (see Baltes, 1991). Modern approaches regarding the functional significance of brain hemisphere asymmetry in memory does not, however, attract enough attention from investigators working in this field even if their own data require the discussion in terms of brain hemisphere asymmetry and peculiarities of image thinking (Baltes, 1991).

The difference between right and left hemisphere contributions to memory indicate an actual problem, and some clinical features of memory disturbances in aged persons brought about the suggestion that brain hemisphere asymmetry may be essential in the explanation of this symptom.

What is the peculiarity of memory disturbances in aged persons? In pronounced cases of aging the short-term memory of the recent events is especially impaired (we are speaking even about regular aging, not about dementia). As a result, the ability to adopt new knowledge and skills is very limited.

However, the long-term memory which is concerned with the past (and especially with significant events in childhood and youth) is not impaired and sometimes these events appear in consciousness spontaneously and in a form of bright and rich image with many details being ignored before. Sometimes the time schedule of these events, in a real time, is disturbed: the event which actually happened many years ago seems, subjectively, to appear much later.

We suggest that the above mentioned conception about the organization of the imaginative and verbal memory can help to explain this phenomenon. Memory disturbances in aged persons, from the authors' point of view, are caused, predominantly, by the deficiency of left-hemisphere mechanisms which are very sensitive to any kind of organic damage, including brain vessels disease, - in combination with natural age-related exhaustion of the right hemisphere ability.

It means that the ability to include new information in the polysemantic context is sharply decreased (Baltes, 1991). This hypothesis is in agreement with the established fact of the decrease of right hemisphere faculty with age (McDowell, Harrison, & Demaree, 1994). As a result, new information can be encoded by these subjects only by mean of the left-hemisphere mechanisms which produce logical monosemantic context.

However, precisely these mechanisms are highly sensitive to brain bloodflow deficit, and even localized damage of the left hemisphere causes disturbance of the whole

system. It is also worthwhile to note of the influence of the reticular activation system on the left hemisphere activity (Rotenberg & Arshavsky, 1991). This system is localized in the brainstem - area, which is especially sensitive to subtle vascular disorders. At the same time, image memory, attributed to past events, is more resistant. (It is necessary to discriminate between the ability to create a new polysemantic context in order to adopt a new information - this function is diminished , - and the ability to preserve a previously formed network for the long-term memory).

The age-dependent decrease of the functional ability of the right hemisphere does not affect long-term memory - engrams which are already encoded). The retention of past events in the right hemisphere memory already happened in the past, and it is not necessary to construct a new network in order to maintain and reproduce information which was previously encoded in the right-hemisphere branched-net.

Right-hemisphere memory, being free from competition and interference caused by the recent information (which is not encoded), becomes even more vivid, but the distribution of these past events, in time, may be disturbed because this distribution depends on left-hemisphere functions.

A high stability of the professional memory may be explained by some other reasons: being very important for self-esteem and being connected to some meaningful life events, professional skills may partly use right-hemisphere mechanisms. Of course, automatisms must be also taken into consideration.

Thus, according to the present conception, memory function in aged persons must depend on the initial ability of the right hemisphere mechanisms to produce polysemantic context.

### **Emotions and memory.**

Polysemantic contexts are supported by the right hemisphere - limbic system interaction. These contexts involve representation of personal, emotional, and episodic memories that have self-reference. In the polysemantic context a particular experience has multiple and interlacing mutual connections with infinitely big number of other memories and experiences.

This structure of personal experiences makes our episodic memory more durable. This effect of polysemantic context on memory functioning can explain the well known fact that emotional facts are remembered better than non-emotional ones. In fact, Kunst-Wilson and Zajonc (1980) found that affective discrimination of objects may be possible even if their supraliminal recognition is precluded. Similarly, Christianson and Loftus (1990) asked 437 patients to report their most traumatic memory. It was found that the rating of degree of emotion and the number of central details were positively related.

It seems plausible that emotional memories activate the limbic system and the right hemisphere. Consequently, the memories are encoded in the right hemisphere polysemantic context. They become connected with a large number of other memories and become more accessible for retrieval. In fact, the above mentioned findings underscore the context-bound quality of our memories.

Whether a particular memory would be encoded in the polysemantic context or in the

monosemantic one, depends more on the context of learning, than on the learned material itself. This context enables a particular cognitive or emotional attitude towards the material, self-involvement, and ability to perceive the world in creative and polysemantic terms as opposed to strict, formal, and even an alienated attitude towards the learned material.

Thus, encoding context stimulates formation of particular internal context of every subject. That is, if encoding context is based on self-involvement and multiple meaning the internal context is maintained by the right hemisphere. On the contrary, when the encoding context is formal and not self-related the internal context is maintained by the left hemisphere. The retrieval context can stimulate either the left hemisphere or the right hemisphere. This process leads to influence of encoding and retrieval context on memory.

There is another memory phenomenon that emphasizes the effect of context on memory. The context-bound nature of our memories is emphasized most succinctly by state-dependent learning. State-dependent learning refers to the fact that events or learning lists are recalled best when the person experience the same emotion as he did during the learning of the original event or learning list. Conversely, if the states of mind during learning differ from the one that accompanies the recall conditions, one's ability to remember the original learning lists or facts diminishes.

Bower, Monteiro, and Gilligan (1978) investigated the effect of mood on the recall of word lists. It was found that words learned in the happy mood were recalled better in the happy mood, while word lists learned in the sad mood were recalled better in that state of mind. On the other hand, the opposite mood diminished ones ability to retrieve the learned words. Other studies confirmed these findings (Bower, 1981).

A different pattern of results appeared for memories of personal episodes. It was found (Bower, 1981) that people in a pleasant mood recalled a greater amount of pleasant memories than in of their unpleasant experiences. The same results were obtained for people in sad mood.

However, happy subjects retrieved many more pleasant than unpleasant memories, whereas for sad subjects the difference between pleasant and unpleasant memories was small. This pattern of results rises a question about a possible asymmetry of effect of state-dependency for personal memories when people experience negative emotions.

In fact, it was found that depressed mood reduces retrieval of episodic memories of any kind (Ellis, Thomas, McFarland, & Lane, 1985). After reviewing the studies in the field, Isen (1987) came to the conclusion that a positive mood improves ones memory for positive personal episodes, however the sad mood does not facilitate the recall of sad personal events.

In other words, state-dependent learning was demonstrated for positive mood for both semantic and episodic memories. However, for episodic memories it was demonstrated that a depressed mood may even decrease ones ability to recall personal events.

In order to explain these findings we would like to distinguish specific effect of emotions on memory from the non-specific one. In general emotions have a non-specific effect on cognitive processes.

Limbic system is connected with both the right and the left hemispheres. This connection leads to non-specific effect on memory, perception, and reasoning. One of these effects is state-dependent learning for semantic memories. However, the relationship of the limbic system to the right hemisphere is closer than to the left one. The close interaction of these two brain structures leads to more specific effect of emotions on memory.

That is, due to the connection between the limbic system and the left hemisphere a particular emotion creates a context of learning or of recall. This context is non-specific since the particular emotional valence of experienced emotion is not crucial. What is more important is the fit between the emotional state during learning and during recall. Emotions serve as a condition of learning.

On the contrary, the specific effect of emotions on the cognitive processes in the right hemisphere includes also the effect of emotional valence on memory. This distinction would help us to explain the differential influence of emotions on memory.

Semantic memories are encoded in the left hemisphere. When the learning person experiences a particular emotion (either positive or negative) during learning, the context, that centers on this emotion, is created. Consequently, when this emotion is aroused once more, the context becomes more available and the recall improves. This context is monosemantic and may be maintained by the left hemisphere.

Thus, the influence of emotions on semantic memory is due to emotional fit between retrieval and encoding contexts. These context may be formed on the basis of either positive or negative emotions. However, the emotional valence does not affect semantic memories. Emotions serve simply as a context for semantic memories.

However, for episodic memories positive emotions improve memory whereas negative emotions have a detrimental effect on it. We call this differential influence of emotions on memory a specific effect. A similar hypothesis has been roused by Isen (1987). She proposed that positive affect activates the right hemisphere, that give rise to holistic processing. This type of processing improves ones memory and recall.

The detrimental effect of negative emotions on memory needs a special discussion. For explanation of these results it should be mentioned that negative mood has a detrimental influence on right hemisphere functioning. Really, depression adversely affects such right hemisphere functions as recognition of facial expression of emotions (Mikhailova, Vladimirova, Inzak, Tsusulkovskaya, & Sushko, 1996; Rubinow & Post, 1992) and spatial performance (Gruzelier, Seymour, Wilson, Jolley, & Hirsch, 1988). Dreams are another product of right hemisphere functioning (Rotenberg, 1993; Joseph, 1988).

The amount of sleep dreams is decreased among depressed individuals (Barret & Loeffler, 1992). These findings are in line with the suggestion according to which depression is associated with the right hemisphere hypofunctioning (Flor-Henry, 1969). That is, depressed affect is associated with decreased functioning of the right hemisphere. Episodic memories can be encoded only in the right hemisphere, since this type of memory is polysemantic, refers to ones self, and emotionally laden.

Thus, ones ability to encode episodic memories depends on the intact right

hemisphere. Depressed affect impairs the functioning of the right hemisphere. Consequently, the polysemantic context is less available as well as episodic memories attached to it. For these reasons depressed, or, more generally, negative affect is not associated with state-dependent learning for personal memories.

This fact shows a special vulnerability of episodic memories to the right hemisphere hypofunctioning. Really, negative affect does not impair semantic memory, because semantic memory depends on the left hemisphere, which is influenced by the presence of emotional experience, and not by the emotional valence.

On the contrary, episodic memories depend on the normal functioning of the right hemisphere and its ability to form a polysemantic context. Since depressed affect impairs the functioning of the right hemisphere, one's ability to recall sad personal episodes diminishes too.

### **Confabulations: Old phenomenon in a new context.**

Confabulation is a mysterious and not well understood adjunct of amnesia (Dalla Barba, 1993; Schnider, von Daniken, & Gutbrod, 1996). Usually it makes itself present by actions or verbal statements that are incongruent to the patient's history, background, and present situation. It differs from lying by its unintentional quality or lack of conscious attempt to deceive. The confabulator seems to be unable to recognize the erroneous nature of his story (Dalla Barba, 1993; Joseph, 1986, 1988).

Confabulations seem to demonstrate in the most succinct way the close relationship among episodic memories, the right hemisphere, and polysemantic context. The following studies yield support to this suggestion.

Dalla Barba and associates (Dalla Barba, 1993; Dalla Barba, Cipolotti, & Denes, 1990) described two patients in whom confabulations were confined to episodic memory.

Confabulations, that are usually associated with memory loss, are associated, at least for Korsakoff's disease, also with right hemisphere damage (Joseph, 1986).

The damage to the right hemisphere leads to fantastical and delusional confabulations (e.g. Bisiach & Luzzatti, 1978; Green & Hamilton, 1976; Luria, 1978, 1980; Shapiro, Alexander, Gardner, & Mercer, 1981).

Sometimes confabulations follow disconnection of cerebral hemispheres (Gazzaniga & LeDoux, 1978; Joseph, 1982). In such instances the confabulations may occur due to disconnection of the left hemisphere from the sources of information contained in the right hemisphere. The left hemisphere infers the nature of this information, failing, however, to convey the essence of it.

This process is very similar to a suggestion according to which confabulations stem from the subject's attempt to fill the gaps in the memory (Bonhoeffer, 1904; Talland, 1961). In addition, this disconnection leads to inability to utilize environmental cues in order to correct the erroneous conclusion (as was already suggested by Shapiro, et al., 1981).

This inability stems from inability to communicate with the right hemisphere, which

is responsible for such utilization of cues (Rotenberg, 1993). In that sense confabulations are very similar to another product of the pure left hemisphere thinking, that is, delusions (Rotenberg, 1994). That is, they are similar to delusions in their freedom from external reality and their contradiction to this reality. However, from the formal, logical approach they lack internal contradictions. The following example demonstrates such response (Weinstein, Kahn, & Malitz, 1956):

A 20-year-old individual suffered a serious head injury in a car accident. When questioned about his accident and injuries he attributed "his hospitalization to having been in an atomic explosion which occurred when his rocket ship had crashed. He stated that he was still filled with radioactive fluid and pointed to the numerous scars on his body to show where the doctors used needles to remove the fluid"

What makes this response so striking is not only its unrealistic and even bizarre quality, so typical for left hemispheric thinking, but also its subtle, however discernible relationship to real facts. Consider, for at least, the following equations: atomic explosion=car accident, rocket ship=car, being full of radioactive fluid=being overwhelmed by disturbing emotions following the crash, etc. The subject not only misrepresent the real occurrence by false memories, but also he is trying to preserve the inner meaning of the event, being oblivious of it, however.

Joseph (1986) mentioned another aspect of confabulations, that makes them similar to delusions. That is, rather than relinquishing an incorrect answer when confronted with contradictory facts, the confabulator may make further erroneous extrapolations or even partially incorporate some aspects of the confrontation within confabulatory response. To cite an example of this kind of response (Stuss, Alexander, Lieberman, & Levine, 1978):

A patient with a frontal lobe injury came to the interview wearing pajamas. When surprise was expressed about this fact, he responded, "I keep them in my car and will soon change into my work clothes".

It seems that confabulations are not only a product of the left hemisphere thinking. We suggest that they appear exactly when the right hemisphere fails to sustain or form a polysemantic context. Confabulations are an artificial attempt to compensate for failure of the right hemisphere to maintain polysemantic context. This failure can stem from damage to medial temporal lobe or to right hemisphere. Similarly, when right hemisphere is disconnected from the left one, the access to polysemantic context by the left hemisphere disappears.

Confabulations are a kind of side products of an attempt to replace a polysemantic reality by the monosemantic complex context. Since confabulations are a part of the complex context we would like to distinguish the complex context from the polysemantic context. In polysemantic context the whole is not determined by its components, since all specific features of the whole are determined only by interconnections between the parts.

On the contrary, any concrete element of such a context bears the stamp of the whole. However, there is no such interrelationship between the whole and the parts in complex context. The complex context is an extended version of monosemantic context in terms of the elements number .

However, unlike polysemantic context it doesn't contain multiple interconnections

among the elements. Therefore, the distinction between polysemantic context and complex context is similar to a distinction between "good figure" of gestalt psychology and a complex figure.

Accordingly, Wapner, Hamby, and Gardner (1981) found that right hemisphere damaged subjects had difficulties in acquiring a sense of the overall gestalt and tended, more than the normal subjects, to complete the complex context by an appropriate elements. That is, they formed complex context, failed to form a polysemantic context. It would be interesting to use the paradigm of Wapner and associates (1981) to extend these findings.

After making a distinction between complex context and polysemantic context let us return to dynamics of confabulations formation. The failure of the right hemisphere to sustain a polysemantic context leads to a switch to the left hemispheric functioning. This transformation would lead to tremendous changes in internal world, flattening of personal experience, and a monotone and empty existence.

However, these changes are adaptively balanced and prevented by confabulations that introduce an artificial possibility of formation of complex context. This kind of context is devoid of polysemanticity of meaning that characterize the polysemantic context, formed by the right hemisphere.

In the right hemisphere polysemantic context the meaning of particular experiences changes due to the changes in the whole context. That is, the polysemantic context sustains its particular elements. On the contrary, confabulations sustain the whole context by adding new information which is potent enough to make the context more rich, vivid, and convincing.

For this reason, confabulations tend to incorporate extraneous and even contradictory information into themselves, as was demonstrated above. This incorporation of new information, and particularly of contradictory one, leads to changes in the whole context. This process leads to the increasing complexity of it. This kind of context is devoid of natural vividness and multiplicity, so characteristic of the right hemispheric polysemantic context.

It is vague, artificial, and fragile, since it depends on confabulations, and it is very much alienated from external reality. Nevertheless, however bizarre they could be, confabulations are an adaptive response of the brain, that try to preserve multiplicity of meaning by all costs. They try to adapt the brain and consciousness to multiplicity of the real world. Bizarreness of confabulations is the cost our brain has to pay for artificial simplification of the reality caused by the right hemisphere insufficiency.

In that sense Joseph (1986) is right in stating that confabulations are not always related to memory disturbance. Confabulations are more than memory phenomena (or, more accurately, memory loss phenomena). They are vehicles of meaning, they help to preserve internal complexity, when the right hemisphere fails to form polysemantic context. Confabulations help to adapt to the polysemantic context of reality without a natural coping mechanism, that is, formation of the polysemantic context by the right hemisphere.

Instead of real multiplicity of meanings, confabulations provide a structure for maintaining episodic memories. In general, there are two way to form complexity of meaning. The first of them consists of organizing personal experience into

multidimensional, polysemantic context, formed by the right hemisphere. Each context gives new meaning to a particular experience or memory.

This context incessantly changes, thus, changing meaning of its parts. In a way, every time new context is formed, new meaning is re-invented for every personal experience. This occurs due to establishment of new connections. This incessant formation of polysemantic contexts is an inherent feature of episodic and autobiographic memories.

On the other hand, confabulations offer another way to change meanings of a particular set of experiences. Instead of establishing of new connections with other experiences, confabulations incessantly transform themselves due to incorporation of new material. This process leads to formation of complex context and, consequently, preservation of complexity of meaning.

In a word, confabulations help to maintain complexity in a monosemantic complex context. In other words, in polysemantic context the vividness is due to new interrelationships among its components. On the contrary in complex context vividness is achieved by adding new element to the whole complex.

The proposed explanation for confabulations helps to understand an interesting finding of Natale and Hantas (1982). They demonstrated that the negative affect increased the subjects' tendency to recall false negative self-description. This bias for false self-descriptions is similar to confabulations.

Really, as it was suggested above, negative affect decreases the functioning of the right hemisphere. This decreased functioning leads, as in the case of right hemisphere damage, to transformation of the polysemantic context into the monosemantic one. However, this process is accompanied by ones attempt to preserve inner complexity of the context, either by means of confabulations in the case of right hemisphere lesions, or by means of false memories in the case of right hemisphere hypofunctioning due to depressed mood.

It may be concluded that our personal memories need a kind of continuous re-fueling by the process of meaning change. It may be attained either by formation of polysemantic context, supported by the right hemisphere, or by formation of confabulations and complex, but monosemantic, context by the left hemisphere. For this reason confabulations are adaptive and even essential for preservation of episodic memories.

As it was stated above, episodic memories exist in a continuously changing context. Thus, when the polysemantic context, supported by the right hemisphere, collapses, confabulations appear as auxiliary, bizarre, and artful inventions. Being normally context-dependent, episodic memories become confabulation-dependent following the right hemisphere damage.