CHAPTER 2

REVIEW OF LITERATURE
2.1. Lexico-semantic skills and the right hemisphere

Contrary to the earlier proposals on the left hemisphere’s exclusive association with the linguistic functions, it is now apparent that the right hemisphere plays a pivotal role in certain linguistic domains. Within the broader realm of research pertaining to language processing and right hemisphere, perhaps, the most debated issue is the right hemisphere’s lexico-semantic processing capabilities. Specifically, this issue began to attract the scientific attention with the pioneering observations of Sperry and colleagues in the early 1960s (as cited in Gazzaniga, 1998) from a group of three subjects with surgical disconnection of corpus callosum (callosotomy or split-brain surgery) to prevent the spread of intractable epilepsy. In the following sections of this chapter, a brief review of both concordant and discordant evidence on the lexico-semantic processing capabilities of the right hemisphere derived from various techniques, paradigms, and populations is presented.

2.1.1. Evidence from split-brain studies

The surgical removal of the corpus callosum (i.e., callosotomy) renders the cerebral hemispheres disconnected from each other (Beaumont, 2008, p – 11). Subsequently, the information presented to the left visual field (i.e., right hemisphere) fails to reach the left hemispheric linguistic cortex and such (i.e., split-brain) subjects are unable to process information linguistically (Gazzaniga, 1998). In contrast, when the visual information is presented to the right visual field (i.e., left hemisphere) these subjects are able to process it linguistically (Gazzaniga, 1998). Thus, the callosotomy or split-brain surgery provides an exciting avenue to study the hemisphere-specific linguistic (and cognitive) processing in humans.

In-depth investigations of split-brain subjects have provided several hypotheses on the possible contribution of the right hemisphere to verbal communication (Joanette, Goulet, & Hennequin, 1990, p - 22). For instance, in 1976, Zaidel demonstrated that the right hemisphere is capable of processing words, at least, if they were common and concrete in meaning; in a group of split-brain and hemispherectomy patients. Burklund and Smith (1977) provided supportive evidence for this argument from their patients who had undergone left
(dominant) hemispherectomy. In accordance with these findings, Gazzaniga, Ledoux, and Wilson (1977) provided interesting evidence for the right hemisphere’s contribution to language processing using divided visual field (DVF) technique in a 15-year-old male who underwent callosotomy. In their study, when the names of objects were presented to the left visual field, the subject could retrieve the designated item from a group with his left hand. Thus, it became apparent from this, rather direct evidence that the right hemisphere of split-brain subjects could comprehend written words. Zaidel (1982) further explored the linguistic capabilities of the right hemisphere by using syntagmatic and paradigmatic word relations. He demonstrated that the RH is capable of processing the syntagmatic word pairs (e.g., flower-garden, window-glass) as opposed to the paradigmatic (e.g., flower-tree, window-door) pairs. A later study by the same author replicated and confirmed similar (i.e., syntagmatic) processing by the right hemisphere (Zaidel, 1995). The RH has also been proposed to have the potential to acquire late lexicon. For instance, Gazzaniga and colleagues (Gazzaniga, Eliassen, Nisenson, Wessinger, Fendrich, & Bayness, 1996) reported the case of a patient (JW), who had left hemisphere dominant language at the time of callosotomy. The first follow up investigation performed 14 years after the surgery revealed accurate naming of approximately 25% of the stimuli, which rose to 60% at the time of second follow up one year later, thus revealing the RH’s (albeit, partial) potential to acquire lexicon at a later age and long-term neural plasticity.

These findings from split-brain subjects are, thus, indicative of RH’s potential to perform subtle linguistic processing including the acquisition of lexicon at a later age. However, several authors admit that the language processing capabilities of the right hemisphere is far more inferior to that of the left hemisphere (e.g., Gazzaniga, Smylie, Baynes, Hirst, & McCleary, 1984; Zaidel, 1976) and the lexicon of this hemisphere is much smaller compared to that of the left hemisphere (Zaidel, 1976). In the following section, evidence for the right hemisphere’s linguistic capabilities from yet another procedure (i.e., sodium amobarbital or Wada) comparable to that from split-brain procedure is presented.

2.1.2. Evidence from Wada test

In 1949, Juhn Wada of the Hokkaido University School of Medicine in Japan, first described the use of the intracarotid amobarbital procedure (IAP) as a technique to
temporarily inactivate one cerebral hemisphere to determine the lateralization of language functions in a group of pre-surgical epileptic patients (Simkins-Bullock, 2000). Since then, this technique had been the ‘gold standard’ for a long time to determine hemispheric specialization (Lee et al., 2008). Although the test protocols vary across the centers (Haag et al., 2008), the oral naming task is an essential part of the protocol (Chlebus, Mikl, Brazdil, Pazourkova, Krupa, & Rektor, 2007). The Wada test has been employed primarily to determine the eloquent cortex in pre-surgical epileptic patients (Rausch, Babb, Engel Jr., & Crandall, 1989). It may, however, be noticed that this procedure is generally employed to determine the hemispheric dominance for language functions and not to examine the specific lexico-semantic processing skills of either hemisphere, per se.

Despite such logical inappropriateness in drawing conclusions from Wada test, investigations have shown that the right hemisphere is capable of processing concrete labels (e.g., Fedio, August, Patronas, Sato, & Kufta, 1997). For instance, Fedio et al. (1997) performed the IAP at low dosage in a group of 30 temporal lobectomy subjects and reported that with the injection to the right hemisphere, the left hemisphere formulated super-ordinate categories (e.g., “insects” for “ants, beetle, spider”) for words and objects. In contrast, when the left hemisphere was injected, the right hemisphere applied labels that are more concrete. In people with complex partial seizure, Yetkin and colleagues (1998) argued that the language representation may be bihemispheric. In yet another recent study, Cunningham and colleagues (Cunningham, Morris III, Drea, & Kroll, 2008) claimed that the right hemisphere of even those subjects with right temporal lobe epilepsy could process language. Thus, the observations, although from clinical population suffering from long-standing epilepsy, indicate that the right hemisphere could process language in addition to the left.

Although Wada test had been the ‘gold-standard’ for a long time in the determination of hemispheric functions (Lee et al., 2008), the results derived from this technique should be interpreted with caution (Helmstaedter & Kurthen, 2002). That is, owing to its invasiveness, this technique is used only in pre-surgical patients with etiologies (e.g., epilepsy) known to have the risk of transfer of cortical functions (Helmstaedter & Kurthen, 2002). Yet, a recent multi-national, multi- centric study (Haag et al., 2008) revealed that clinicians from 26
epilepsy centres across four countries reported of its good reliability and validity in the
determination of hemispheric language lateralization.

As apparent from the studies reviewed above, the IAP, in general, focus on
determining the hemispheric specialization for language functions and are rarely used in
specific investigations into the lexico-semantic processing capabilities of either hemisphere.
Thus, the nature of the etiology (i.e., epilepsy) with its known risk of inter-hemispheric
transference of linguistic functions (Helmstaedter & Kurthen, 2002) combined with the lack
of specific research focus on lexico-semantic processing capabilities of the right hemisphere
render the evidence derived from IAP, tangential. That said, in the following section, evidence
for the RH’s contribution to lexico-semantic processing from yet another, perhaps a
ubiquitous population – i.e., people with aphasia – is presented.

2.1.3. Evidence from people with aphasia

Investigations in people with aphasia have added a new dimension of evidence to the
right hemisphere’s role in language processing. In right-handed subjects, aphasia occurs
frequently after left-sided brain damage (Mesulam, 2009). However, it may also be found
after right-sided lesions in this population (Mesulam, 2009). Aphasia following right
hemispheric lesion – crossed aphasia – in right-handed individuals is rare, with a prevalence
rate of about 5.5 % (Karanth, Ahuja, Nagaraj, Pandit, & Shivashankar, 1991) in the Indian
population. However, two studies have reported an increased incidence (20 - 25%) of aphasia
in left- and non-right handers after right-hemispheric stroke (Basso, Farabola, Grassi,
Laiacona, & Zanobio, 1990; Gloning, 1977). In contrast, a study by Kimura (1983) did not
suggest any significant role of right hemisphere in speech (language) function in a group of
left handers without the history of early left hemisphere damage. Additionally, the variability
of language lateralization has been reported more frequently in left- than right-handers
(Hécaen & Sauget, 1971).

Higher incidence of aphasia in left- than right-handers and quicker and better recovery
in the former group (Zangwill, 1960) led to inferences about the relationship between
handedness and the degree of language lateralization (Knecht et al., 2000). Lower degrees of
lateralization have been correlated with better recovery from aphasia (Knecht et al., 2000).
However, studies on subjects with stroke have shown that aphasia resulting from damage to either left or right hemisphere differs only in terms of its frequency, but not in terms of the aphasia profile (Seghier, Kherif, Josse, & Price, 2011).

Like crossed aphasia in right-handed subjects, crossed non-aphasia is also indicative of the linguistic processing capabilities of the right hemisphere. Subjects with crossed non-aphasia are those right-handed subjects who exhibit normal language functioning despite an apparent lesion in the left hemispheric linguistic cortex (Hund-Geordiadis, Zysset, Weih, Guthke, & von Cramon, 2001; Krishnan, Tiwari, Rao, & Rajashekar, 2009).

It must be noted that these studies on both typical and atypical lateralization of language functions (to the left and right hemispheres, respectively), were on general linguistic functions, rather than on specific lexico-semantic skills. Hence, definite inferences on the right hemisphere’s role in lexico-semantic processing drawn from such studies may be misleading. On similar lines, evidence from investigations aiming to delineate the mechanism(s) of recovery in aphasia has also provided compatible views on the right hemisphere’s potential in language processing. In the following section, a brief review of such evidence is presented.

**2.1.4. The right hemisphere and recovery from aphasia**

The mechanism of language recovery in people with aphasia subsequent to left hemisphere damage has stimulated considerable amount of research in the past few decades. As a result of this, distinct schools of thoughts have emerged to explain the underlying mechanisms of language recovery in people with aphasia. For instance, as early as in 1877, Thomas Barlow (as cited in Finger, Buckner, & Buckingham, 2003) reported of the right hemisphere’s potential for language processing in subjects with left hemispheric lesion and subsequent aphasia. Barlow reported of a 10-year-old boy who lost his speech only for ten days following an initial episode of stroke restricted to the pars opercularis and ventral premotor cortex of the left hemisphere. One month later, a second episode of stroke in the right hemisphere homologous areas resulted in further loss of the previously recovered speech. Based on these observations, Barlow claimed that the right hemisphere is capable of language processing (in children) in the event of left hemisphere damage. More than a century
later, Cambier, Elghozi, Signoret, and Henin (1983) supported and extended Barlow’s proposal to adult subjects with left hemisphere damage. In their study, Cambier et al. (1983) reported the cases of two subjects with some language recovery after a left hemisphere stroke. However, these subjects lost their partially recovered language functions subsequent to a second lesion in the right hemisphere. Several subsequent studies have also supported these observations (e.g.s., Musso, Weiller, Kiebel, Müller, Bülau, & Rijntjes, 1999; Sharp, Scott, & Wise, 2004; Weiller et al., 1995). Such clinical findings may, therefore, be considered as evidence for the right hemisphere’s role in language recovery subsequent to left hemisphere damage.

Recent neuroimaging techniques provide additional evidence for the role of right hemisphere in recovery from aphasia. However, such results, in general, unlike those from the clinical studies, have been equivocal in terms of the right hemisphere’s role in language recovery. Several authors (e.g.s., Ansaldo, Arguin, & Lecours, 2002; Blank, Bird, Turkheimer, & Wise, 2003; Weiller et al., 1995; ) have argued that the activations in the right hemisphere are indicative of its role in the recovery of language functions in people with aphasia. For instance, Weiller et al. (1995) found an increased activation in the RH areas homologous to LH language zones in a verb generation task studied with PET scan. However, the proposed role of RH in post-aphasic language recovery has only been moderate (Perani et al., 2003).

Several arguments against the right hemisphere’s role in post-aphasic language recovery have also been reported in the literature. For instance, Metter et al. (1990) employed Positron Emission Tomography (PET) to measure the distinct roles of right and left hemispheres in the recovery of language functions in subjects with aphasia subsequent to left hemisphere damage. Their results showed that the left hemisphere, but not the right, played a major role in the language recovery. Specifically, Metter et al. (1990) found significant correlations between neuropsychological deficits and metabolic alterations of the left hemisphere language areas, while no such correlations were observed in the RH regions. Support for this argument has come from a number of studies in the past (Musso et al., 1999; Sharp et al., 2004; Weiller et al., 1995) including certain longitudinal investigations (Heiss, Kessler, Karbe, Fink, & Pawlik, 1993; Heiss et al., 1997; Karbe et al., 1995).
Rosen and colleagues (Rosen, Ojemann, Ollinger, & Petersen, 2000), however, argued that activations observed in the right hemisphere of people recovering from aphasia could be maladaptive in nature. For example, these authors evaluated the possible role of these RH areas in language processing in aphasic patients and found that better performance in a word-stem completion task correlated with LH perilesional rather than the RH homologous activation. Rosen and colleagues (2000) further argued that the RH frontal lobe activations were indicative of certain disinhibitive processes, which in turn, were suggestive of maladaptive cortical functional reorganization in people with LHD and aphasia.

Quite distinctly, a recent study by Saur and colleagues (2006) proposed alternating neuroanatomical loci of recovery in subjects with aphasia. That is, shortly after the stroke, Saur et al. (2006) found activations in the perilesional left hemispheric areas correlating with the linguistic (i.e., word-retrieval) task. In the sub-acute stage, the focus of activation shifted to the homologous areas of the right hemisphere, which in turn, showed a shift back to the left hemisphere in the chronic stage.

Thus, in general, the hemodynamic-based functional neuroimaging investigations provide ambiguous findings regarding the role of right hemisphere in post-aphasic language recovery, where, the proposed contribution of right hemisphere in the language recovery ranged from complete functional take over to some maladaptive strategy.

Investigations employing the evoked electrical and magnetic responses, like the hemodynamic-based ones, have also shed light into the right hemisphere’s role in post-aphasic language recovery. In a recent study, Breier, Maher, Schmadeke, Hasan, and Papanicolaou (2007) reported that in the pre- and immediate post-treatment period, the magnetoencephalography (MEG) activations were focused in the right hemisphere. However, at 3-months-post-onset, the activations were observed in both hemispheres, with the left temporal lobe showing stronger activations. Thus, Breier et al.’s (2007) observations show that the right hemisphere may contribute to language processing in the pre- and immediate post-treatment phases, although, the left hemisphere may be required for the long-term language processing.
However, counterevidence for right hemisphere’s role in post-aphasic language recovery has also been reported from previous investigations using repeated Transcranial Magnetic Stimulation (rTMS). For example, rTMS applied to the left and right frontal lobes has been found to influence the language performance in patients with brain tumors (Thiel et al., 2005) and aphasia (Winhuisen et al., 2005) during word generation and semantic tasks, respectively. The aphasic patients who recruited the right frontal lobe to perform the language tasks showed worse language performances than those who relied on their LH perilesional areas (Winhuisen et al., 2005). This observation was in accordance with the findings of Naeser and colleagues (2005) who reported of improved picture naming in an aphasic patient following rTMS in the right hemisphere. Thus, it may be inferred that the activations observed in the right hemisphere in stroke aphasic patients during functional neuroimaging studies may correspond to the maladaptive linguistic organization, supporting Rosen et al.’s (2000) arguments.

In brief, the role of right hemisphere in post-aphasic language recovery remains equivocal. Whereas, several clinical observations (such as Barlow’s case in 1877) have provided concrete evidence for the right hemisphere’s potential in this regard, more recent neuroimaging investigations have failed to provide consistent results on right hemispheric contribution to post-aphasic language recovery. The activations observed in hemodynamic-based investigations have been interpreted as both evidence for and against (i.e., maladaptive strategy) the right hemisphere’s role in language recovery. Furthermore, the experimental suppression of the right hemisphere during language processing (e.g., picture naming) task with rTMS has shown to improve the performance, supporting the argument that participation of RH in language processing in post-aphasic patients is a maladaptive strategy. In this context, direct investigations of people with right hemisphere damage may provide better insight into the role of this hemisphere in language processing. In the following section, a review of studies on this dimension is presented.

2.1.5. Evidence from subjects with RHD

The investigations of lexico-semantic skills in RHD subjects with intact left hemispheric language processing skills provide, perhaps, the most convincing evidence for the right hemisphere’s role in language processing (Joanette et al., 1990). Such investigations
are expected to reveal the arguably subtle, yet, identifiable contribution of the right hemisphere to the lexico-semantic processing.

One of the earlier studies by Gainotti, Caltagirone, Miceli, and Masullo (1981) provided evidence for the lexico-semantic processing skills of the right hemisphere from a group of participants with RHD. Participants of this study were grouped into ‘deteriorated’ and ‘non-deteriorated’ subgroups based on their general mental functioning. The ‘deteriorated’ subgroup exhibited apparently lower performance on lexico-semantic tasks compared to the ‘non-deteriorated’ subgroup and normal participants. More strikingly, the ‘non-deteriorated’ subgroup also showed marked difference in performance compared to the normal control subjects, thus revealing the right hemisphere’s role in lexico-semantic processing. Subsequent investigations have endorsed the arguments of Gainotti et al. (1981). For instance, Brownell and colleagues (Brownell, Potter, Michelow, & Gardner, 1984) showed that subjects with RHD were able to process explicit (i.e., denotative), but not implicit (i.e., connotative) meanings, whereas, those with LHD showed exactly opposite (i.e., implicit > explicit) pattern. In contrast to both RHD and LHD, normal participants were able to process both types of words. Thus Brownell et al. (1984) concluded that the right hemisphere is vital for the processing implicit meanings. Evidence for the right hemisphere’s lexico-semantic processing capability was also reported by Chiarello and Church (1986). They employed a judgment task based on rhyme, meaning, and visual similarity in left and right hemisphere damaged participants. The left hemisphere damaged group performed poorly on all three conditions, whereas, the right hemisphere group showed marked deficit only in the meaning judgment condition. Chiarello and Church’s (1986) findings, thus, indicated the right hemisphere’s capability to process word meanings. In addition to the processing capabilities of word meanings, the hemisphere in question is reportedly capable of processing words with high (but not low) imageability (Deloche, Seron, Scius, & Sequi, 1987).

Nocentini, Goulet, Roberts, and Joanette (2001) explored the semantic processing capabilities of the hemispheres by requiring the left- and right hemisphere damaged as well as normal participants to judge three intraconceptual (viz. superordinate, categorical, and whole-part relations) and two interconceptual (viz. locative relation & same location) relationships among the words. The findings of this study showed the right/left difference
only in one type (each) of *intraconceptual* (i.e., *whole-part relation*) and *interconceptual relations* (i.e., *same location*). Thus, the findings from this study did not support the existence of inter-hemispheric sensitivity difference during semantic processing. In a subsequent study, Nocentini et al. (2006) further investigated the contribution of the left and right hemispheres to the processing of denotative (implicit) and connotative (explicit) meanings of words. Specifically, these authors replicated and extended an earlier study by Brownell et al. (1984), who used only adjectives as stimuli. Therefore, Nocentini et al. (2006) used both adjectives (replication) and nouns (extension) in three groups of (i.e., left-, right-, & non-brain damaged) subjects. In the first experiment (adjectives), the authors required their participants from each group to judge the semantic similarity between two words (e.g., *deep*, *shallow*, & *warm*) of the stimulus triad printed in a single card. The results revealed a significant main effect for type of semantic relationships, but not for group as well as for interactions. That is, some RHD participants showed sensitivity to connotative words, whereas, others showed sensitivity to denotative words. Similar pattern was observed with LHD participants as well. In the second experiment, the adjectives were replaced with nouns. The results of this experiment showed a similar trend as in the first. Based on these observations from the two experiments, Nocentini et al. (2006) claimed that there is no such issue as a single LHD or RHD pattern of word processing impairment. Thus, Nocentini et al.’s (2006) study concluded that the lexico-semantic abilities of brain damaged individuals are more different between individuals of a given brain-lesion group than it is the case between left- vs. right-damaged individuals. Additionally, this study supported the view that both hemispheres contribute to the lexico-semantic processing of words.

Support for right hemispheric contribution to lexico-semantic processing has also come from traditional naming studies. For example, Myers and Mackisack (1990) reported that subjects with RHD experience mild difficulties in confrontation naming, word fluency, body part naming, in addition to their subtle difficulties in auditory comprehension of complex materials, oral sentence reading, and writing. Similarly, Thomson and colleagues (Thomson, Taylor, & Whittle, 1998) reported that 21% of their 33 subjects with RHD was aphasic by definition. Additionally, Thomson et al. (1998) showed that 21% were anomic when Boston Naming Test was employed. However, Damasio, Tranel, Grabowski, Adolphs,
and Damasio (2004) reported of relatively higher proportion of people with naming disturbance among 65 RHD subjects.

The event-related potentials from people with RHD have also contributed to the debate on lexico-semantic processing capabilities of the right hemisphere. For instance, Hagoort, Brown, and Swaab (1996) reported that the N400 effect – the reduction in amplitude of the negativity at about 400 ms – was smaller in people with RHD for semantically related, but not for semantically associated word pairs. In contrast, people with LHD showed reduction of N400 for both of these word types. From these observations, Hagroot et al. (1996) argued that people with RHD were specifically impaired in the processing of semantically more distant relationships.

Recently, Abusamra, Côté, Joanette, and Ferreres (2009) reviewed the communication impairments in subjects with RHD and stated that these subjects exhibit discursive, lexico-semantic, pragmatic, and prosodic impairments. Further, to address the issues on the lack of sensitive and standardized assessment instruments as well as the theoretical and methodological limitations of the existing ones (Joanette & Ansaldo, 1999), Joanette, Ska, and Côté (2004) introduced the MEC protocol (Montreal Protocol for the Evaluation of Communication) for the evaluation of verbal communication deficits in subjects with RHD. This protocol contains 14 tasks of which four (i.e., verbal fluency without constraint, verbal fluency with orthographic criteria, verbal fluency with semantic criteria, & semantic judgment) had direct bearing on lexico-semantic processing. A subsequent standardization of the protocol into Brazilian language and the administration of the same (Fonseca, Parente, Côté, & Joanette, 2007) in a group of 29 RHD subjects and 58 control (non-neurological) subjects showed significant deficits in the lexico-semantic skills (e.g., verbal fluency with orthographic and semantic criteria) in the neurological group.

2.1.5.1. Interim summary: Evidence from subjects with RHD

The foregoing section reviewed the pertinent studies exploring the right hemisphere’s contribution to the lexico-semantic processing in subjects with RHD. The evidence from these investigations has been derived through the application of various types of methods such as behavioral (naming, semantic judgment studies) as well as ERPs. Having reviewed the
evidence for right hemispheric contribution to lexico-semantic processing, what follows next is the counterevidence on the hemisphere’s role in lexico-semantic processing.

### 2.1.6. Counter evidence from subjects with RHD

Despite the evidence for the right hemisphere contribution in lexico-semantic processing from several lines of investigations (see foregoing sections), there are research studies that cast off such findings. For instance, in 1965, Marcie, Hecaen, Dubois, and Angelergues reported that on lexical and grammatical tasks, subjects with RHD performed more or less similar to the normal subjects. Similar findings have also been reported by Eisenson in 1962 as well as Hier and Kaplan (1980). In yet another early study, Coughlan and Warrington (1978) failed to show any significant difference between the RHD and normal (control) participants in a series of tests that included object and description naming. Rivers and Love (1980) endorsed these arguments and stated that subjects with RHD do not exhibit lexico-semantic deficits. Rivers and Love (1980) administered a series of seven tests viz. word reading test, word definition test, word context test, picture stimuli test, fragmented picture naming test, printed sentence construction test, and oral story telling test in three groups (i.e., LHD, RHD, & Normal) of participants. Though the LHD group showed significantly poor performance compared to the RHD and normal participants, which was anticipated, the RHD subjects failed to show any significant difference with the normal participants. These early investigations, therefore, provided strong evidence against the right hemisphere’s role in lexico-semantic processing.

In addition to such findings from these early investigations, relatively recent studies have also provided counterevidence for the right hemisphere’s role in lexico-semantic processing. For instance, Varley (1993) compared the picture naming performance of four groups of participants that included: a) fluent aphasics; b) non-fluent aphasics; c) right-brain damaged; and d) non-brain damaged. Though, as in the previous studies, LHD subjects showed group differences with RHD and NBD groups, the RHD group failed to exhibit such difference with the NBD group. Similar findings were also reported by Rainville, Goulet, and Joanette (1995) who failed to show group difference between RHD and normal control participants in lexical and semantic judgment tasks. Quite recently, Khatoonabadi and colleagues (2008) did not find statistically significant group differences in Farsi-speaking
right brain damaged and control populations while performing the lexico-semantic tasks. These authors argued that the processing of concrete words may not require the integrity of the right hemisphere.

2.1.6.1. Interim summary: counterevidence from RHD

Compared to the indirect evidence derived from relatively non-specific investigations employing IAP, split-brain subjects, and those with aphasia as well as those recovering from aphasia, specific investigations in subjects with RHD provide arguably stronger evidence for the hemisphere’s role in lexico-semantic processing skills. However, such studies are not without contrasting evidence. Further, it is worthwhile mentioning certain methodological shortcomings of the early investigations. For instance, the early studies investigating the lexico-semantic processing were primarily focused on left hemisphere damage and such studies included subjects with RHD as a control group in addition to the neurologically normal subjects. This is apparent from some studies (e.g., Coughlan & Warrington, 1978) that have not explicitly mentioned the performance of RHD group in comparison with the neurologically normal subjects. Yet, in general, investigations of subjects with RHD have provided plausible evidence for this hemisphere’s role in lexico-semantic processing. In addition to the evidence from various clinical populations, investigations of normal subjects under conditions of controlled stimulus presentation have also provided insights into the role of right hemisphere in lexico-semantic processing. In the following section, a few such important studies are reviewed.

2.1.7. Behavioral studies in normal subjects

Investigations in normal subjects using behavioral techniques such as divided sensory field have provided invaluable information on the nature of each hemisphere’s contribution to lexico-semantic processing skills. The major advantage of investigations in normal subjects is that the process under examination is not confounded by any brain pathology (Joanette et al., 1990). One of the most common, valid, and easy-to-use behavioral technique in normal (as well as in clinical) subjects is the divided visual field (DVF or tachistoscopic) technique (Bourne, 2006; Chiarello, Kacinik, Manowitz, Otto, & Leonard, 2004). In this technique, when the stimulus is briefly presented to the left visual field (LVF), it will be first processed
by the right hemisphere, whereas, when the stimulus is presented to the right visual field (RVF), it will first be processed by the left hemisphere (Gazzaniga, 2000). It has been well-stated in the literature that the left (or language dominant) hemisphere processes linguistic stimuli more efficiently and faster (Bourne, 2006; Hunter & Brysbaert, 2008).

In one of the early studies, Chiarello (1985) found larger priming for orthographically similar stimuli (e.g., beak-bear) when presented to the left visual field (RH) compared to the right visual field (LH) in a group of normal subjects. Further he observed that priming was equally effective in either visual field for phonologically related word pairs (e.g., juice-moose). However, for semantically similar pairs (e.g., inch-yard), larger priming was observed only in the right visual field (LH). These observations indicated that both orthographic and phonologic information may be available to the right hemisphere (Chiarello, 1985).

Following Chiarello’s (1985) study, Drews (1987) investigated the organization of lexical knowledge in the intact left and right hemispheres using the DVF technique. The participants in this study were instructed to judge the semantic relation between words that differed in quality (i.e., intraconceptual – coordinates or interconceptual – locative). The outcome of this study revealed that, in the left hemisphere, the lexical entities are organized based on the coordinate (intraconceptual) relationships. On the other hand, in the right hemisphere, the lexical entities were organized based on their locative (interconceptual) relationship. Drews (1987) attributed the analytical-sequential processing capability of the left hemisphere to intraconceptual relationships and the gestalt-wholistic processing of right hemisphere to the interconceptual relationships. In a subsequent investigation, Abernethy and Coney (1990) suggested that the left hemisphere lexicon is organized in accordance with a hierarchy of logical semantic relationships, whereas, the right lexicon is organized on the basis of simple associations between concepts, thus supporting the proposals of Drews (1987). However, Abernethy and Coney (1990) argued that the right hemisphere was unable, by itself, to activate words related to the exemplar prime. In the right hemisphere, Chiarello, Senehi, and Nuding (1987) showed evidence for the lack of inhibition of irrelevant information, whereas, in the left hemisphere, such information was apparently inhibited. In a subsequent study, Chiarello and colleagues (Chiarello, Burgess, Richards, & Pollock, 1990) extended
their previous arguments to claim that the automatic (or involuntary) access to semantic category relatedness occurs primarily in the right cerebral hemisphere. Thus, Chiarello et al. (1990) concluded that there is rapid selection of target meaning and suppression of other (i.e., non-target) candidates in the left hemisphere, whereas, in the right hemisphere, the activation spreads more diffusely, activating several (distant) semantic alternatives ready for lexical processing or selection.

Comparable findings on right hemispheric lexico-semantic skills were reported by Nakagawa (1991) who reported of strong inhibitory effects for remote or unrelated targets in the left hemisphere and lack of such inhibition in the right hemisphere. Similarly, Chiarello and Richards (1992) observed the semantic priming for words that were members of the same category (but, were not strongly associated) only in the right, but not in the left hemisphere. Together these studies (Nakagawa, 1991; Chiarello & Richards, 1992) showed that right hemisphere neither inhibited the remotely-associated words nor processed un-associated same-category members.

The investigations in normal participants have, however, yielded certain contradictory evidence on the right hemisphere’s role in lexico-semantic processing. For instance, Richards and Chiarello (1995) hypothesized that the ability of the right hemisphere to activate multiple, distant, and associated semantic alternatives would facilitate the priming of word pairs that are mediated by a common concept (e.g., ‘drink’ primed by ‘soap’ through the associated concept ‘water’). However, the authors did not observe any specific advantage on such word pairs when presented to the left visual field (i.e., to the RH).

A qualitative difference in the semantic organization between the hemispheres has been proposed by Koivisto and Laine (1995). That is, the right hemisphere is capable of processing locative relations (e.g., \textit{priest-church}) compared to the left hemisphere which processed the coordinate (e.g., \textit{coffee-tea}) relations (Koivisto & Laine, 1995). In a similar study, Weisbrod and associates (Weisbrod, Maier, Harig, Himmelsbach, & Spitzer, 1998) investigated how direct and indirect semantic priming is mediated by the left and the right hemispheres. These investigators presented \textit{directly-related}, \textit{indirectly-related}, and \textit{non-related targets} to either visual half-field preceded by a centrally presented prime word. Priming effects were obtained for directly-related targets in either hemisphere. Indirectly-related words, in contrast, were facilitated only in the right hemisphere. Further, the left, but
not the right hemisphere, showed a tendency to inhibit the indirectly related targets supporting the previous arguments (e.g., Drews, 1987). Koivisto (1998), in yet another study, investigated the relationship between the nature of priming (i.e., automatic vs. post-lexical-semantic) and the cerebral hemispheres using the DVF paradigm in normal subjects and demonstrated that the right hemisphere was capable of performing post-lexical matching. Subsequently, Collins (1999) compared the automatic and strategic processing in the right and left hemispheres and reported that both hemispheres were capable of automatic processing, whereas, only the left was able to perform strategic processing of lexical items.

The presence of an intact left hemisphere was hypothesized to underestimate the lexico-semantic processing capabilities of the right hemisphere (Querne, Eustache, & Faure, 2000). To test this hypothesis, Querne et al. (2000) overloaded their (normal) subjects’ left hemisphere with heavy verbal memory load and presented a tachistoscopic-based lexical-decision task, where, the targets were presented to the left visual field (i.e., to the RH). The results of this investigation showed that when the left hemisphere was overloaded, the right showed improved performance. Thus, Querne et al. (2000) argued that the right hemisphere possessed a larger lexico-semantic network. Faust and Lavidor (2003) investigated potential for divergent processing in either hemisphere through a lexical ambiguity resolution task. The results revealed that the left hemisphere showed an advantage to semantically convergent primes, whereas, the right showed benefit from semantically divergent primes (Faust & Lavidor, 2003). In the same year, Livesay and Burgess (2003) also showed a comparable pattern of results for mediated prime-target pairs that were likely to be experienced in the same context (e.g., bat and bounce mediated by a common context ball) and for those that were not (e.g., summer and snow, mediated by winter). Equivalent amounts of mediated priming (relative to an unrelated baseline) were seen in the two VFs for both types of pairs. From this experiment, Livesay and Burgess (2003) argued that the right hemisphere is capable of processing semantic concepts that are distantly associated. Evidence for distributed representation of semantic concepts has also been reported by Deacon, Grose-Fifer, Yang, Stanick, Hewitt, and Dynowska (2004). These authors investigated the semantic representation in the left and right cerebral hemispheres using the DVF technique in a group of normal subjects. In the first of the two experiments, those items that were associatively related, but that did not share features of semantic categories (e.g., honey-bee), produced
priming when delivered to the LH (RVF), but not to the RH (LVF). The second experiment showed that those items that shared semantic features but were neither associates nor the same category members (e.g., wig-mop) produced priming in the RH (LVF), but not in the LH (RVF). Together these two experiments showed that in the right hemisphere, semantic memories are represented in a distributed manner, on the basis of the semantic features, whereas, in the left hemisphere, the representations are connected via associative links.

It is apparent from the investigations employing DVF technique in normal subjects that the right hemisphere is capable of processing the lexico-semantic aspect of language in several ways. For instance, the RH, along with LH, is capable of processing phonologically similar words as well as the post-lexical semantic information, thus complementing the function of the latter hemisphere. Further, certain studies have shown that, distinct from the LH, RH is capable of processing inter-conceptual relations aiding the holistic processing, automatic access of semantic category information, as well as sustaining the activation of remotely- or distantly-associated lexical items. Together these findings from normal subjects show that RH contributes to the lexico-semantic processing either independently or by supporting the left hemisphere in the selection of remote or distant semantic associates. In this context, alternate evidence emerging from other tasks and paradigms is worthwhile considering. Therefore, in the following section, evidence for right hemispheric contribution to lexico-semantic skills from the widely-employed verbal fluency task is presented.

2.1.8. Verbal fluency studies in RH

Verbal fluency tasks have also been proved to be a reliable means of assessing the lexico-semantic processing capabilities. Typically, the verbal fluency task requires subjects to generate exemplars of a given category within a time limit (usually one minute) (Troyer, Moscovitch, & Winocur, 1997). The categories may be phonemic (i.e., words starting with a given phoneme) or semantic (i.e., words from a given semantic category, e.g., animals) (Venegas & Mansur, 2011). The responses are scored for the number of accurate exemplars retrieved under each category (Troyer et al., 1997). Unlike picture naming and other convergent tasks that limit the response set, verbal fluency tasks are designed to activate a broad semantic field (Koren, Kofman, & Berger, 2005). It has been shown that both measures...
of verbal fluency are sensitive to brain damage (Butters, Granholm, Salmon, Grant, & Wolfe, 1987; Janowsky, Shimamura, Kritchevsky, & Squire, 1989; Stuss et al., 1998).

Several investigations in the past have shown that subjects with RHD compared to the non-brain damaged show reduced verbal fluency scores in response to common semantic categories (Diggs & Basili, 1987; Hough, Pabst, & DeMarco, 1994; Joanette & Goulet, 1986). However, in general, these studies have shown that subjects with RHD perform better compared to those with LHD on verbal fluency tasks (Diggs & Basili, 1987).

Using an unconstrained naming task proposed by Le Blanc and Joanette (1996), Beausoleil, Fortin, Le Blanc, and Joanette (2003) investigated the role of right hemisphere in lexico-semantic skills. The participants of this study were instructed to list out maximum number of words without forming a sentence (Beausoleil et al., 2003). Further, no specific criteria, that is, orthographic (phonemic) or semantic, were provided (i.e., unconstrained). Beausoleil et al. (2003) administered this task to a group of 30 RHD, 30 LHD, and 30 normal subjects and analyzed the performance both quantitatively (total number of items retrieved accurately) and qualitatively (i.e., time course analysis, number of semantic categories, and number of words per semantic category). The results of this investigation showed that the clinical population produced fewer words than normal counterparts. Further, the LHD group produced fewer semantic categories than normal and RHD subjects, and irrespective of the group membership, all the participants produced more words at the beginning of the trial. In this study, subjects with RHD produced fewer exemplars than their control counterparts.

Within the verbal fluency tasks, Joanette and Goulet (1986) argued that the semantic fluency task has been more sensitive to the right hemisphere damage compared to the phoneme fluency task. These authors compared the verbal fluency skills of 35 right brain-damaged subjects with that of 20 normal subjects and reported that the right brain-damaged subjects showed marked reduction in the exemplars generated under the semantic verbal fluency, but not under the phoneme fluency task. However, there have been several other studies reporting reduction in verbal fluency performance under orthographic (i.e., phonemic) criterion (e.g., Adamovich & Henderson, 1984; Albert & Sandson, 1986; Bolter, Long, & Wagner, 1983). With respect to the semantic fluency, Villardita (1987) provided evidence for right hemispheric contribution. The author required two groups of subjects (24 right brain-
damaged & 20 normal) to perform an immediate and delayed recall of two lists of words subsequent to the initial presentation of these lists to the participants. Among the word lists, the first included 15 semantically unrelated words and the second included 15 two-syllable words that belonged to one of three categories. The results of this study demonstrated no difference between the two subject groups, either in the immediate or in the delayed recall condition of the semantically unrelated words. However, for the category related words, subjects with RHD exhibited significant difficulty during the immediate recall condition. Varley’s (1995) comparison of RHD group with NBD group also showed significantly poor performance in the former group on various categories that included animals, furniture, colors, fruits, and time units. Comparable result from subjects with temporal lobe epilepsy (TLE) has been reported by N’Kaoua, Lespinet, Barsse, Rougier, and Claverie (2001). That is, subjects with right TLE performed poorly on verbal fluency tasks (letter, phonetic, & semantic) compared to normal participants. The results of this study also were in accordance with the findings of Diggs and Basili (1987) that people with LHD performed poorly compared to those with RHD on these tasks.

Certain methodological issues have been raised in the administration of verbal fluency task, specifically in phoneme fluency tasks. For instance, quite often, this (phoneme fluency) task is employed subsequent to the semantic fluency tasks in the clinical practice (Goulet, Joanette, Sabourin, & Giroux, 1997). In the light of Lezak’s (1983) proposal that the fatigability associated with the brain damage may influence the task performance, Goulet et al. (1997) performed a series of verbal fluency tasks employing both semantic and phonemic criteria in a group of 15 subjects with RHD. These authors hypothesized that by randomizing the order of semantic and phonemic fluency criteria, previously reported advantage for semantic as opposed to the phonemic verbal fluency task may be eliminated. Interestingly, the results proved their hypothesis, which, in turn, highlighted the need for randomized presentation of the semantic and phonemic fluency tasks in subject with RHD.

Variations from the traditional means of analysis (i.e., by counting the number of accurate exemplars generated during the given time) have provided additional insights into the lexico-semantic processing in people with brain damage. For example, Joanette, Goutlet, and Le Dorze (1988) analyzed the error pattern as well as the time course of item retrieval in their earlier study (Joanette & Goulet, 1986). The results of error analysis did not show any
difference between the right RHD and control groups in terms of the number of errors produced as well as in the error patterns. However, the analysis of the time course of item retrieval showed that the right brain-damaged group showed reduction in semantic verbal fluency only after 30 seconds of one minute response time. From this observation, Joanette et al. (1988) argued that the reduction of word production in right brain-damaged subjects is not the consequence of any nonspecific factors such as perseveration or spontaneity. Rather, it reflected problems with less automatic exploration of the semantic field (Joanette et al., 1998).

In general, the verbal fluency tasks, that are purported to measure the lexico-semantic skills, have shown that subjects with RHD exhibit apparent deficits in the retrieval of category exemplars, more specifically from semantic categories. Additionally, attempts to circumvent the methodological issues in the administration as well as the application of qualitative methods to analyze the data have all provided evidence for RH’s contribution to lexico-semantic skills. Yet, studies, in general, have shown that subjects with RHD as a group, is less impaired than those with LHD on verbal fluency skills.

The foregoing sections of the review provide both general and specific evidence for and occasionally against the role of RH in language processing from various populations (e.g., those with callosotomy, hemispherectomy, aphasia, as well as from those recovering from aphasia and from normal participants). In the next few sections, the RH’s role in the processing of specific categories of knowledge, including emotions, colors, and famous faces is reviewed.

2.1.9. Category-specific deficits and right hemisphere

The seminal works of Warrington and colleagues (Warrington & McCarthy, 1983, 1987, 1994; Warrington & Shallice, 1984) on category-specific deficits have revealed that knowledge about the entities in the world is categorically organized in the human brain. To date, deficits in the processing of several specific categories (e.g., animals, fruits, natural objects, man-made objects etc.) have been documented in subjects with left brain damage (Moore & Price, 1999) and a few among them in subjects with right hemisphere damage. In the following section, a brief review of such studies is presented.
Specifically, in the LHD population, anterior lesions have been proposed to lead to verb processing deficits, whereas, posterior (i.e., temporo-parietal) lesions have been associated with noun processing deficits (Tyler, Russell, Fadili, & Moss, 2001). Neininger and Pulvermüller (2003) reported similar findings on subjects with RHD. The right hemisphere’s category-specific processing potential has also been investigated in normal participants using DVF technique. For instance, Pilgrim, Moss, and Tyler (2005) examined the hemispheric differences in the representation and/or processing of concepts from living/nonliving domains of knowledge. Based on previous research, these authors predicted processing disadvantage for concepts relating to the nonliving entities with preserved processing of living entities. The results of this experiment apparently showed a disadvantage for nonliving entities in the left visual field (right hemisphere). That is, the subjects showed increased reaction times as well as higher error rates when the pictures were presented to the right hemisphere, revealing the quality of the semantic processing in the hemisphere.

In a recent meta-analysis, Chouinard and Goodale (2010) investigated the category-specific neural processing underlying naming pictures and tools and revealed that naming animals and tools involved distinct and disseminated networks in the brain. Their result showed maximum activations during animal naming in the frontal lobes, whereas, tool naming showed heightened activations in the ventral stream. In this study, along with several left hemispheric areas, certain right hemispheric areas also showed activations during both tasks. Specifically, while naming animals, activations were found in right rectus and uncus gyri. Comparison of studies that addressed animal vs. tool naming showed activations in the right fusiform gyrus as well as in the right middle occipital gyrus, in addition to several left hemispheric areas, while naming animals. It is, therefore, apparent from this meta-analysis that, a few right hemispheric areas are involved in the processing of names of animals.

Although the category-specific deficits have overwhelmingly been reported in subjects with LHD, relatively recent studies show that subjects with RHD also exhibit such deficits. These observations, therefore, substantiate the RH’s role in lexico-semantic processing. In the following section, the role of RH in the processing of yet another specific domain of knowledge – i.e., semantic information about the face – is reviewed.
2.1.10. Right hemisphere and semantic information of the face

The ability to recognize people and recall their names plays a fundamental role in social communication (Campanella, Joassin, Rossion, De Volder, Bruyer, & Crommelinck, 2001) and the way in which the brain organizes the semantic information associated with people is a debatable issue. In the last 25 years, several studies have focused on the phenomenon of semantic face priming. Two models (Ellis, 1983; Rhodes, 1985) have been proposed to explain the various aspects of face processing in the hemispheres. Both models propose distinct patterns of lateralization for the perceptual and semantic aspects of face processing (Vladeanu & Bourne, 2009). According to these models, the perceptual aspects are lateralized to the right hemisphere and the semantic aspects to a left greater-than right lateralization (Vladeanu & Bourne, 2009).

Evidence from the clinical population supports the distinct roles of left and right hemispheres in face processing. For instance, patients with left hemisphere lesions have been found to be impaired at accessing semantic information, whereas, those with comparable lesion to the right hemisphere did not exhibit such difficulties (e.g., Warrington & Taylor, 1978). Sergent and Villemure (1989) reported the case of a right hemisphere hemidecorticate subject whose face processing abilities were disrupted, but who was able to access semantic information about people and their names. Although such evidence from clinical population suggest that the semantic information is lateralized to the left hemisphere, studies in non-clinical population have provided contradictory findings. For instance, two studies (Kampf, Nachson, & Babkoff, 2002; Sergent, Ohta, & Macdonald, 1992) investigated the lateralization of face-related semantic information (i.e., the occupation of the person whose face is shown) using a DVF task. In Sergent et al.’s (1992) study, a right visual field advantage (in terms of speed and accuracy) was observed, which in turn, supported the evidence from the clinical population. In contrast, Kampf et al.’s (2002) findings did not show any visual field effects. From this observation, Kampf et al. (2002) argued that the semantic information about the face is distributed bihemispherically. Subsequent ERP investigations have provided supportive evidence for the bihemispheric distribution of semantic information of the face (Huddy, Schweinberger, Jentzsch, & Burton, 2003). Interestingly, two PET studies have found different patterns of distribution, with slightly more activation in the right hemisphere.
(Sergent & Signoret, 1992; Sergent et al., 1992). Recently, Gainotti (2007) reviewed the research pertaining to the recognition of famous people (face) in subjects with brain damage and argued that different patterns of impaired recognition of familiar people can be observed in patients with right and left anterior temporal pathology. These patterns involved the loss of feelings of familiarity and of person-specific information retrieval in right temporal lobe damage and an impairment in name retrieval in those with left anterior temporal lobe damage (Gainotti, 2007). Further, quite recently, Neilson and colleagues (2010) reported from their event-related fMRI study that the activations associated with the recognition of famous faces were predominantly right-lateralized, whereas, the activations concerned with famous names were largely left-lateralized. Thus, although there have been discrepant results, the general assumption is that the damage to the right hemisphere leads to face recognition deficits, whereas, the inability to retrieve the names of people was associated with left temporal lobe damage.

2.1.11. Right hemisphere and color processing

Though the role of the right hemisphere in various higher order cognitive processes such as face recognition (Barton, Press, Keenan, & O’Conner, 2002; Kanwisher, McDermott, & Chun, 1997) and visuospatial functions (Corballis, 2003) is well-documented, the color processing capability of this hemisphere was rarely investigated. In this context, Sasaki, Morimoto, Nishio, and Matsuura (2007) designed a study which included three experiments. The first experiment was designed to establish the reaction time difference between the right and left handedness in their participants (normal subjects). In the second experiment, these researchers found that the processing time for chromatic stimuli was 17s shorter in the right hemisphere compared to the left in right-handed subjects. However, their left-handed subjects failed to reveal such a superiority of the RH. Additionally, when achromatic stimuli were presented, neither right-handed nor left-handed subjects showed any processing advantage. From these observations, Sasaki et al. (2007) argued that the right hemisphere processes the colors faster than the left hemisphere. It may be noted that the color processing skills in subjects with RHD have not been explicitly reported in the literature.

2.1.12. Right hemisphere and emotional expressions

Clinical and experimental studies reveal that the right hemisphere plays a vital role in the processing of emotions (Van Strien & Morpurgo, 1992; Borod, 1993; Darby, 1993).
DeKosky and colleagues (1980) reported that right hemispheric lesions could lead to difficulty in processing emotional faces. This has been corroborated by Fried and colleagues (1997), who, in their electrocortical stimulation study, found that stimulation of the right temporal visual-related cortices can disrupt the processing of facial expressions. Additionally, selective impairments in recognizing facial expression, sparing the ability to recognize the identity have been reported in subjects with RHD (Bowers, Bauer, Coslett, & Heilman, 1985). Rapcsak and colleagues (Rapcsak, Kaszniak, & Rubens, 1989; Rapcsak, Comer, & Rubens, 1993) have reported anomia for emotional facial expression in subjects with RHD. In 1996, Adolphs, Damasio, Tranel, and Damasio studied facial recognition of six basic emotions (happiness, surprise, fear, anger, disgust, & sadness) in a group of 37 subjects with brain damage including 22 with RHD. Their results revealed a differential effect of the type of emotions on task performance. That is, emotions expressing happiness were recognized by all participants. However, those depicting negative emotions (e.g., fear, sadness) incurred processing difficulty in some participants. Thus, Adolph et al.’s (1996) observations as well as the previous findings support the role of right hemisphere in the processing of emotional facial expressions.

The foregoing sections of this chapter compile the pertinent studies in various categories of knowledge and provide certain indications on the role of the right hemisphere in the processing of such information. It is also apparent that there is, in general, a dearth of studies in subjects with RHD in these areas, which in turn, call for more investigations. The review now focuses on evidence for the right hemispheric linguistic processing from today’s state-of-the-art, functional neuroimaging techniques.

2.1.13. Functional imaging studies and right hemisphere language

Functional neuroimaging methods provide a potential source of novel data on language organization/processing both in the intact and damaged brain (Petersen, Fox, Posner, Mintun, & Raichle, 1998; Démonet et al., 1992; Bottini et al., 1994). Within the realm of functional neuroimaging, several techniques have been employed to investigate the brain-language relationship such as functional magnetic resonance imaging (fMRI), Positron Emission Tomography (PET), Magnetoencephalogram (MEG), to name a few.
Contrary to the ‘lesion-deficit’ approach that identified the core areas of language processing in the left hemisphere (Price, 2000), the functional neuroimaging techniques have shown activations in the right hemisphere (in addition to the predominant left hemispheric activations) during language processing tasks such as picture naming. In the following section, a brief review of studies pertaining to the right hemispheric activation during lexico-semantic processing is presented.

While naming the pictures of animals and tools, normal subjects show activations in different locations in the brain (Perani, Cappa, Bettinardi, Bressi, Gorno-Tempini, & Fazio, 1995). In Perani et al.’s (1995) PET study, processing animal names activated bilateral inferior temporo-occipital areas, whereas, processing tool names activated left dorsolateral frontal cortex and middle temporal gyrus. In a subsequent study, Tranel, Damasio, and Damasio (1997) reported that right medial temporo-occipital lobe lesion resulted in impaired knowledge about animals. Tranel et al., (1997) also showed that the left perisylvian lesion was associated with impaired processing of non-living entities. These complementary findings obtained from both normal and disordered population show that the processing of animal knowledge activates the right hemispheric temporo-occipital areas in addition to their left counterparts. Several other functional neuroimaging investigations have reported of activations in the right hemisphere, in addition to the left during language processing (e.g.s., Binder, Frost, Hammeke, Cox, Rao, & Prieto, 1997; Brannen, Badie, Moritz, Quigley, Meyerand, & Haughton, 2001; Cao, Vikingstad, George, Johnson, & Welch, 1999; Saykin et al., 1999).

In a study that combined the verbal fluency tasks and functional MRI, Sztatkowska, Grabowska, and Szymańska (2000) reported that the phonological fluency task is supported by the left dorsolateral prefrontal cortex and the semantic verbal fluency task revealed wider prefrontal activations including both the left and right dorsolateral and the right ventromedial cortices, respectively. Further, linguistic tasks such as verbal fluency, verb generation, and picture naming (Maldjian, Laurienti, Driskill, & Burdette, 2003; Rutten, Ramsay, van Rijen, Alpherts, & van Veelan, 2002) have all shown to activate the right hemisphere in addition to the left.
Right hemispheric activation has been noticed in investigations employing tasks distinct from the traditional tasks such as picture naming and verbal fluency. For example, Farias, Harrington, Broomand, and Seyal (2005) employed the responsive naming task in addition to the visual confrontation naming task in a group of 20 healthy participants. Their results revealed activations in the right hemisphere in addition to the left during both naming tasks. More interestingly, Farias et al. (2005) noted that the responsive naming task involved several other (including the right hemispheric) areas compared to the confrontation naming task. In yet another investigation, Jeon, Lee, Kim, and Cho (2009) compared the brain activation patterns associated with antonyms, synonyms, and non-words. These authors found that both antonyms and synonyms activated a region in the left middle frontal gyrus, whereas, the nonwords activated bilateral inferior frontal gyrus as well as left occipital gyrus. Additionally, task-specific activations were also noticed in the population. For instance, while processing antonyms, the activation extended more to the anterior areas, whereas, while processing synonyms, it extended more laterally in the left hemisphere. Further, the synonym task also revealed right hemispheric activations in the fusiform gyrus. Jeon et al. (2009) suggested that the activations in the neural areas common to both antonyms and synonyms may indicate the mental processes shared by these tasks such as engaging the semantically related parts for the word search. On the other hand, Jeon et al. (2009) attributed the distinct activation patterns to additional processing strategies such as reversal of polarity while retrieving antonyms. It is, therefore, apparent from this study that processing of antonyms and synonyms exhibit similarities as well as differences in the underlying neural substrates.

Despite the mounting evidence for the right hemispheric contributions to the lexicosemantic tasks, Fiebach and Friederici (2003) provided counterevidence from their event-related fMRI study. They argued that processing of concrete words, as opposed to the previous claims, primarily involved the left hemispheric linguistic cortex. Further, a meta-analysis by Indefrey and Levelt (2004) provided only moderate evidence for the right hemispheric activation during lexicosemantic processing. Of the 82 neuroimaging studies reviewed, these authors reported activations in the right hemispheric areas only in approximately half of the studies. The functional neuroimaging investigations in normal subjects during lexicosemantic processing, thus, provide moderate evidence for the right hemisphere’s role by means of the activations in certain right hemispheric areas. Additionally,
the activations in the right hemisphere were apparently low in quantity as well as in consistency, making such results difficult to interpret. Further, it is also not clear what these activations tell us about the role of such areas, in the light of the arguments that the activations could indicate either a facilitatory or an inhibitory activity (Aue, Lavelle, & Cacioppo, 2009).

In addition most of the functional neuroimaging studies were designed to explore research questions other than lexico-semantic processing. Hence, the contribution of these findings to the ongoing debate is, rather questionable.

2.1.14. Event-Related Potential (ERP) studies

Akin to the functional neuroimaging techniques that tap the metabolic activities of the brain, the event-related potentials (ERPs) have also provided valuable insights about the brain-language relationship. ERPs are specific time-locked potentials picked up from the scalp subsequent to the presentation of stimulus (Rodden & Stemmer, 2008).

Evidence for the right hemispheric participation in lexico-semantic processing using ERP technique was initially reported by Hagoort et al. (1996). These authors found that non-aphasic RHD subjects were impaired in the processing of semantically more distant relationships, thus rendering evidence for the participation of right hemisphere in divergent lexico-semantic processing. It is proposed that the right hemisphere contributes to the generation of remote associations with words (Abdullaev & Posner, 1997). For instance, when their participants were required to generate a novel use for a given noun, Abdullaev and Posner (1997) observed potentials in the right temporo-parietal areas in addition to the left temporo-parietal and frontal areas. Interestingly, this right hemisphere ERP effect was not present when a common use had to be generated. By combining the ERP with lexical decision task, Kiefer and colleagues (1998) observed priming effect for indirectly related words only in the right hemisphere, whereas, directly related word pairs elicited potentials from both hemispheres thus revealing the RH’s potential in distant semantic relations. In Federmeier and Kutas’ (2002) study, the N400 effect was investigated while normal participants read sentence pairs ending with the lateralized presentation of three target types such as: (1) expected pictures; (2) unexpected pictures from the same semantic category; and (3) unexpected
pictures from an unexpected category. The authors observed an increased negativity when contextually unexpected pictures were presented to either visual field (Federmeier & Kutas, 2002), thus revealing the participation of the right hemisphere in lexico-semantic processing. However, the ERP findings from Atchley and Kwasny’s (2003) study did not support the lexico-semantic processing capabilities of the right hemisphere. That is, Atchley and Kwasny (2003) did not observe the N400 effect when the stimuli were presented to the left visual field (i.e., RH) although this effect was apparent when the stimuli were presented to the right visual field (i.e., LH).

The growing application of magnetoencephalography (MEG) in the exploration of brain-language relationship has yielded some evidence for right hemisphere participation in language processing. For instance, Zouridakis, Simos, Breier, and Papanicolaou (1998) employed the MEG technique to assess the functional brain asymmetry while a group of 11 normal subjects performed a linguistic (word recognition) and non-linguistic (face recognition) task. Their results showed that MEG activation in the left hemisphere was apparently double the magnitude of that seen in the right hemisphere during word recognition task. The face recognition task, however, showed symmetrical activations in bilateral occipital lobes. In yet another experiment, Cornelissen and co-workers (Cornelissen, Laine, Renvall, Saarinen, Martin, & Salmelin, 2004) investigated the cortical dynamics while a group of five normal young right-handed adults learnt new names for new objects. There was substantial MEG activation seen in the left parietal area. Interestingly, two of their participants (4 & 5) showed right hemispheric MEG focus. Recently, more direct evidence for right hemisphere’s participation in lexico-semantic processing was provided by Chan, Halgren, Marikovic, and Cash (2011) from their EEG and MEG recordings of subjects performing a language task designed to access the lexico-semantic knowledge. This study showed that accessing the semantic information activated several brain regions bilaterally including anterior temporal, inferior frontal, as well as left inferior temporal-occipital regions.

The application of functional neuroimaging techniques has paved a novel avenue to explore the contribution of right hemisphere in lexico-semantic processing. Though, these techniques, in general, have shown the superiority of left hemisphere in linguistic tasks, the right hemispheric activations have also been reported, albeit, occasionally. Yet, in general,
most of the investigations reporting right hemispheric activations have revealed only moderate activation.

2.1.15. Evidence from the combinatorial approaches

Combinatorial approaches, as the name suggests, combine two or more techniques to investigate the experimental questions and the findings from such investigations are considered to be scientifically more rigorous than those derived from any single technique. For instance, Kandhadai and Federmeier (2008) combined the DVF technique with ERP (N400) to investigate the role of the hemispheres in semantic processing. These authors presented primes with ambiguous and unambiguous word triplets to each visual field and simultaneously monitored the N400 effect. The results supported the role of right hemisphere in lexico-semantic processing as the authors did not find any difference in the pattern of measured ERP between the hemispheres. In yet another recent study that combined dichotic listening and fMRI techniques (the subjects performed sentence completion task while in the scanner), van Ettinger-Veenstra and colleagues (2010) provided evidence for the role of right-hemispheric counterparts of Broca’s and Wernicke’s areas in language processing. It is also proposed that the right hemisphere links the language input to the sensory imagery as well as to multiple, distinct, cognitive, and neural sources for concrete nouns as observed in an investigation that combined DVF and ERP techniques (Huang, Lee, & Federmeier, 2010). Thus, the combinatorial approaches, a relatively new method of research to improve the scientific vigorousness of the observations, have provided results suggestive of the right hemisphere’s role in lexico-semantic processing.

2.2. General summary: Right hemisphere in lexico-semantic processing

The foregoing sections reviewed the pertinent studies that employed various populations and techniques in the investigations of lexico-semantic processing skills of the right hemisphere. It is apparent from these studies that the role of right hemisphere in lexico-semantic processing remains equivocal. These disparate findings may be attributed to the variability in the population (i.e., RHD, LHD with aphasia, normals, callosotomees, hemispherectomees), techniques (i.e., Wada, Divided Visual Field, functional neuroimaging, event-related potentials, MEG), as well as to the tasks employed in the previous
investigations. In this context, the following section focuses on the tasks employed in the previous investigations of subjects with RHD – a potential population from which direct inferences on lexico-semantic processing capabilities of the right hemisphere could be obtained (Joanette et al., 1990) – in order to understand the disparate evidence obtained from this population. This section is followed by the prevailing explanatory hypotheses on lexico-semantic processing by the right hemisphere, which in turn, is followed by brief reviews on the tasks employed in the previous research as well as the analyses of naming errors. Finally, a critical evaluation of the various techniques and population employed in the past research to highlight the need for further research in this area is presented.

2.3. Tasks employed in the past research

It is widely accepted that the assessment tools for aphasia are often insensitive to detect the deficits in the processing of linguistic functions in people with RHD (Abusamra et al., 2009; Bryan, 1995). This is because the individuals with RHD do not present typical language alterations such as those seen in aphasic subjects (Myers, 1999). Therefore, the evaluation process for linguistic disorders in individuals with RHD must include the use of instruments constructed specifically to examine communicative processes related to the right hemisphere (Turgeon & Macoir, 2008). The research in the past employed a variety of tasks that often varied considerably across the studies as is apparent from the brief review presented below.

In one of the earliest studies, Coughlan and Warrington (1978) used a battery of nine tests to assess the word comprehension and word retrieval skills in subjects with localized cerebral lesions. Their battery included tasks like intelligence quotient (IQ), phoneme discrimination, articulation, WAIS vocabulary subtest, Modified Token Test, Modified Peabody Test, Auditory choice vocabulary test, object naming, and description naming. The object naming subtest included an array of 15 objects, where, the participants were required to name each item when pointed out by the examiner. In the description naming subtest, the subjects were asked to name 15 objects from their verbal descriptions. In a subsequent investigation, Rivers and Love (1980) employed a battery of seven tests that included word reading test, word definition test, word context test, picture stimuli test, fragmented picture naming test, printed sentence construction test, and oral story telling test to assess the
language performance in three groups of 10 subjects each, including one RHD group. Within this battery, the tasks like word definition test, picture stimuli test, and the fragmented picture tests were meant to assess the lexical retrieval skills in their participants. In Joanette et al.’s (1983) study, the Protocole d’examen de la function linguistique (PEFL, Joanette, 2004) that included 20 subtests of which tests such as naming, lexical evocation (i.e., verbal fluency), antonyms, sentence completion, closure, and definitions were specifically aimed at the examination of lexical processing. Varley (1993) employed single word lexical retrieval task that included: a) reference production test (i.e., picture labeling), and b) sense-production test (i.e., production of an opposite item to a stimulus) in the assessment of brain damaged subjects including RHD. In addition to these tasks that elicit the retrieval of lexical items, several additional tasks that tap the lexico-semantic processing skills such as, for instance, word judgment (Brownell et al., 1984; Chiarello & Church, 1986) and priming tasks (Chiarello et al., 1990) have also been used in the previous investigations in the RHD population.

It is apparent that there is a considerable variability in the tasks employed in the assessment of lexico-semantic processing skills of subjects with RHD. Although some authors have used standardized instruments (e.g., Joanette et al., 1983), others have used custom-made assessment instruments. The disparities reported in the literature on the role of right hemisphere in lexico-semantic processing skills may have arisen from the variability in the assessment procedure or task employed in the past. Additionally, considering the fact that the lexico-semantic processing capabilities of the right hemisphere are arguably weak, assessing this population with a comprehensive set of lexical retrieval tasks may provide more reliable and valid outcomes. The present study focuses on this assumption. Before proceeding to the critical evaluation of the techniques and population that supports the need for further investigation into the lexical retrieval skills in subjects with RHD, in the following section, a brief note on the analysis of naming errors in brain damaged population with special reference to subjects with RHD is presented.
2.4. Analysis of naming errors

Naming errors are commonly observed in several classes of brain-damaged patients such as people with aphasia, dementia, traumatic brain injury, to name a few (Rohrer, Knight, Warren, Fox, Rosor, & Warren, 2008).

“The confrontation naming task is one of the typical tests conducted by the neuropsychologists or speech language pathologists. In this test, the subject is asked to pronounce the names of targets presented to him, aiming at as natural and correct pronunciation as possible. In this test, the targets are common things of everyday life so that an average person can easily recognize them. In the confrontation naming tests, the target objects are represented by clear and simple pictures. These pictures… are tested beforehand with a group of healthy subjects to ensure that the figures are so fully obvious that they cannot be misperceived” (Juhola, Vauhkonen, & Laine, 1994, p. 1).

While assessing the naming performance, the retrieval of an item’s name indicates that the subject has accessed the conceptual-semantic and lexical information accurately (Nicholas, Obler, Au, & Albert, 1996). However, an absence of response to the stimulus provides no clues to the level at which the naming difficulty originates (Nicholas et al., 1996). Most naming failures fall between an accurate and ‘no response’ and by carefully analyzing the error patterns (that fall between these two extremes), one could infer the stage of lexical retrieval at which the naming failure arises (Nicholas et al., 1996).

Although, qualitative analyses of the error pattern have often been performed in people with aphasia, dementia, and normal aging, such attempts are apparently lacking in investigations of RHD population. In a well-known study, Hodges, Salmon, and Butters (1991) conducted a fine-grained analysis of error responses in patients with Alzheimer’s disease and Huntington’s disease as well as in control subjects, using categories that distinguished errors that were category names (‘animal’ for beaver), within-category semantic errors (‘skunk’ for beaver), semantic associates (‘dam’ for beaver) and semantic circumlocutions (‘an animal that builds dams’ for beaver). Hodges et al. (1991) interpreted
that certain types of semantic errors reflected a more serious disturbance of semantic knowledge than other types. For example, superordinate (e.g., *pear* – *fruit*) responses were interpreted to imply that only broad category membership knowledge is accessed.

In a recent study, Corina and colleagues (Corina, Loudermilk, Detwiler, Martin, Brinkley, & Ojemann, 2010) provided a scheme of error classification taking into account certain previous proposals (Snodgrass & Vanderwart, 1980; Nickels, 2001; Goodglass & Kaplan, 1972; Dell, Schwartz, Martin, Saffran, & Gagnon, 2000). Corina et al. (2010) classified the errors primarily into: a) *semantic paraphasias*; b) *circumlocution errors*; c) *phonological paraphasias*; d) *neologisms*; e) *performance errors*; and f) *no-response errors*.

Semantic paraphasia refers to the substitution of a semantically related or associated word for the target word (e.g., ‘*cow*’ for ‘*horse*’). Corina et al. (2010) classified semantic paraphasias into one of the six categories as follows:

Coordinate – a response that is a different exemplar from the same category (e.g., *lion* → *tiger*); associate – a response that is related to the target, but which does not share semantic features with the target (e.g., *foot* → *shoe*); superordinate – a hyponym response in which a more general term is produced *in lieu* of the basic term (e.g., *pear* → *fruit*); subordinate – a hypernym response in which a term more specific than the basic level is produced (e.g., *flower* → *rose*); and visual – a response that has a vague or tenuous semantic relationship to the target but which shares visual features (e.g., *nail* → *knife*) (Corina et al., 2010, p. 103).

Additionally, these authors described various types of semantic errors as below:

The circumlocution errors are responses in which the subject talks about or around the target *in lieu* of naming it. The subject may describe attributes of the target, describe its use (e.g., *chair* → *sit down*), or talk about the target in a roundabout manner (e.g., *shoe* → *cover foot*). Circumlocutory errors differ from semantic paraphasias in that they are typically multiword responses for a single word (e.g., *couch* → ‘*something I lay on besides my bed*’) (Corina et al., 2010, p. 103).
Goodglass and Kaplan (1972) differentiated semantic paraphasia from circumlocution on the basis of volition, that is, the former is produced unintentionally, whereas, the latter is produced deliberately. Phonological paraphasias, according to Corina et al. are characterized by “unintended phonemic epenthesis, omission, substitution, metathesis, and repetition. Phonological paraphasias differ from neologisms in that the former bears a resemblance to the intended target” (Corina et al., 2010, p. 103). Neologisms are characterized by extreme contamination by unintended sounds (Goodglass & Wingfield, 1997). Neologisms barely resemble their target forms (Dell et al., 2000). Often a criterion of less than 50% phonemic resemblance (Nickels, 2001) is used to differentiate neologisms from phonemic paraphasias.

The verbal fluency tasks (also known as divergent naming tasks), on the other hand, invite a large number of lexical alternatives during the performance. These tasks too, like the confrontation naming tasks (a form of convergent naming task), have a common place in the investigations into the lexico-semantic processing skills of the cerebral hemispheres. Several methods of analysis have been employed in verbal fluency tasks. For instance, Troyer et al. (1997) proposed two measures such as clustering and switching in addition to the correctly retrieved words in the stipulated time (usually 60 seconds). “Clustering refers to the production of words within the semantic or phonemic subcategories and switching indicates the ability to shift between the clusters” (Troyer et al., 1997, p. 140). These authors provided six measures for the analysis of clusters and switches in verbal fluency tasks such as: a) total number of correct words generated in semantic fluency task; b) total number of correct words generated in phoneme fluency task; c) mean cluster size in semantic fluency task; d) mean cluster size in phoneme fluency task; and the number of switches in e) semantic fluency task; and f) phoneme fluency task (Troyer et al., 1997). The total number of correct words generated was calculated as the sum of all words produced, excluding the errors and repetitions under each task and the mean cluster size was calculated by starting with the second word in a cluster (Troyer et al., 1997). That is, a single word was given a cluster size of zero, two words had a cluster size of one, and three words had a cluster size of two, and so forth (Troyer et al., 1997). The mean cluster size was calculated for both phonemic and semantic trials and the number of switches was calculated as the total number of transitions between clusters, including single words (Troyer et al., 1997). Such a detailed analysis was expected to provide greater insights into lexical-semantic processing (Troyer et al., 1997).
Although error analysis is commonly reported in studies of left hemisphere damaged populations, such analysis has seldom been employed in studies investigating the lexico-semantic skills of the RHD population. An exception to this was Joanette et al.’s (1988) study that qualitatively analyzed errors in this population. In their study, Joanette et al. (1988) analyzed the number of errors as well as the error patterns. Further, these authors analyzed the time course of the exemplar generation while their subjects performed the verbal fluency tasks and they found that RHD subjects showed a reduction in verbal fluency only after the initial 30 seconds of the one minute period. It may, however, be noted that the error analysis procedure employed by Joanette et al. (1988) is considerably different from the later proposals of Troyer et al. (1997). In this context, detailed analysis of errors produced by the RHD group using Troyer et al.’s guidelines may yield additional insights into the lexico-semantic processing deficits of people with right hemisphere damage.

2.5. Critical evaluation of the past research

The foregoing survey of literature shows mixed evidence in terms of the right hemisphere’s role in lexico-semantic processing. This equivocal evidence has largely been derived from different populations (people with aphasia and those recovering from aphasia, people with RHD, normal participants, callosotomies, & hemispherectomies) and a variety of techniques (commissurotomy, Wada, DVF, fMRI, ERP, & their combinations) employed in the previous studies. In this context, a critical appraisal of these variables is worthwhile considering.

Two of the early techniques that laid the foundation for the study of the right hemisphere’s linguistic capabilities were: a) commissurotomy and b) intracarotid amobarbital procedure (i.e., Wada technique). As discussed under the pertinent sections of the preceding review, both these techniques are often performed in people with the known risk (e.g., epilepsy) of alterations in the natural organization of hemispheric functions. In addition to this, subjects who undergo commissurotomy may also exhibit post-surgical compensations and, it is unclear whether the pattern of performance in these individuals is a result of plasticity of function of the impaired hemisphere or functional compensation or pathological inhibition from the opposite hemisphere (Zaidel, 1983). Therefore, these studies leave us uncertain on the generality of this evidence to the normally functioning brain.
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Studies on subjects with post-stroke aphasia as well as on those who are recovering from aphasia subsequent to the left hemispheric lesion have shown occasional evidence for the right hemisphere’s linguistic capabilities. However, it is apparent from the literature that such studies do not necessarily provide information on the specific role of right hemisphere in the lexico-semantic processing. For instance, certain studies on subjects with post-stroke aphasia highlight the atypical lateralization of language functions in the cerebral hemispheres as in the case of crossed aphasia (e.g., Bramwell, 1899) or crossed non-aphasia (e.g., Hund-Geordiadis et al., 2001; Krishnan et al., 2009). Further, a major portion of studies employing people with post-stroke aphasia primarily aimed at establishing the relationship between language, handedness, and the lateralization of cerebral functions. Similarly, studies pertaining to the recovery from aphasia strive to delineate the neural mechanisms of language recovery in such subjects. This too, has led to ambiguous findings with a few studies reporting that the left hemisphere peri-lesional areas take over the lost functions (e.g., Warburton, Price, Swinburn, & Wise, 1999) and some other studies suggesting that the homologous areas of the right hemisphere take over the lost functions of the left hemisphere (e.g., Weiller et al., 1995). More recent studies have shown phasic or staged recovery patterns, which alternates between the right and left hemispheres (Saur et al., 2006). Such investigations, therefore, do not provide conclusive evidence either for or against the role of right hemisphere in lexico-semantic processing.

Perhaps, one of the clinical groups from which reliable information pertaining to the role of right hemisphere in lexico-semantic processing skills may be inferred is subjects with RHD (Joanette et al., 1990). The surveyed literature has, however, failed to show concrete and consistent evidence for the role of RH in lexico-semantic processing from this population. One possible reason for the variance in the results may be the lack of uniformity of the tasks employed in such investigations (addressed earlier). At this juncture, an investigation of subjects with right hemisphere damage with a comprehensive set of lexical retrieval tasks may provide affirmative evidence for/against the role of right hemisphere in lexico-semantic processing. The present study finds its root in this assumption.

In addition to the evidence derived from people with brain damage, investigations in normal subjects have also provided evidence for the right hemisphere’s role in lexico-
semantic processing. However, like the evidence from the clinical populations, this is also not without counter-evidence (e.g., Richards & Chiarello, 1995). Thus, by combining the results of studies employing various participant populations, it becomes apparent that the available evidence on the role of right hemisphere in lexico-semantic processing are equivocal and are confounded by counter-evidence.

In addition to the distinct populations, various techniques employed in the previous investigations have also contributed to the mixed evidence on the role of right hemisphere in lexico-semantic processing. The survey of literature shows that the major techniques employed in these investigations were: a) divided visual field; b) hemodynamic-based neuroimaging techniques, and c) event-related potentials. In the following section, a brief critique of these techniques is presented.

In divided visual field (DVF) investigations primes can be presented either laterally in a single visual field or centrally to both visual fields, while targets are presented to each visual field (i.e., contralateral hemisphere) individually (Fassbinder & Tompkins, 2006). Although the current evidence suggests that hemispheric differences in semantic processing can be found for stimuli that vary in semantic distance or strength (e.g.s., Burgess & Simpson, 1988; Koivisto & Laine, 2000), Smith, Chenery, Angwin, and Copland (2009) reminded that the DVF technique continues to produce variable findings regarding the nature of each hemisphere’s role in lexico-semantic processing. Further, Joanette et al. (1990) argued that although the results of DVF studies are informative with respect to the lexical-semantic potential of the right hemisphere, they cannot be taken as evidence of a necessary RH participation in normal processing. Joanette et al. (1990) rather claimed that the demonstration of deficits in tasks requiring the participation of lexical-semantic processes after right hemisphere damage would argue for such an RH contribution.

In the contemporary literature, the hemodynamic-based neuroimaging techniques have richly contributed to the exploration of the functional organization of the cerebral hemispheres. For instance, the functional Magnetic Resonance Imaging (fMRI) and Positron Emission Tomography (PET) are two of the major techniques employed in the exploration of the brain-language relationship (Démonet, Thierry, & Cardebat, 2005). Despite the several advantages of these techniques such as their non-invasiveness, ever-increasing availability, as
well as their capacity to demonstrate the entire network of brain areas engaged when the subject performs a particular task, they also exhibit certain (albeit, frequently-overlooked) limitations (Logothetis, 2008). For instance, all the hemodynamic-based techniques rely on neuronal activity and this is picked up as either an increase in regional glucose metabolism (e.g., PET) or increased blood flow to the local vasculature (e.g., fMRI) (Frye, Rezaie, & Papanicolaou, 2009). Though all these methods, and fMRI in particular, are capable of localizing the brain activations, the measured metabolic responses occur several seconds after the original neurophysiological event is transpired (Frye et al., 2009) and, surprisingly, majority of the investigators ignore these limitations while drawing inferences from such experiments (Logothetis, 2008).

Yet another issue pertaining to the application of fMRI in language research is related to the activations observed in the brain region. Several authors have questioned the nature of activations in fMRI research and even proposed that the observed activations may correspond either to the inhibitory or facilitatory functions of the activated hemispheric areas (for a review, see Crosson et al., 2007). In this context, it is not clear whether the activations in the right hemisphere are facilitatory or inhibitory in nature. It is also worth considering the claims of Henson (2005) that the hemodynamic-based neuroimaging (e.g.s., PET & fMRI) may not reveal useful information to the experimenter. Further, in his extensive critical analysis of functional neuroimaging techniques, Henson (2005) upheld the potential of behavioral investigations in cognitive research.

The fMRI technique suffers from yet another methodological limitation. For instance, Bonakdarpour, Thompson, and Parrish (2005) cautioned that the hemodynamic response function (HRF) – that is, the vascular response induced by neuronal activation in fMRI – may be significantly different in people with altered cerebral blood flow, such as in stroke. They found that the HRF was different from that in normal subjects with a significant delay of the time to peak in both hemispheres. Currently, most fMRI studies model brain-damaged patients’ HRF in comparison with that of the normal subjects and this leads to a potential risk of underestimation of the activation in brain damaged subjects (Bonakdarpour et al., 2005).

The event-related potentials (ERPs) are small voltage fluctuations in the EEG (Picton et al., 2000) that are contemporarily used in the linguistic research. For instance, the N400
component, a negative peak around 400 ms after stimulus onset, has proven to be a useful measure of semantic processing (Federmeier et al., 2008). Yet, it has been proposed that there is sufficient variance in the ERP to capture the psycholinguistic features of interest. Further, the assumptions of purely psycholinguistic variance will be highly obscured in the general ERP paradigm by factors related to working memory demands, attentional allocation, general stimulus, response and task demands (Segalowitz & Chevalier, 1998). Further, in ERP research, a major criticism is that words are presented at a rate that does not correspond to the rate at which natural speech is perceived (Levelt, 1989).

The behavioral investigation of lexical retrieval skills often includes the (visual) oral naming task. In addition to being a common and standard clinical and research tool, it has many virtues that make it a critical instrument for understanding many aspects of human cognition and their neural bases (Gordon, 1997). For instance, the ability to refer to objects by their names may be at the root of human language development, in phylogeny as well as in ontogeny (Terrace, 1985). Further, “naming is a relatively straightforward cognitive operation, whose outlines are relatively well understood and the naming task uses only a limited number of cognitive processing stages and the nature of these stages is fairly well known” (Goodglass & Wingfield, 1997, p. 31). These qualities make the naming task an efficient means of exploring the lexico-semantic skills in subjects with RHD. Broadly, the oral naming tasks may be divided into: a) convergent and b) divergent naming tasks (Worrall & Hickson, 2003). The convergent naming task, as the name indicates, elicits a specific response to an individual stimulus presented to the subject (e.g., visual confrontation naming task) and the divergent naming task, on the other hand, elicits a multitude of responses to the stimulus provided (e.g., verbal fluency task, Worrall & Hickson, 2003). The convergent task requires the respondent to converge onto a specific lexical item from a group of alternatives, whereas, the divergent task requires the respondents to provide more diverging responses. The administration of these two tasks together is expected to provide a comprehensive measure of lexical retrieval skills (Worrall & Hickson, 2003).

Integrating the results of various investigations employing different populations, techniques, and paradigms, it becomes obvious that the role of right hemisphere in lexico-
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Semantic processing is rather debatable. In the following section, the need for specific research in this area of inquiry is presented.

2.6. Need for the study

It is apparent from the foregoing review that the role of right hemisphere in lexico-semantic task has been either directly or indirectly investigated or inferred from studies using various techniques, paradigms, and populations. However, these studies have failed to provide consistent evidence either for or against the hemisphere’s role in lexico-semantic processing skills. In the very first instance, this observation necessitates the re-appraisal of the role of right hemisphere in lexico-semantic processing skills.

Further, even direct investigations in subjects with RHD have provided discrepant results. As the foregoing review highlighted, this may be attributed to the extreme variability in the tasks employed in the previous investigations. It is, therefore, worthwhile examining the lexico-semantic processing skills in this population with a comprehensive set of tasks, which in turn, would circumvent the task-related variability of the previous investigations.

Related to the above issue, a serious methodological limitation of a sizeable number of investigations is the inclusion criteria of subjects with RHD in the previous investigations. It is apparent from several of such investigations that the principal aim of such studies was the lexical retrieval skills in subjects with LHD (i.e., with aphasia). The subjects with RHD were often included as the control or one of the control groups for the purpose of comparison of LHD subjects’ performance. Some studies have even passed the performance of RHD subjects un-discussed. In this context, evidence from such studies, where the principal focus is not on RHD population, shall be interpreted with caution.

The neuroimaging investigations such as fMRI, PET, and MEG often reveal the supplementary neural areas during language processing in addition to the core linguistic areas. As reviewed above, not all studies have shown the involvement of right hemispheric neural areas during the linguistic processing. However, some studies have shown activations in the right hemisphere. Although there are methodological limitations in drawing inferences from studies that are not primarily designed to investigate the lexico-semantic processing of the right hemisphere, the available evidence are only moderate about the right hemisphere’s role
in lexico-semantic processing. Such moderate findings call for more direct and reliable investigations.

It may also be noted that, owing to the historical attribution of language functions to the left hemisphere, there is considerable gap in the number of studies devoted to the right hemisphere damaged population compared to the left. Although the left hemisphere is undoubtedly superior to the right in terms of lexico-semantic processing, various functional dissociations such as category-specific impairments are often revealed with the in-depth and extensive investigations. The report of such dissociations in the RHD population shows that the categories of knowledge in the brain are vulnerable subsequent to the right hemisphere damage. This necessitates further exploration of such interesting and as yet unidentified linguistic processing deficits.

Finally, the informal clinical observations of subjects with RHD have shown poor performance on certain tasks like verbal fluency, thus, warranting more systematic investigations in this population.

2.7. Aim of the study

The present study attempted to provide further insights into the ongoing debate on the right hemisphere’s possible contribution to the lexico-semantic processing.

2.8. Objectives of the study

The specific objectives of this study were:

1. To investigate the lexical retrieval skills in subjects with right hemisphere damage.
2. To scrutinize the error patterns in this population, if any, to understand the nature of underlying lexico-semantic processing deficit.