Review Article

Review of Emotion Recognition in Stroke Patients

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Key Words

Emotion recognition · Emotion processing · Brain damage patients · Communication channels · Neuropsychology

Abstract

Objective: Patients suffering from stroke have a diminished ability to recognize emotions. This paper presents a review of neuropsychological studies that investigated the basic emotion processing deficits involved in individuals with interhemispheric brain (right, left) damage and normal controls, including processing mode (perception) and communication channels (facial, prosodic-intonational, lexical-verbal). **Methods:** An electronic search was conducted using specific keywords for studies investigating emotion recognition in brain damage patients. The PubMed database was searched until March 2012 as well as citations and reference lists. 92 potential articles were identified. **Results:** The findings showed that deficits in emotion perception were more frequently observed in individuals with right brain damage than those with left brain damage when processing facial, prosodic and lexical emotional stimuli. **Conclusion:** These findings suggest that the right hemisphere has a unique contribution in emotional processing and provide support for the right hemisphere emotion hypothesis. **Significance:** This robust deficit in emotion recognition has clinical significance. The extent of emotion recognition deficit in brain damage patients appears to be correlated with a variety of interpersonal difficulties such as complaints of frustration in social relations, feelings of social discomfort, desire to connect with others, feelings of social disconnection and use of controlling behaviors.

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Introduction

Stroke is an increasingly common condition which significantly affects the life of a patient on many levels. It is the third leading cause of death in developed and developing countries, and it was estimated to cause 5.5 million deaths worldwide, which is equivalent to 9.6% of all deaths [1]. Stroke causes impaired motor control, language and memory impairments, and produces a disruption in a patient's ability to perceive emotions [2]. Over the last two decades, the study of emotional processing following stroke has received major attention in the emotion literature. Here, the term 'emotion perception' involves the identification of emotional information in the environment across multiple channels of communication (facial, prosodic and lexical). Decoding emotion signals (e.g., the face) is considered to be an important part of social interactions. Research has identified numerous neuroanatomical structures and neurophysiological systems that modulate emotion at the cortical, subcortical and limbic levels of the nervous system [3]. Many successful paradigms have been used to study emotional processing including behavioral techniques (dichotic listening and tachistoscopic viewing), or expressions (facial asymmetry, vocal, verbal and gestural/postural), brain lesion methods (studies of individuals with known brain damage), neurosurgical procedures and functional neuroimaging techniques [3]. The purpose of this review was to examine the literature on hemispheric specialization of emotion processing. Findings from experimental studies with normal controls and individuals with right- or left-sided brain damage with respect to three communication channels (face, voice and lexical perception) will be summarized. Wherever available, valence-specific findings will be reported. This growing body of research has potential implications for the assessment of emotional disorders in patients that are associated with right hemisphere stroke, including depression, anxiety, anger and/or mania [4], and with left hemisphere stroke, including aphasia [5].

Theories of Hemispheric Specialization of Emotion

Hemispheric specialization refers to the differentiation of higher functions between the two hemispheres; its study is based on findings in which certain functions are predominantly affected by damage to one hemisphere [6]. There are two major hypotheses concerning hemispheric specialization for emotion.

The first hypothesis is known as the 'right hemisphere hypothesis', which proposes that the right hemisphere plays a greater role in emotion processing regardless of valence [7, 8]. Emotional processing at the behavioral level involves strategies (nonverbal, integrative, synthetic, holistic and gestalt) and functions (pattern perception, visuospatial organization and visual imaging) for which the neuroanatomical design and the neuropsychological organization of the right hemisphere are better suited [6]. The right cerebral hemisphere has been described as having greater ability to perform intermodal integration [9], greater interlobular organization [10], stimulus-evoked physiological activity [11] and functional interconnectivity among regions compared to the left hemisphere [12]. Heilman [13] suggested that the right hemisphere is more in touch with subcortical systems that are important for emotion processing. Tucker and Williamson [14] argue that the right hemisphere's specialized processing features lend themselves to nonverbal (e.g., emotional) processing, whereas the left hemisphere's features lend themselves to verbal (e.g., cognitive) processing. Support also comes from studies in which right hemisphere pathology was more involved in emotion processing. This has been associated with abnormal patterns of autonomic nervous system responses, as measured by heart rate [15] and skin conductance [16].

The second hypothesis is known as the 'valence hypothesis', which proposes that the right hemisphere is specialized for negative or unpleasant emotions, and the left hemisphere is

specialized for positive or pleasant emotions [14, 17, 18]. Borod et al. [19] suggested that the quality of decision making is different in the case of negative compared to positive emotions. Since negative emotions are linked with survival, a system is required that is sensitive to multi-modal inputs and that quickly scans the environment and evaluates the situation. This type of behavior seems to be more linked to right than to left hemisphere function. Positive emotions, on the other hand, may be more dominated by the left hemisphere. Borod et al. [20] suggested that positive emotions often are more linguistic and communicative than emotional and reactive, thus possibly reflecting left hemisphere involvement in their function. It has also been proposed that social emotions (e.g., affection, pride, embarrassment) are modulated by the left hemisphere whereas primary emotions (e.g., anger, fear, sadness) are modulated by the right hemisphere [21]. Two studies involving patients with brain damage have shown an involvement for patients with right hemisphere brain damage (RBD) in social emotions [22] and impairment for patients with left hemisphere brain damage (LBD) in this domain [23].

Methods

Criteria for Study Inclusion

Types of Studies. Only studies comparing emotion recognition performance in a group of participants with brain damage to that in a normal control group were used for the purposes of this review. Emotion recognition was defined as any task in which stimuli conveying emotional information were presented, and for which participants were asked to state or choose which emotion they thought was represented by the stimulus. The stimulus could be facial, prosodic or lexical and of any form (e.g., static faces, videos, recorded voices). Any target emotions were considered. Studies looking exclusively at emotion production rather than the recognition of emotions, or studies which focused on neuroanatomy rather than behavioral performance (e.g., discrimination task measures) or semantic knowledge (e.g., situations that might be expected to induce emotions) were excluded. Reviews, editorials, letters or other articles that did not contain original data were excluded as well. The methodology scheme for the selection of articles is shown in detail in figure 1.

Types of Participants. The patient group consisted of participants whose brain damage resulted from stroke, confirmed by neurologists and/or radiologists based on neuroimaging results using either computed tomography or magnetic resonance imaging. Studies of both right and left brain damage participants were included. The control group consisted of neurologically healthy participants. Only data from adult participants over the age of 18 were considered.

Electronic Search

We conducted a systematic electronic search in the PubMed database, which included Taylor & Francis, PsycINFO, PsycNET, Science Direct, Wiley's Online Library and SpringerLink. We used the following keywords: 'emotional impairment', 'recognition', 'behavior', 'perception', 'facial expression', 'prosody', 'lexical' and 'emotion comprehension', and limited these searches to stroke or brain damage. This literature search was carried out from December 2011 to July 2012 at the University Malaysia Perlis, Malaysia. The search articles included all relevant papers until March 2012. Only peer-reviewed published articles were accepted for inclusion. Attempts were also made to contact corresponding authors of articles included in the review to either ask for access to more demographic or experimental data or to make queries about particular studies. For each study included in the review, a manual search of references and a citation search were also conducted to identify additional studies.

Study Selection

Based on these criteria, initial searches identified 966 articles. The title and abstract of each citation were examined independently in the PubMed database for the pre-specified inclusion and exclusion criteria listed above. 127 articles were included based on title and abstract alone. The full text of these papers was obtained through our university library to assess whether they fully met inclusion criteria. Four additional citations were identified from the reference list and citation search. Data were extracted to a data collection form. This covered clinical characteristics, details of emotion recognition tests and results.

Fig. 1. Methodology scheme for the selection of articles. CT = Computed tomography; MRI = magnetic resonance imaging.

Results

Search Results

After the full text of each article had been examined, 92 articles were found to meet the inclusion criteria. The characteristics of the brain damage patients included in these studies are illustrated in tables 1–3.

Assessment of Methodological Factors

The study methodology was assessed in four distinct categories: participant characteristics, emotional stimuli employed, stimuli presentation and response options, and control tasks.

Participant Characteristics

The exclusion criteria reported were generally consistent among the studies. Participants with disorders known to impact upon cognitive status (e.g., history of neurological disorders or other major medical illness) or emotion processing (e.g., psychiatric disorders) were excluded. Participants who had vision disturbance or hearing difficulties were also excluded. In the studies that were reviewed, mean illness duration ranged from 26.5 days [39] to 23 months [43]. The majority of studies had selected patients receiving some form of medication for the treatment of stroke [31, 50, 53]. Even among the studies that enrolled patients who were generally receiving medication, there may be substantial ‘on-off’ variation depending on the time of day and when participants last took their medication. Moreover, some participants may have received optimal medication, whereas others may not have done so. Only one study reported on stroke severity measures [39]. All studies recruited normal controls as a comparison group. Neuropsychological testing was used to assess performance on language, memory and executive functioning. In all studies, the Mini-Mental State Examination (MMSE) score was a key part of neuropsychological evaluation [24]. One study used a cut-off score of 21 and another a cut-off score of 23 on the MMSE [25, 26].

Emotional Stimuli

The majority of studies used very similar sets of stimuli. In order to study facial emotion recognition, participants were asked to discriminate, identify or match a range of facial emotional expressions to either photographs, cartoons or line drawing stimuli, depending on the study [25, 30–37]. Studies varied in the use of either black and white [25, 31, 32, 38] or color facial photographs [39]. Most research was done using static stimuli, predominantly from the Pictures of Facial Affect battery [40]. Only a small number of studies employed dynamic images (video recordings) [41, 42]. However, there were a number of variations of this task: some studies used simple facial images [32, 54] and some morphed facial images [31], others used neutral faces whereas some did not; additionally, the overall number of stimuli used differed. Some researchers opted to use other validated facial stimuli [34] or worked with their own personally designed stimuli [41, 43].

Studies of prosodic emotion recognition often ask participants to discriminate between two emotionally toned sentences that convey a particular emotion and to identify the affect being expressed. These study stimuli were mostly drawn from the New York Emotion Battery (NYEB) database [27, 43, 44], and most studies varied in the use of emotional prosody sentences. Past studies have asked participants to identify or discriminate the recorded emotional prosody category of semantically neutral sentences [26, 28, 29, 45–47], low-pass filtered sentences [48–50], sentence pairs [7, 33, 51, 52], congruent or incongruent sentences [53], pseudo-sentences [30, 41, 54] or hummed utterances [55].

Lexical emotion recognition tasks require individuals to identify the emotion underlying spoken sentences [22, 56, 57]. This pool of emotional items was derived from numerous sources, including dictionaries, word lists and monographs. Few studies attempted to explore all the stimuli in parallel emotional processing [41, 43, 44, 54]. For example, Schmitt et al. [41] investigated the performance under conditions of multimodal channels in terms of facial expression, emotional prosody and the emotional meaning of underlying spoken sentence. After presentation of each item, the participant was required to judge the corresponding emotion, being offered a choice of emotions. With regard to emotion examined, all communication channels were presented with a range of basic emotions, such as happiness, sadness, anger, fear, disgust, surprise, neutral emotion or a combination of these.

Table 1. Summary of emotion processing studies from the facial channel

Reference	n	Clinical measures	Control task	Emotional stimuli	Emotions	Dependent variables	Results
Blonder et al. [33]	12 RBD 9 NC	GDS; PANAS	no	static female faces	H, Sa, A, F, N	discrimination; matching	RBD < NC
Harciarek and Heilman [32]	11 ASRH 16 PSRH 31 NC	MMSE	no	static photographs (Pictures of Facial Affect)	H, Sa, F, A, Su, D	identification	ASRH < PSRH < NC
Cheung et al. [31]	19 NC 19 RSS 19 LSS 6 T 6 BG	NA	no	static photographs (Pictures of Facial Affect)	H, Sa, A, Su, D, F	identification	in the group, (i) RSS = LSS = NC, (ii) T < NC (Sa)
Harciarek et al. [54]	30 RBD 31 NC	MMSE	no	static photographs (Pictures of Facial Affect)	H, Sa, A	recognition	RBD < NC
Braun et al. [39]	13 RBD 11 LBD 29 NC	SSS; EBI; ZVT-G; BDI	no	static color photographs	H, Sa, F, A, Su, D	identification; labeling	RBD < LBD < NC (F, A, Sa, D)
Yip et al. [34]	14 SS 14 NC	FDST; BT; BDST; ST; VFT; HVOT	no	static photographs (JACFEE)	H, Sa, A, Su, D, F	identification; discrimination	SS < NC (F, Sa, D)
Charbonneau et al. [25]	15 RBD 17 LBD 16 NC	MMSE	no	static photographs (Pictures of Facial Affect)	H, Sa, A, Su, D, F	discrimination; identification	facial: RBD < LBD < NC (H, Su, F)
Kucharska-Pietura et al. [26]	30 RBD 30 LBD 50 NC	MMSE	no	static photographs	H, Sa, F, A, Su, D	labeling; discrimination; recognition	in all the tasks, RBD < LBD < NC
Zgaljardic and Borod [43]	9 RBD 7 LBD 7 NC	MDRS; BPD; BDAE; WAIS-R	yes	static photographs (Pictures of Facial Affect)	PE: H, I, Ple.Su NE: Sa, F, A, D, UnPle.Su	identification	RBD < LBD < NC
Karow et al. [96]	10 RBD 10 LBD 5 NC	WAB	no	dynamic faces	H, Sa, A, N	identification	RBD < LBD < NC
Rapcsak et al. [36]	63 FBD 80 NC	NA	no	static photographs	H, Sa, A, Su, F, D	matching	FBD < NC (F)
Mandal et al. [35]	30 RBD 30 LBD 50 NC	EHS	no	static photographs	H, Sa, F, A	matching	RBD < LBD < NC
Borod et al. [44]	11 RBD 10 LBD 15 NC	MDRS; BDAE; BNT; BPD; BVFD	yes	static photographs (Pictures of Facial Affect)	PE: H, I, Ple.Su NE: Sa, F, A, D, UnPle.Su	discrimination; identification (Likert)	identification: RBD < LBD < NC discrimination: no group differences
Vuilleumier et al. [97]	1 RBD	MMSE; WAIS-R	no	static photographs	H, Su, A, Sa, F, D	identification; discrimination	in both tasks, RBD showed impairment
Peper and Irle [65]	27 RBD 37 LBD 15 NC	NA	no	static photographs (Pictures of Facial Affect)	H, Su, A, An, Gr, D	categorization; selection; matching; discrimination; decoding	RBD < LBD < NC
Schmitt et al. [41]	27 RBD 25 LBD 26 NC	NA	no	dynamic faces	H, F, N	identification	RBD < LBD < NC (F)
Adolphs et al. [98]	37 RBD 15 NC	WAIS-IQ	no	static photographs (Pictures of Facial Affect)	H, Su, F, A, D, Sa	judgment	RBD < NC (F and Sa)
Reilly et al. [67]	5 RBD 5 LBD (6–24-month-old infants)	NA	no	toys; wrist restraint paradigm	Pos and Neg responsiveness	infant attention (video-recorded)	RBD < LBD (Pos)
Starkstein et al. [28]	29 RBD 30 NC	MMSE; JHFI; STC; HAD	no	static photographs (Pictures of Facial Affect)	H, Sa, A	recognition; identification	in both tasks, RBD < NC
Weddell [29]	27 RBD 24 LBD 15 NC	WAIS-R; VIQ; PIQ; WMS	no	static photographs (Pictures of Facial Affect)	H, Sa, A, F, D, Su, N	matching; response; categorization; recognition	in all the tasks, RBD < LBD < NC

Table 1 (continued)

Reference	n	Clinical measures	Control task	Emotional stimuli	Emotions	Dependent variables	Results
Borod et al. [64]	19 RBD 21 NC	WAIS-R; DRS; BPRS	yes	static photographs (Pictures of Facial Affect)	H, Sa, A, F, D, Su, N	discrimination; identification	in both tasks, RBD < NC
Young et al. [71]	15 RBD 19 LBD 32 NC	NA	no	static photographs (Pictures of Facial Affect)	H, Sa, A, F, D, Su	recognition; matching; analysis	in all the tasks, LBD < RBD < NC
Blonder et al. [7]	10 RBD 10 LBD 10 NC	NA	no	static photographs	H, Sa, A, F, N	discrimination; labeling; matching	in all the tasks, RBD < LBD < NC
Mandal et al. [63]	10 RBD 10 LBD 20 NC	EHS	no	static photographs	H, Sa, A, Su, D	matching; labeling	in both tasks, RBD < LBD < NC (F and A)
Borod et al. [91]	19 RBD 21 NC	SADS-L	no	static photographs (Pictures of Facial Affect)	H, Sa, A, Su, F	discrimination; identification (Likert)	in both tasks, RBD < NC
Cancelliere and Kertesz [45]	28 RBD 18 LBD 20 NC	NA	no	static photographs	H, Sa, A, N	identification; elicitation; repetition; identification	in all the tasks, RBD = LBD = NC
Ehlers and Dalby [99]	17 RBD 5 LBD 4 NC	air conduction test	no	static photographs	J, A, Sor, F	response	RBD < LBD < NC
Borod et al. [62]	12 RBD 15 LBD 16 NC	BDAE; PIQ	no	static photographs (Pictures of Facial Affect)	PE: H, Ple.Su, SA NE: Sa, F, A, D, C	identification (Likert)	RBD < LBD < NC (NE)
Bowers and Bauer [61]	11 RBD 11 LBD 11 NC	NA	no	static photographs (Pictures of Facial Affect)	H, Sa, A, N	discrimination; identification; indication	in all the tasks, RBD < LBD < NC
Kulikov and Sidorova [100]	17 RBD 37 LBD 31 NC	MMSE	no	static photographs (Pictures of Facial Affect)	H, Su, Sa, F, A, D	identification	RBD < LBD < NC
Etcoff [69]	12 RBD 12 LBD 12 NC	NA	no	static photographs (Pictures of Facial Affect)	H, Su, Sa, F, A, D, N, Inte, Cont	identification	RBD < LBD < NC
Dekosky et al. [59]	9 RBD 9 LBD 9 NC	NA	no	static photographs	H, Sa, A, indifferent	discrimination; identification	in both the tasks, RBD < LBD < NC
Benowitz et al. [42]	5 RBD 4 LBD 4 SB 1 RH	WAIS-IQ	no	dynamic faces	Pos, Neg, Dom, Sub	identification	RBD < LBD
Prigatano and Pribram [60]	8 RBD 7 LBD 5 bilateral 10 NC	NA	no	static photographs (Pictures of Facial Affect)	H, Sa, F, A	identification; recall	RBD = LBD = bilateral = NC
Kolb and Taylor [70]	35 RBD 24 LBD 20 NC	NA	no	static photographs (Pictures of Facial Affect)	H, Sa, F, A, Su, D, I	matching	RBD < LBD < NC

A = Anger; An = anxiety; ASRH = anterior strokes of right hemisphere; BDAE = Boston Diagnostic Aphasia Examination; BDI = Beck Depression Inventory; BDST = Backward Digit Span Test; BG = patients with damage to the basal ganglia; BNT = Boston Naming Test; BPD = Benton Phoneme Discrimination Test; BPRS = Brief Psychiatric Rating Scale; BT = Ballons Test; BVFD = Benton Visual Form Discrimination Test; C = confusion; Cont = contentment; D = disgust; Dom = dominant; DRS = Depression Rating Scale; EBI = Extended Barthel Index; EHS = Edinburgh Handedness Inventory Scale; F = fear; FBD = focal brain damage; FDST = Forward Digit Span Test; GDS = Geriatric Depression Scale; Gr = grief; H = happy; HAD = Hospital Anxiety and Depression Scale; HVOT = Hooper Visual Organization Test; I = interest; Inte = interrogative; J = joy; JACFEE = Japanese and Caucasian Facial Expressions of Emotion; JHFI = Johns Hopkins Functioning Inventory; Likert = Likert scale; LSS = left subcortical stroke; MDRS = Mattis Dementia Rating Scale; N = neutral; NA = not available; NC = normal controls; NE = negative emotions; Neg = negative; PANAS = Positive and Negative Affect Schedule; PE = positive emotions; PIQ = Performance Intelligence Quotient; Ple.Su = pleasant surprise; Pos = positive; PSRH = posterior strokes of right hemisphere; RH = right hemispherectomy; RSS = right subcortical stroke; Sa = sad; SA = sexual arousal; SADS-L = Schedule for Affective Disorders and Schizophrenia – Lifetime Version; SB = split brain; Sor = sorrow; SS = patients with subcortical brain damage; SSS = Scandinavian Stroke Test; ST = Stroop Test; STC = Social Ties Checklist; Su = surprise; Sub = submissive; T = patients with damage to the thalamus; Unple.Su = unpleasant surprise; VFT = Verbal Fluency Test; VIQ = Verbal Intelligence Quotient; WAB = Western Aphasia Battery; WAIS-IQ = Wechsler Adult Intelligence Scale-Intelligence Quotient; WAIS-R = Wechsler Adult Intelligence Scale-Revised; WMS = Wechsler Memory Scale; ZVT-G = Number Relation Test.

Table 2. Summary of emotion processing studies from the prosodic channel

Reference	n	Clinical measures	Control task	Emotional stimuli	Emotions	Dependent variables	Results
Blonder et al. [33]	12 RBD 9 NC	GDS; PANAS	no	sentence pairs	H, Sa, A, F, N	discrimination; matching	in both tasks, RBD < NC
Ross and Monnot [51]	16 RBD 10 LBD 43 NC	EHS	no	sentence pairs	H, Sa, A, Su, N, Di	identification; discrimination	in all the tasks, RBD < LBD < NC
Rymarczyk and Grabowska [52]	37 RBD 26 NC	HAD; WAIS-R	no	sentence pairs	H, Sa, A	discrimination; identification	RBD < NC
Harciarek et al. [54]	30 RBD 31 NC	MMSE	no	pseudo-sentences	H, Sa, A	identification	RBD < NC
Nakhutina et al. [27]	9 RBD 8 LBD 7 NC	MDRS; SADS-L; BDAE	yes	sentences	H, Sa, A, F, N	judgment; accuracy; intensity (Likert); confidence (Likert)	in all the tasks, RBD = LBD = NC
Pell [30]	9 RBD 11 LBD 12 NC	MMSE	yes	pseudo-sentences	H, Ple.Su, A, D, Sa	discrimination; identification; rating	in all the tasks, RBD < LBD < NC
Yip et al. [34]	14 SS 14 NC	FDST; BT; BDST; ST; VFT; HVOT	no	sentences	H, Sa, A, Su, D, F	identification; discrimination	in both the tasks, SS < NC (F, Sa, D)
Charbonneau et al. [25]	15 RBD 17 LBD 16 NC	MMSE	no	sentence pairs	H, Sa, A, Su, D, F	discrimination	RBD < LBD < NC (F, Sa, A)
Kucharska-Pietura et al. [26]	30 RBD 30 LBD 50 NC	MMSE	no	sentences	H, Sa, F, A, Su, D	identification	RBD < LBD < NC
Walker et al. [53]	8 RBD 8 LBD 8 NC	WAB; RICE	no	congruent or incongruent sentences	H, Sa	identification	RBD < LBD < NC
Zgaljardic and Borod [43]	9 RBD 7 LBD 7 NC	MDRS; BPD; BDAE; WAIS-R	yes	sentences	PE: H, I, Ple.Su NE: Sa, F, A, D, UnPle. Su	identification	RBD < LBD < NC
Karow et al. [96]	10 RBD 10 LBD 5 NC	WAB	no	sentences	H, Sa, A, N	identification	RBD < LBD < NC
Borod et al. [44]	11 RBD 10 LBD 15 NC	MDRS; BDAE; BNT; BVFD; BPD	yes	sentences	PE: H, I, Ple.Su NE: Sa, F, A, D, UnPle. Su	discrimination; identification (Likert)	identification: RBD < LBD < NC discrimination: no group differences
Pell [68]	9 RBD 11 LBD 10 NC	air conduction test	no	sentences	H, A, Sa, N	identification	in all the tasks, RBD < LBD < NC
Wertz et al. [47]	20 RBD 18 NC	NA	no	sentences (read out by the experimenter)	H, Sa, A, Su, T, Di	identification	RBD < NC
Pell and Baum [49]	9 RBD 10 LBD 10 NC	air conduction test	no	filtered sentences; pseudo-sentences	intonation patterns: AC: A, Sa, H LC: Dec, Inte, Impe	discrimination; identification	RBD = LBD = NC
Ross et al. [50]	12 RBD 10 LBD 16 NC	WAIS-R; WAB	no	filtered sentence pairs	H, Sa, A, Su, Di, N	discrimination	RBD < LBD < NC
Schmitt et al. [41]	27 RBD 25 LBD 26 NC	NA	no	pseudo-sentences	H, F, N	identification	RBD < LBD < NC (F)
Starkstein et al. [28]	29 RBD 30 NC	MMSE; JHFI; STC; HAD	no	sentences	H, Sa, A	recognition; identification	in both the tasks, RBD < NC
Weddell [29]	27 RBD 24 LBD 15 NC	WAIS-R; VIQ; PIQ; WMS	no	sentences	H, Sa, A, F, D, Su, N	matching; response; categorization; recognition	in all the tasks, RBD < LBD < NC

Table 2 (continued)

Reference	n	Clinical measures	Control task	Emotional stimuli	Emotions	Dependent variables	Results
Lalande et al. [55]	12 RBD 10 LBD 16 NC	NA	no	hummed utterances	J, Sa, F, Su, D, A	identification	RBD < LBD < NC
Van Lancker and Sidtis [80]	13 RBD 24 LBD 37 NC	SSLE	no	sentences	H, Sa, A, Su	matching	RBD = LBD = NC
Blonder et al. [7]	10 RBD 10 LBD 10 NC	NA	no	sentence pairs	H, Sa, A, F, N	discrimination; identification	in all the tasks, RBD < LBD < NC
Bradvik et al. [72]	20 RBD 18 NC	PTAT	no	sentences	A, H, Ind, Sa, Ast	identification	in all the tasks, RBD < NC
Twist et al. [101]	12 RBD 9 LBD 10 NC	air conduction test	no	sentences	H, Sa, A, Su, D	discrimination	RBD = LBD = NC (ERP component)
Borod et al. [91]	19 RBD 21 NC	SADS-L	no	sentences	H, Sa, A, Su, F	discrimination; identification (Likert)	in both tasks, RBD < NC
Cancelliere and Kertesz [45]	28 RBD 18 LBD 20 NC	NA	no	sentences	H, Sa, A, N	identification; elicitation; repetition; identification	in all the tasks, RBD = LBD = NC
Bowers et al. [75]	9 RBD 8 LBD 8 NC	NA	no	neutral and filtered sentences	H, Sa, A, indifferent tone	categorization	RBD < LBD < NC
Ehlers and Dalby [99]	17 RBD 5 LBD 4 NC	air conduction test	no	sentences	J, A, Sor, F	identification	RBD < LBD < NC
Gorelick and Ross [73]	14 RBD	NA	no	sentences; gestures	H, A, Sa, Su, indifferent	matching; identification	in both tasks, impairment in RBD
House et al. [79]	10 RBD 10 LBD 10 NC	HAD	no	sentences	Sa, N, Ex	judgment	RBD = LBD = NC
Kulikov and Sidorova [100]	17 RBD 37 LBD 31 NC	MMSE	no	sentences	H, Su, Sa, F, A, D	identification	RBD < LBD < NC
Lebrun et al. [81]	1 RBD	NA	no	sentences	A, Sa, J, Su	identification	no significant impairment
Tompkins and Flowers [46]	11 RBD 11 LBD 11 NC	NA	no	filtered sentences; filtered sentence pairs	H, A, Af	discrimination; identification	in all the tasks, RBD < LBD < NC
Tompkins and Mateer [102]	10 RBD 8 LBD 24 NC	WAIS-IQ	no	sentences	NA	judgment	RBD < LBD < NC
Denes et al. [76]	15 RBD 15 LBD 6 NC	NA	no	vowels	H, F, A, Sa, D	discrimination; identification	in both tasks, RBD < LBD < NC
Heilman et al. [48]	8 RBD 9 LBD 15 NC	NA	no	filtered sentences	H, Sa, A	identification	RBD < LBD < NC
Hughes et al. [103]	12 RBD 7 NC	NA	no	sentences; various emotional gestures	H, Sa, Su, A, Fla, H, A, Su, Sa, N	discrimination; repetition; identification	in all the tasks, RBD < NC
Ross [77]	10 RBD	air conduction test	no	sentence	H, Sa, A, Su, indifferent, Di	identification	RBD showed impairment
Tucker et al. [58]	11 RBD 7 LBD 8 NC	NA	no	sentences	A, H, S, indifferent tone	recognition; discrimination	in all the tasks, RBD < LBD < NC
Schlanger et al. [104]	20 RBD 40 aphasic	NA	no	sentences	H, Sa, A	identification; intensity (Likert)	RBD = aphasic group
Heilman et al. [74]	6 RBD 6 LBD	NA	no	sentences	H, Sa, A, indifferent	judgment	RBD < LBD

(For footnote see next page.)

Stimulus Presentation and Response Options

There were a number of dissimilarities in the presentation of a stimulus and in response options. Some of these differences include the length of time for which participants were exposed to stimuli, whether with [25–27, 34, 39] or without time restriction [32, 43, 54]. Kucharska-Pietura et al. [26] imposed a time restriction for presentation of approximately 10 s, with an interval of 10 s between two consecutive photographs. All studies of facial, prosodic and lexical emotion recognition used an alternative forced choice response paradigm, but they varied in the choices given. Most gave the same number of response options as there were emotion categories. For example, if six different emotions were presented, there would be six response options.

Control Tasks

The inclusion of a control task for perceptual emotional processing tasks was not noted in most of the studies. Rather, discrimination tasks, in which participants indicate whether photographs of people are the same or different, or identification tasks, in which the participants are required to label the emotion associated with each face [38, 43, 44], were used. In the studies of prosodic perception, participants were asked to listen to an audiotope which contained sentences [30, 43, 44]. Similarly, in lexical emotion recognition, tasks from the NYEB were used [58].

Description of Research with Normal Controls and Brain Damage Patients

The following studies were reviewed to assess the two emotion hypotheses regarding lateralization and valence (i.e., right hemisphere and valence) with respect to emotional perception, communication channel, hemisphere and valence. Studies involved individuals with brain damage and healthy normal controls. The results of these studies are summarized in tables 1–3.

Facial Channel

Patients with stroke often have a ‘mask-like’ face and rarely express facial emotions [3]. Thus, when stroke patients view a face expressing emotion, they may fail to mimic this facial expression since they cannot activate motor representations important for recognition [3, 8]. The first formal studies of emotional impairments in the facial channel associated with stroke were initiated in the 1980s [42, 59–62]. In later years, several studies regarding the performance of patients with brain damage in perceiving facial expressions were reported. These studies showed that individuals with RBD experienced greater difficulty in processing emotional faces than individuals with LBD and normal controls [6, 7, 25, 26, 30, 35, 39, 41, 43, 44, 48, 54, 63–70]. In contrast, most studies found no differences between RBD and LBD patients in the processing of emotional faces [27, 31, 45, 60], and one study found that LBD

(Footnote to table 2)

A = Anger; AC = affective context; Af = afraid; Ast = astonishment; BDAE = Boston Diagnostic Aphasia Examination; BDST = Backward Digit Span Test; BNT = Boston Naming Test; BPD = Benton Phoneme Discrimination Test; BT = Ballons Test; BVFD = Benton Visual Form Discrimination Test; D = disgust; Dec = declarative; Di = disinterest; EHS = Edinburgh Handedness Inventory Scale; ERP = event-related potential; Ex = excited; F = fear; FDST = Forward Digit Span Test; Fla = flatness; GDS = Geriatric Depression Scale; H = happy; HAD = Hospital Anxiety and Depression Scale; HVOT = Hooper Visual Organization Test; I = interest; Impe = imperative; Ind = indifference; Inte = interrogative; J = joy; JHFI = Johns Hopkins Functioning Inventory; LC = linguistic context; Likert = Likert scale; MDRS = Mattis Dementia Rating Scale; N = neutral; NA = not available; NC = normal controls; NE = negative emotions; PANAS = Positive and Negative Affect Schedule; PE = positive emotions; PIQ = Performance Intelligence Quotient; Ple.Su = pleasant surprise; PTAT = pure tone audiometry test; RICE = RIC Evaluation of Communication Problems in Right Hemisphere Dysfunctions; Sa = sad; SADS-L = Schedule for Affective Disorders and Schizophrenia – Lifetime Version; Sor = sorrow; SS = patients with subcortical brain damage; SSLE = Standard Speech-Language Evaluation; ST = Stroop Test; STC = Social Ties Checklist; Su = surprise; T = patients with damage to the thalamus; UnPle.Su = unpleasant surprise; VFT = Verbal Fluency Test; VIQ = Verbal Intelligence Quotient; WAB = Western Aphasia Battery; WAIS-IQ = Wechsler Adult Intelligence Scale-Intelligence Quotient; WAIS-R = Wechsler Adult Intelligence Scale-Revised; WMS = Wechsler Memory Scale.

Table 3. Summary of emotion processing studies from the lexical channel

Reference	n	Clinical measures	Control task	Emotional stimuli	Emotions	Dependent variables	Results
Zgaljardic and Borod [43]	9 RBD 7 LBD 7 NC	MDRS; BPD; BDAE; WAIS-R	yes	sentences, words	PE: H, I, Ple.Su NE: Sa, F, A, D, UnPle.Su	identification	RBD < LBD < NC
Cicero et al. [56]	11 RBD 10 LBD 15 NC	MDRS; BDAE; BPD	yes	sentences, words	PE: H, I, Ple.Su NE: Sa, F, A, D, UnPle.Su	identification; discrimination	RBD < LBD < NC
Borod et al. [44]	11 RBD 10 LBD 15 NC	MDRS; BDAE; BNT; BVFD; BPD	yes	sentences, words	PE: H, I, Ple.Su NE: Sa, F, A, D, UnPle.Su	discrimination; identification (Likert)	identification: RBD < LBD < NC discrimination: no group differences
Schmitt et al. [41]	27 RBD 25 LBD 26 NC	NA	no	sentences	H, F, N	identification	RBD = LBD = NC
Weddell [29]	27 RBD 24 LBD 15 NC	WAIS-R; VIQ; PIQ; WMS	no	sentences (written)	H, Sa, A, F, D, Su, N	matching; response; categorization; recognition	RBD < LBD < NC
Borod [6]	16 NC 16 RBD 16 LB	BDAE	yes	sentences, words	PE: H, Ple.Su NE: Sa, F, A, D, C	identification; discrimination	in both tasks, RBD < LBD < NC
Brownell et al. [57]	16 RBD 16 NC	NA	no	vignettes	H, A	response	RBD < NC
Lalande et al. [55]	12 RBD 10 LBD 16 NC	NA	no	sentences	J, Sa, F, Su, D, A	identification; decision; indication	RBD = LBD = NC
Blonder et al. [7]	10 RBD 10 LBD 10 NC	NA	no	sentences	H, Sa, A, F, N	discrimination; identification	RBD < LBD < NC ^a no selective deficits ^b
Ostrove et al. [22]	12 RBD 12 NC	NA	no	sentences (vignettes)	Pos, Neg, N	categorization; response	in both tasks, RBD < NC (NE)
Bihrlé et al. [105]	10 RBD 17 LBD 10 NC	BDAE	no	jokes, stories	NA	identification (Likert)	in both conditions, RBD < LBD < NC
Semenza et al. [84]	20 RBD 23 LBD 23 NC	NA	no	words	H, Sa, D, A, F	judgment	RBD < LBD < NC
Etcoff [69]	12 RBD 12 LBD 12 NC	NA	no	words	H, Su, Sa, F, A, D, N, I, Cont	judgment	RBD = LBD = NC
Brownell et al. [106]	12 RBD 12 NC	NA	no	jokes	NA	identification	RBD < NC
Kolb and Taylor [70]	35 RBD 24 LBD 20 NC	NA	no	sentences	H, Sa, F, A, Su, D, I	matching	LBD < RBD < NC

A = Anger; BDAE = Boston Diagnostic Aphasia Examination; BNT = Boston Naming Test; BPD = Benton Phoneme Discrimination Test; BVFD = Benton Visual Form Discrimination Test; C = confusion; Cont = contentment; D = disgust; F = fear; H = happy; I = interest; J = joy; Likert = Likert scale; MDRS = Mattis Dementia Rating Scale; N = neutral; NA = not available; NC = normal controls; NE = negative emotions; Neg = negative; PE = positive emotions; PIQ = Performance Intelligence Quotient; Ple.Su = pleasant surprise; Pos = positive; Sa = sad; Su = surprise; UnPle.Su = unpleasant surprise; VIQ = Verbal Intelligence Quotient; WAIS-R = Wechsler Adult Intelligence Scale-Revised; WMS = Wechsler Memory Scale.

^a Comprehension of sentences involving nonverbal expressions of emotion. ^b Comprehension of sentences involving emotional event.

patients were more impaired than RBD patients [71]. In the latter study, there were findings which provided support for the valence hypothesis. Braun et al. [39] and Yip et al. [34] showed evidence that RBD patients were more impaired, particularly in the recognition of negative emotional facial expressions. In studies by Borod et al. [44] and Mandal et al. [35], brain damage patients were typically required to identify and match a range of facial emotions expressed. As a result, RBD patients had impairments relative to patients with LBD for

negative emotions, but there were no differences between the two groups for positive emotions. On the other hand, Charbonneau et al. [25] found that RBD patients were impaired in the recognition of positive emotions such as happiness and surprise. In a tachistoscopic study with normal controls, right hemisphere involvement was obtained for the perception of facial emotional expressions with photograph, cartoon and line drawing stimuli [37].

Prosodic Channel

For the prosodic channel, participants are usually required to discriminate whether two emotionally toned sentences are the same or different and to identify the affect being expressed. Clinical studies have demonstrated that deficits in the perception of emotional prosody are associated more frequently with the right than the left hemisphere [25, 26, 30, 41, 44, 51, 58, 72–74]. Studies using an identification task found that RBD patients were significantly impaired relative to LBD patients and normal controls [44, 48, 75]. In studies using a discrimination task, RBD patients had impairment in the comprehension of emotional prosody task [58, 76, 77]. In a study by Ross and Monnot [78], different patterns of deficits were observed following left and right brain damage, suggesting that affective prosody is a dominant and lateralized function of the right hemisphere. In contrast, House et al. [79] found that RBD and LBD participants were equally impaired in emotional prosody when judging the emotion conveyed by a recorded voice on a seven-point Likert scale. This is consistent with findings reported by Heilman et al. [48], in which RBD and LBD patients were equally impaired on the nonemotional prosody task compared with normal controls. However, other studies showed no significant impairments among RBD and LBD patients [27, 49, 80, 81]. Some studies in which RBD patients were impaired at recognizing negative emotions from the prosodic task [25, 35, 41] provided support for the valence hypothesis. In a dichotic listening study with normal controls, a left ear (i.e., right hemisphere) involvement was found for the identification of prosodic information conveyed by speech stimuli from the NYEB [82].

Lexical Channel

One of the earliest studies was conducted by Wechsler [83], in which RBD patients had more difficulty than LBD patients in recalling emotional stories. Semenza et al. [84] reported that RBD patients showed greater impairment in processing emotional words relative to normal controls and LBD patients on a perceptual task involving analysis of hierarchical clustering. Ostrove et al. [22] showed that individuals with RBD had difficulties in understanding vignettes describing various social and emotional sets among positive, negative and neutral situations. Blonder et al. [7] found that RBD patients were impaired relative to LBD patients in making judgments about the emotional content of sentences involving nonverbal expressions of emotions. In a series of experiments with normal controls, Borod et al. [44] found that the presentation of emotional words and sentences during identification and discrimination tasks resulted in impairment of the right hemisphere. A study by Zgaljardic and Borod [43] reported that RBD patients were impaired relative to LBD patients and normal controls on identification tasks involving emotional words and sentences, as well as on nonemotional control tasks from the NYEB. In one study, the LBD group showed greater impairment on a sentence matching test where the subjects was asked to describe the emotion of a person in each sentence [70].

In a review of the normal control literature, there were findings of right and left hemisphere mediation in lexical emotional perception, which also support the valence hypothesis [85]. In a recent review of the behavioral and neuroimaging literature, the findings provided partial support for the valence hypothesis [86]. Additional support for the valence hypothesis can also be found in a recent functional magnetic resonance imaging study with normal controls [87]. This study demonstrated significant right hemisphere activation for negative

Fig. 2. Comparison of emotional processing deficits in brain-damaged patients.

emotion, but not for neutral, words. In a study by Graves et al. [88], healthy male subjects processed emotional words more accurately than nonemotional words in the right hemisphere, whereas neither men nor women showed differences between the two types of words in the left hemisphere. This finding suggests a special role for the right hemisphere in the perception of emotional words.

Interchannel Relationships among Communication Channels

There has been considerable work examining hemispheric specialization for emotional perception focused on three communication channels in parallel in both brain damage patients and normal controls [6, 70, 89, 90]. In these studies, brain-damaged participants were required to identify emotion expressed in a facial stimulus item or to discriminate between two emotionally toned stimuli. The results from these studies were associated more frequently with pathology of the right than of the left hemisphere. The majority of these studies indicated that there was a significant correlation between the facial and prosodic channels, as compared to correlations with the lexical channel [7, 41, 43, 44, 54]. In a similar vein, studies looking at emotional behavior showed that the right hemisphere hypothesis of emotional processing is supported by examining the emotional perception for facial and prosodic channels [27, 68, 91]. However, studies involving normal participants typically examined facial, prosodic and lexical communication channels in parallel [92, 93]. Borod et al. [44] demonstrated that RBD patients were significantly impaired relative to LBD patients and normal controls across channels and valence, supporting the right hemisphere hypothesis.

Reporting of Analysis and Outcomes

A total of 92 studies were analyzed in this review. Among these studies, 35 discussed the facial channel, 41 studied the prosodic channel, and the remaining 16 reported on the lexical

channel. In facial perception studies, 91% (32/35) of the studies showed impairment in patients with RBD, 3% (1/35) showed impairment in patients with LBD, and the remaining 6% (2/35) showed no significant impairment. For prosodic perception, 80% (33/41) of the studies showed impairment in patients with RBD and 20% (8/41) showed no significant impairment. For lexical perception, 69% (11/16) of the studies showed impairment in patients with RBD, 6% (1/16) showed impairment in patients with LBD, and the remaining 25% (4/16) showed no significant impairment. In summary, although impairment for emotion perception was more frequently observed in individuals with RBD than with LBD, there were a very fair number of studies that found no differences between the two patients groups (fig. 2).

Discussion

This review provides an analysis of the literature on emotional processing impairments in stroke patients. Our review supports the hypothesis that RBD patients have impairment relative to patients with LBD, normal control participants or both in processing facial and prosodic emotional stimuli. Certain results in the reviewed studies appear to be relatively robust and consistent with the behavioral literature involving facial and prosodic emotional perception in normal controls. For example, a recent review indicated that for facial and prosodic channels, the majority of observations revealed a greater involvement of right than left hemisphere specialization, regardless of emotional valence [86]. Taken together, these findings suggest that the right hemisphere is more involved in facial and prosodic emotional stimuli than the left hemisphere. In terms of lexical emotion perception, our review of studies involving individuals with brain damage supports right hemisphere specialization. These findings do not accord with the general literature. Specifically, in normal controls, evidence for the lexical channel demonstrated that there is relatively more involvement of the right than the left hemisphere, implicating some left hemisphere involvement in language processing [86]. The inconsistency between these findings for the two groups may result from difficulty in separating emotion from language processing in studies using normal control participants [85].

In addition, the method of stimulus presentation and task demands may impact emotion recognition results. Most of the earlier studies investigated emotion perception across all communication channels with the discrimination, identification, indication, judgment or imitation tasks using basic emotions such as happiness, sadness, anger, fear, disgust, surprise, neutral emotion or a combination. However, the studies did not obtain uniform results regarding the contribution of each cerebral hemisphere to emotion processing [34, 39, 63]. Other clinical studies provide results indicating equal impairment [27, 45, 49, 79, 80]. Many of the emotional processing clinical studies used a single modality of stimulus presentation, such as facial, prosodic or lexical, with few researchers attempting to explore the combination of the three. This variation between studies linked to different paradigms used for emotion recognition, even within a modality, led to divergent findings. Moreover, our understanding of emotion processing mechanisms remains too rudimentary to offer a principled account of this process.

In conclusion, our review of the literature on patients with brain damage and normal controls in which behavioral techniques were used point to right hemisphere dominance in the processing of emotion. Thus, the right hemisphere hypothesis was strongly supported; less evidence emerged for the valence hypothesis. The lateralization findings for emotional perception were stronger for the facial and prosodic channels than for the lexical channel. The conflicting findings across the three communication channels in the literature might be

attributed to several different factors. The first set of factors concerns characteristics of brain damage patients themselves (disease measure stages, cognitive impairment, medication, disease duration, illness severity, behavior symptoms and different most affected side), whereas the second set of factors concerns aspects of the emotional task (stimulus modalities, task type and type of emotion). Without using a suitable emotional task, it is difficult to ascertain whether participants' poor performance with tasks of emotion recognition is due to an inability to identify emotions or whether their difficulties arise from decision making, categorization skills or the inability to identify the most salient features defining category boundaries. Indeed, the extent of emotion recognition in stroke patients appears to be correlated with a variety of interpersonal difficulties, such as complaints of frustration in social relations, feelings of social discomfort, desires to connect with others, feelings of social disconnection and use of controlling behaviors [94, 95]. Future research should aim to explore the need for large, longitudinal studies of emotion recognition in brain damage patients that are informed by emerging 'neurobiological data' together with a 'suitable methodological' approach, and which use consistent measures of disease stage and overall severity as well as uniform assessment instruments. In additional studies, it will be important to include more ecological types of emotion processing beyond the relatively artificial scenario of a forced choice recognition protocol.

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