Neuropsychology
2003, Vol. 17, No. 1, 93–99

0894-4105/03/$12.00 DOI: 10.1037/0894-4105.17.1.93

Cerebral Hemodynamics During Discrimination of Prosodic and Semantic Emotion in Speech Studied by Transcranial Doppler Ultrasonography

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Simultaneous measurement of blood flow velocity (BFV) in the middle cerebral arteries was achieved by transcranial Doppler ultrasonography in 36 right-handed volunteers who were instructed to identify the emotion conveyed by prosody or semantics of a number of sentences. The tasks were performed under 2 levels of interference: neutral versus discordant affective value of the modality that had to be ignored. A multivariate analysis of variance showed a significant bilateral increase in BFV during the discordant conditions reflecting increased attentional demand. A significant left-hemispheric lateralization of BFV was observed as emotional semantics were labeled. When attention was shifted to affective prosody, the lateralization effect disappeared as a result of a marked increase in right-hemispheric BFV.

The emotional relevance of a spoken message is conveyed by its semantic content ("what" is said) and by the affective prosody used by the speaker ("how" it is said). The listener has to pay attention to both types of information in order to comprehend the emotional message as a whole. Although both types of information are communicated simultaneously, there is evidence that the neuroanatomical basis for the processing of the affective quality of semantic information and prosodic information is differently lateralized in the human brain. Understanding the semantic meaning of a message activates the parieto-temporal region of the left hemisphere in most right-handed individuals. In contrast, many (but not all) lesion, dichotic listening, and neuroimaging studies have supported the notion of a right-hemispheric dominance for processing affective information of the voice (for a review of research before 1999, see Baum & Pell, 1999; see also Barrett, Crucian, Raymer, & Heilman, 1999; Bryden & MacRae, 1989; Kawashima et al., 1993; Lalande, Braun, Charlebois, & Whitaker, 1992; Luks, Nusbaum, & Levy, 1998; Mayer et al., 2001; Pihan, Altenmüller, & Ackermann, 1997; Pihan, Altenmüller, Hertrich, & Ackermann, 2000; Schmitt, Hartje, & Willmes, 1997; Stirling, Cavill, & Wilkinson, 2000; Wertz, Henschel, Auther, Ashford, & Kirshner, 1998). Linguistically relevant prosodic cues have demonstrated relatively consistent involvement of the left hemisphere (Baum & Pell, 1999). The alleged right-hemispheric asymmetry for affective prosody has been attributed to (Lalande et al., 1992) (a) a right-hemispheric specialization for processing (nonverbal) emotion in general (Blonder, Bowers, & Heilman, 1991; Borod, 1993); (b) a right-hemispheric specialization for processing tonal discrimination, sentence contour, or other phonetic aspects necessary to assess affective intonation that could be partially or even entirely independent of emotional categorization per se; and (c) a right-hemispheric dominance in attention or resistance to distraction in tasks that require modulation of attention over experimentally, dissociated semantic and prosodic task demands (Bowers, Coslett, Bauer, Speedie, & Heilman, 1987). Closer investigation of the second hypothesis has yielded several major possibilities regarding the neuroanatomical regions active in prosodic processing (Baum & Pell, 1999): (a) All aspects of prosody are processed in the right hemisphere and integrated with linguistic information through callosal connections (Klouda, Robin, Graff-Radford, & Cooper, 1988); (b) affective prosody is controlled in the right hemisphere and linguistic prosody is processed in the left hemisphere—the functional lateralization hypothesis (Van Lancker, 1980); (c) comprehension and production of prosody are subserved largely by subcortical regions and are not lateralized (Cancelliere & Kertesz, 1990); or (d) individual acoustic cues to prosody may be independently lateralized (Van Lancker & Sidtis, 1992).

An interesting feature of human verbal communication is that the emotional value of the semantic message and the affective prosody are not necessarily in concordance. Discrepancies in emotional tone or intensity between semantic content and affective prosody can be used deliberately by the speaker to communicate an emotional status or intention. Interpretation of subtle discrepancies between the emotions conveyed by both modalities contributes significantly to the richness and complexity of the emotional communication in humans. The impact of an affective discordance between prosodic features and the semantic content of phrases has been examined in patients with unilateral left or right hemispheric brain damage by Tompkins and

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Mateer (1985), Bowers et al. (1987), Lalande et al. (1992), and Schmitt, Hartje, and Willmes (1997). In these studies, patients with right-hemispheric brain damage performed significantly worse on detecting inconsistencies or recognizing emotions than did patients with lesions in the left hemisphere.

The aim of this study was to investigate the behavior and the cerebral hemodynamics of normal volunteers who were instructed to label the emotion communicated by either the semantic content of the sentence (and ignore the prosody) or by the affective prosody used by the speaker (and ignore the semantic meaning) of the verbal message. A similar paradigm was used in normal, healthy volunteers in a positron emission tomography (PET) study (George et al., 1996). In the latter study the affective prosodic and propositional content were congruent in some sentences, different in others, and in still others either the prosody or verbal content was neutral. In the present study, tasks were performed under two levels of interference. In the first (easy) level the affective tone of the modality that has to be ignored was neutral. In the second (more difficult) level both semantic meaning and prosody conveyed an emotional message; moreover, the affective value of the modality that has to be ignored was discordant with the modality on which the volunteer was instructed to focus. This condition was believed to elicit a higher attentional demand of the listener and to reflect more complex, verbal affective communication.

Whereas behavioral data were assessed by observing performance accuracy, cerebral hemodynamics were studied with functional transcranial Doppler ultrasonography (fTCD). TCD is a noninvasive diagnostic tool with high temporal resolution that allows a continuous and bilateral monitoring of blood flow velocity (BFV) in the basal cerebral arteries through a temporal window in the intact skull. Evidence has accumulated that changes in cerebral BFV reflect changes in cerebral metabolism due to the mental activity required to perform the cognitive task (Bishop, Powell, Rutt, & Browse, 1986). The changes in BFV that result from this activation are sensitive enough to demonstrate lateralized mental activity (for a review, see Stroobant & Vingerhoets, 2000).

We hypothesized that in comparison with a resting phase, labeling the emotion conveyed through semantic meaning should show a left-hemispheric lateralization. Shifting of the attention to the affective prosody would be expected to reveal an increased right-hemispheric contribution. We further hypothesized higher error rates and increased BFVs in the emotionally discordant conditions due to increased task difficulty and increased attentional demand, respectively.

Method

Participants

Thirty-six students and hospital staff members (17 men, 19 women, mean age = 23 years, *SD* = 2.6, range 19–29 years) participated in the study. All volunteers were right-handed, as measured by the Edinburgh Handedness Inventory (Laterality Index, *M* = 88%, *SD* = 11%; Oldfield, 1971). None of the participants took psychoactive medication, had an active medical disease, or had a history of cardiovascular, neurological, or psychiatric disorders. They all refrained from drinking caffeine-containing beverages or smoking at least 12 h before the study. All Dutch speaking volunteers were experimentally naive about TCD procedures.

Apparatus

A commercially available 2-MHz pulsed-wave TCD unit (Multidop X2 hardware, DWL Version 2.53j of TCD 7 software, DWL Elektronische Systeme GmbH, Sipplingen, Germany) continuously and simultaneously monitored BFV of the middle cerebral arteries (MCA). Two dual 2-MHz transducers, fitted on an elastic headband (DWL 4038) and placed on the left and right temporal skull window, transmitted the ultrasonic signal and received the echoes. Details of the insonation technique and the correct insonation of the MCA have been described elsewhere (Ringelstein, Kahlscheuer, Niggemeyer, & Otis, 1990). Starting from an insonation depth of 50 mm, depth and angles of insonation were adjusted to obtain the highest signal intensity of the M1 segment of the MCA (insonation depth ranged from 46 to 50 mm). The standard algorithm implemented on the instrument using a fast Fourier transform calculated the outline or envelope of the velocity spectrum and mean maximal BFV. The TCD unit allowed continuous-wave Doppler recording of the intracranial artery with online calculation of mean flow velocity in centimeters per second.

Task Construction and Paradigm

We constructed a large list of sentences of approximately equal length (about seven words) that had one of four basic emotional (happy, sad, angry, fear) or a neutral semantic meaning. For example, happiness, “He really enjoys that funny cartoon”; sadness, “The little girl lost both her parents”; anger, “Tina kills him when she finds out”; fear, “Panic broke out in that dark tunnel”; and neutral, “Always store disc in its protective case.” Only the sentences that were correctly classified by at least six of seven independent raters were selected for further use. From this selection, we constructed eight lists of 24 sentences to obtain two lists for each of four conditions. The first two conditions constituted the easy interference level. In the first condition, we used sentences with neutral semantic content only. To control for individual and/or gender differences in affective prosody, each sentence was articulated by two professional actors (a female voice and a male voice) and recorded with a Sony Digital Mega Bass MZ-R55 portable Minidisk recorder. The sentences with neutral semantic content were pronounced in a happy, sad, angry, or anxious tone of voice (the actors were allowed several attempts, and the best recording was selected by consensus of the authors). In this condition, participants would be instructed to determine the emotion conveyed by the affective prosody of the voice (attend prosody-neutral semantics condition). For the second condition, we used sentences with emotional semantic content only, which were pronounced by the actors in a neutral tone of voice. Now the volunteers would have to attend to the emotional content of the message (attend semantics-neutral prosody condition). In the two remaining conditions, constituting the difficult interference level, all sentences not only had an emotional semantic content but were also pronounced with an affective prosody that was different from the emotion conveyed by the semantic content of the sentence. Of the 24 sentences of each condition, 6 had a happy, 6 had a sad, 6 had an angry, and 6 had a fearful semantic meaning. Of the 6 happy semantic sentences, 2 were read with angry intonation, 2 with sad, and 2 with fearful intonation, thereby equally combining the discordant emotions with each other. A similar method was used to construct the discordant messages of the 6 sad, angry, and fearful semantic sentences. In the third condition the participants were instructed to indicate the affective prosody (and ignore the emotion communicated by content; attend prosody-discordant semantics condition). In the fourth condition volunteers had to attend to the emotional content of the message (and ignore the affective prosody; attend semantics-discordant prosody condition). The types of affective prosody, emotional semantic content, or both were equally divided over the lists in a pseudorandomized order. The digitized stimuli were positioned in the list, alternating between the male and female voices and with a 2-s interstimulus interval between each sentence, using Adobe Premiere 5.1. All stimuli were recorded on compact disk and presented binaurally through earphones.

Procedure

The experiment was performed in a quiet room with illumination held constant. Each participant was seated in a comfortable chair in front of a white wall. The basic principles of the equipment and the general design of the study were explained to promote a relaxed atmosphere and to reduce possible anxiety. After informed consent was obtained, we noted demographic data and assessed the Edinburgh Handedness Inventory. The two TCD probes were fixed over the left and right temporal region of the participant's head and adjusted to obtain optimal signals. Blood pressure, respiratory rate, hematocrit, or end-tidal CO_2 were not monitored. There is ample evidence that these variables do not change in a significant way during the course of the experimental procedure (Silvestrini, Cupini, Matteis, Troisi, & Caltagirone, 1994). Participants were told that they would hear spoken sentences through their earphones and that they would be asked to concentrate on and identify either the emotional semantic content of the message (what was said) or the emotional melody or tone of the message (how it was said). Immediately following each sentence the volunteers indicated their answer by pointing with both index fingers to the appropriate emotion on a card that listed the names of the four emotions. Bimanual pointing was performed to avoid unilateral activation of the motor cortex. The card was positioned immediately in front of the participant and pointing required minimal arm movements. We constructed four answering cards listing each emotion in a different vertical position. We randomly selected an answering card for each condition.

The entire session took about 50 min. The order of the tasks was rotated from participant to participant, thus beginning with a different task each time without changing the remainder of the sequence. Each condition was assessed twice with a different list of stimuli. The specific instructions were given before each task. Each task lasted approximately 2 min. The entire activation period, delineated by a set of markers in the TCDU protocol, was used to determine the mean BFV for that task. Each activation phase was preceded by a 120-s rest period. During the 120-s rest periods, participants were requested to look at the white wall, to relax and breathe regularly without falling asleep, and to "think of nothing." They were not allowed to move or speak, nor were they spoken to. The first 60 s of each rest period served as a recovery period in which posttask activation could subside (Harders, Laborde, Droste, & Rastogi, 1989). Only the last 60 s of the rest period served as the baseline measurement for the subsequent activation phase.

Statistical Analysis

We calculated the average of all mean maximal BFVs over the last 60 s of the rest periods and of the 2-min activation periods. Because TCD cannot make the difference between real asymmetries in BFV and differences caused by slightly different insonation angles, we calculated the relative increase from baseline to activation, [(BFV activation − BFV baseline)/BFV baseline] × 100 (Rihs, Gutbrod, Steiger, Sturzenegger, & Mattle, 1995). We always used the immediately preceding rest period to determine the BFV change of the cognitive task under study (Vingerhoets & Stroobant, 1999). Because each condition was assessed twice, the mean percentage change of both tasks was calculated to represent the relative change for that condition. The mean number of correct responses of each condition constituted the behavioral data. General linear models were used to analyze the behavioral and hemodynamic data.

Results

Inspection of the behavioral data (see Table 1) reveals that fewer errors were made in labeling the correct semantic emotion than in labeling prosodic emotion. In addition, more errors are made in conditions with discordant emotional messages. Multivariate analysis of variance (MANOVA) of the behavioral data using level of interference (neutral vs. discordant distraction) and content (semantics vs. prosody) as within-subjects factors statistically confirmed a main effect of level of interference, Hotelling's T^2 (1, 35) = 16.2, $p < .01$, and a main effect of content, Hotelling's T^2 (1, 35) = 28.8, $p < .01$. The interaction effect was not significant. Error analysis revealed that there existed 5 (of 192) sentences that were incorrectly classified by more than 50% of the participants; in all cases expression of anxiety was intended (semantically in 1, prosodically in 4 cases). None of the conditions contained more than 2 such sentences. It appeared that in a minority of sentences (2.6%) the emotion was not expressed unambiguously and that prosody of anxiety was most difficult to produce. On the other hand, the results showed that even under discordant circumstances the volunteers succeeded in correctly identifying the intended emotion in over 80% of the stimuli. This success rate illustrated the adequate discriminative power of most stimuli and indicated that the results reflected a valid measure of semantic and prosodic affective perception.

Table 1
Behavioral and Hemodynamic Data for Each Emotion-Labeling Condition

Condition	% correct responses		% BFV change in left MCA		% BFV change in right MCA	
	M	*SD*	*M*	*SD*	*M*	*SD*
Attend prosody-neutral semantics	86.6	6.1	4.6	5.7	4.2	5.7
Attend semantics-neutral prosody	93.5	6.0	4.7	5.9	2.8	5.8
Attend prosody-discordant semantics	83.7	8.8	5.8	4.9	5.5	4.8
Attend semantics-discordant prosody	88.4	7.5	5.6	5.1	4.3	4.4

Note. BFV = blood flow velocity; MCA = middle cerebral arteries.

A repeated measures analysis of variance comparing the absolute BFVs of the rest and the activation conditions revealed a significant effect for activation, Hotelling's T^2 (8, 28) = 11.9, $p < .01$. Posthoc analyses showed a significant increase in absolute BFV for all conditions and sides. A MANOVA on the relative BFV (percent change) data (see Table 1) using level of interference (neutral vs. discordant distraction), content (semantics vs. prosody), and laterality (left hemispheric vs. right hemispheric) as within-subjects factors showed a significant main effect for level of interference, Hotelling's T^2 (1, 35) = 6.0, $p = .02$, and laterality, Hotelling's T^2 (1, 35) = 12.8, $p = .01$, but not for content. Posthoc analyses using paired sample *t* tests to explore the main effect of interference level revealed that, overall, there was a greater BFV percentile change in the discordant conditions. Posthoc analyses exploring the main effect of lateralization indicated that, overall, the BFV percentile changes were greater in the left hemisphere. In addition to the main effects of level of interference and laterality, we found a significant content by laterality interaction effect, Hotelling's T^2 (1, 35) = 10.8, $p < .01$. This interaction effect is illustrated in Figure 1. When attention was shifted to prosody, there was a marked rise in estimated marginal mean right-hemispheric BFV (regardless of level of interference), whereas estimated marginal mean left-hemispheric BFV (regardless of level of interference) remained almost identical whether the volunteer was labeling semantics or prosody. The level of interference by laterality and the level of interference by laterality-by-content interaction effects were not significant. Introducing gender as a between-subjects factor in the MANOVA did not reveal a main effect for gender.

Discussion

The high number of correct responses in all conditions suggests that the volunteers understood the task instructions correctly and were able to perform the task without major difficulty. The high performance scores also demonstrate that both semantic and prosodic stimuli adequately conveyed the intended emotions. As could be expected, labeling emotions in the discordant conditions proved to be more difficult regardless of the modality that was attended to. This implies that the discordant emotional information that was not attended to, slightly but significantly disrupts the labeling performance of the targeted modality. Other observations also confirm that the volunteers processed both semantics and prosody. Many volunteers spontaneously smiled during the experimental tasks or told us afterward that they inhibited this behavior. Debriefing indicated that this was the case when the message was perceived as being funny, for example, when a sad semantic message was pronounced in a happy way, and the global message could be interpreted as being ironic or sarcastic. This observation underlines the fact that this study was not about processing either semantic or prosodic information as the participants assimilated both modalities. We must keep in mind that the study investigated the hemodynamic effect of the volunteers' ability to focus the attention to the assignment of an emotional label conveyed by semantics or prosody.

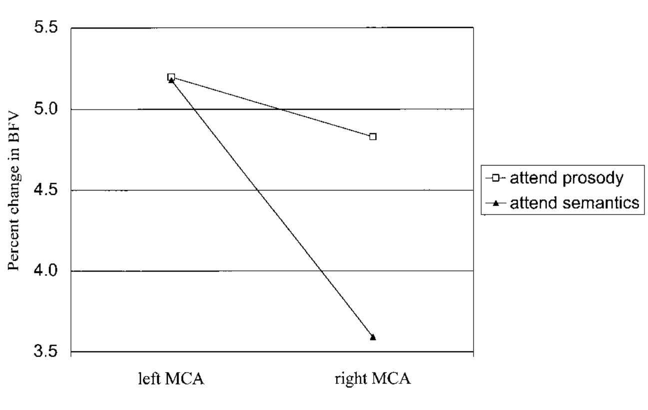

Figure 1. Estimated marginal mean percent blood flow velocity (BFV) change in left and right middle cerebral arteries (MCAs) during discrimination of affective prosody or affective semantics.

We also found lower performance scores when attending to prosody than when attending to semantics. This finding does not necessarily mean that labeling affective prosody is more difficult. It can also be explained by the difficulty the actors encountered in adding affective prosody to sentences with neutral or discordant emotional content in an unnatural communication and setting. The difficulty of this task could result in less discriminative prosodic information in the experimental paradigm than would be the case in natural, predominantly concordant emotional messages, and thus lead to a poorer performance in labeling affective prosody. Nevertheless, performance scores over 80% indicate that in most cases the discriminative power of the prosodic stimuli was sufficient to categorize the intended emotion.

The hemodynamics of this paradigm show a significant 3%–6% increase in MCA-measured BFV compared with a rest condition, depending on side and level of interference. Although the proportion of BFV rise that has to be attributed to activation of the motor cortex is unknown, unilateral activation of the (left) motor cortex in our (right-handed) volunteers is avoided by using a bimanual response mode. The amount of motor activity is identical in all conditions. BFV increase is higher in the discordant conditions, and this is probably due to the increased attentional demand of these tasks. Vingerhoets and Luppens (2001) suggested that the level of BFV change is associated with task demand and reflects the attentional capacity necessary to perform the task. The association between attentional capacity and hemodynamics also appears more pronounced in the right hemisphere as repeatedly illustrated in PET (Pardo, Fox, & Raichle, 1991) and fTCD research (Droste, Harders, & Rastogi, 1989; Knecht et al., 1996; Vingerhoets & Luppens, 2001; Vingerhoets & Stroobant, 1999). Although the effect of task complexity is more marked in the right hemisphere where the rise in BFV is significant for attending prosody or semantics, whereas the left-hemisphere BFV only increases significantly in the attend prosody condition, the level of interference by laterality interaction effect was not significant in this study.

In addition to a main effect of laterality, showing larger BFV changes in the left MCA, laterality also shows an interaction effect with content. When the volunteers were trying to label the emotional value of the semantic message, we observed a significantly lateralized rise in BFV in favor of the left hemisphere. Although this is what can be expected when right-handed individuals are concentrating on understanding the semantic meaning of a spoken message, this appears also the case when the semantic meaning refers to emotions and is in agreement with other research using discordant emotional messages (Schmitt et al., 1997). When the volunteers were trying to label the emotional intonation of the prosodic message, the lateralization effect disappeared. As can be inferred from Figure 1, the lateralization effect is negated by a rise in right-hemispheric BFV that just failed to reach statistical significance in posthoc analyses. The right-hemispheric increase in BFV when attending to affective prosody is in agreement with the presumed right-hemispheric specialization in processing affective prosody. The right hemisphere has demonstrated a dominance for processing spectral information such as pitch and spectral complexity that are important acoustic correlates of prosody (Robin, Tranel, & Damasio, 1990). Left and right brain-damaged patients appear to use acoustic cues differently to identify affective-prosodic stimuli (Van Lancker & Sidtis, 1992), although other research could not confirm this finding (Pell, 1998; Pell & Baum, 1997a, 1997b).

Several methodological remarks need to be addressed. It can be argued that the observed rise in right-hemispheric BFV may, at least in part, be due to the very low BFV in the condition with neutral prosody (Table 1). This could suggest that when prosody is not involved, the right hemisphere is not very active and that the measured effect could be attributed to the absence or presence of prosody rather than to shifting the attention to prosody. On the other hand, in the discordant condition (where prosody is always present) a comparable shift is observed. If the mere presence of prosody would be sufficient to induce right-hemispheric activity, right-hemispheric BFV would have to be similar in both discordant conditions, which is not the case. Our data suggest that it is the shift of attention to prosody and not the absence or presence of prosody that induces the right-hemispheric BFV increase. The rightward shift in BFV can also be explained by increased attentional demands of the attend-prosody condition. In this case, we would expect a higher error score and higher BFVs in the attend-prosody conditions similar to the discordant conditions where attentional demand was deliberately manipulated. Because no main effect for content nor a level of interference by content-interaction effect was observed in the hemodynamic data, and the higher error scores may have a methodological explanation (see supra), the latter hypothesis appears unlikely. Another consideration refers to the hypothesis of a different hemispheric lateralization for positive and negative emotions. Three of the four emotions used in our study have a negative valence, and a predominant effect on a right-hemispheric “center for negative emotions” cannot be excluded. In addition, the observation that several participants smiled when hearing some of the discordant sentences could imply that, at least partially, the task influenced the emotional state of the volunteers that could, in turn, lead to lateralized hemodynamic responses. Recent research has not confirmed the hypothesis of negative or positive affective laterality and considers a general superiority of the right hemisphere for the perception and expression of both positive and negative emotions (Gainotti, 1999). It is unlikely that the predominance of negative emotions in the present study is causing the right-hemispheric shift when attending prosody, especially when we remind ourselves that this predominance also applies for the attend-semantics conditions where an opposite trend was found. If listening to the discordant sentences influenced the emotional state of the participants, then this too applies to both the attend-prosody and attend-semantics conditions, neutralizing its effect in comparison.

Note that there is no decrease in left-MCA BFV during the attend-prosody conditions. This could be due to the fact that although the participants were instructed to attend to prosody, they simultaneously processed the semantic content of the message as well, as was suggested by the behavior of our volunteers during the task. This hypothesis does not explain why the right BFV drops when attention is turned to semantic emotional content if people listen to both modalities anyway. An alternative explanation is that labeling emotions, which in essence is a semantic categorization task, requires a left-hemispheric effort over and above a right-hemispheric phonological analysis of specific intonation characteristics. According to this hypothesis, left hemispheric activity remains required to classify an affective prosodic signature as a semantic emotional category. Still another explanation refers to the linguistic character of the response procedure that required reading and selection of a written emotional category on the response cards and was identical in all conditions.

A PET study by George et al. (1996) used a very similar paradigm in normal volunteers. This comparable study found bilateral prefrontal activation during discrimination of the emotional propositional content, with a larger area of activation on the left side. Discrimination of emotional prosody resulted in increased activity in the right prefrontal cortex and in a smaller region of left prefrontal cortex, although this failed to meet statistical significance. In general, the PET study revealed bilateral activation in the attend-prosody and the attend-semantics conditions, with a small left-hemispheric lateralization in the attend-semantics condition, and a significant right-hemispheric lateralization in the attend-prosody condition. In comparison, the fTCD study showed a larger contribution of the left hemisphere in both conditions, leading to a significant left hemispheric lateralization in the attend-semantics condition and (because of a right hemispheric rise in BFV) an unlateralized bilateral activation in the attend-prosody condition. The difference between both studies can be explained by the use of a sensorimotor control condition in the PET study to contrast the discrimination tasks. In this control condition, the participants listened to each sentence and repeated aloud the second word in the sentence. Clearly, this task relies predominantly on left-hemispheric processing (attending to semantic content, articulating the word). Subtracting the metabolic activity elicited by this task from the experimental conditions eliminates some of the linguistic (left-hemispheric) bias that is inherent to this paradigm. Considering this methodological difference, we discovered the findings of both studies are in agreement and appear to confirm a right-hemispheric activation when attention is turned to the understanding of affective prosody.

Summarizing our data in view of the existing models for a right-hemispheric dominance in affective speech perception (Lalande et al. 1992), we found no evidence for an emotional-categorization model that views the right hemisphere responsible for categorizing emotion in general. In fact, labeling emotion based on semantic information shows a significant left-hemispheric lateralization, and categorizing emotion based on prosodic information did not reveal a side effect. We also found no evidence for the attentional hypothesis. Although we observed a significant rise in BFV in the attentionally demanding, Stroop-like, discordant conditions, these findings were independent of attention for either modality. Only when the attention was turned to the discrimination of affective prosody, we observed a rise in right-hemispheric BFV. Future research should determine whether the increased right-hemispheric activity is in agreement with the phonetic model that suggests a right-hemispheric contribution for phonetic discrimination, for example, on the basis of the perception of affect-specific spectral information (i.e., not necessarily related to emotional categorization per se). The absence of a simultaneous reduction in left-hemispheric BFV can be interpreted in several ways that may or may not be involved with the discrimination of affective prosody proper and also requires further investigation. A left-hemispheric contribution in the perception of affective prosody cannot be ruled out. Finally, our data are not indicative for either cortical or subcortical involvement because the measuring point of BFV in the MCA is situated upstream of both territories.

Although, in absolute hemodynamic values the measured effects are small, the proposed experimental paradigm revealed interesting results and could be refined further. One of the options would be to test the paradigm in patients with lateralized brain damage to investigate the relationship between behavioral performance and hemodynamics. Another option would be to reduce the linguistic load of the paradigm, either by working with different response cards (depicting faces instead of words), by masking the propositional meaning of the sentences, by masking specific spectral characteristics of the prosodic message, or by investigating normal volunteers who are unfamiliar with the language in which the sentences are spoken.

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Received October 9, 2001
Revision received April 15, 2002
Accepted July 3, 2002 ■

United States Postal Service

Statement of Ownership, Management, and Circulation

1. Publication Title	2. Publication Number	3. Filing Date
Neuropsychology	0 8 9 4 - 4 1 0 5	October 2002
4. Issue Frequency	**5. Number of Issues Published Annually**	**6. Annual Subscription Price**
Quarterly	4	Mbr $47 Indv $95 Inst $157

7. Complete Mailing Address of Known Office of Publication *(Not printer) (Street, city, county, state, and ZIP+4)*
750 First Street, N.E. Washington, D.C. 20002-4242
Contact Person: Barbara Spruill
Telephone: 202-336-5578

8. Complete Mailing Address of Headquarters or General Business Office of Publisher *(Not printer)*
750 First Street, N.E., Washington, D.C. 20002-4242

9. Full Names and Complete Mailing Addresses of Publisher, Editor, and Managing Editor *(Do not leave blank)*

Publisher *(Name and complete mailing address)*
American Psychological Association
750 First Street, N.E.
Washington, D.C. 20002-4242

Editor *(Name and complete mailing address)*
James T. Becker, PhD
Neuropsychology Research Program, 830 Oxford Building
3501 Forbes Avenue, Pittsburgh, PA 15213-3323

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PS Form 3526, October 1999 *(See Instructions on Reverse)*

13. Publication Title: Neuropsychology
14. Issue Date for Circulation Data Below: July 2002

15. Extent and Nature of Circulation	Average No. Copies Each Issue During Preceding 12 Months	No. Copies of Single Issue Published Nearest to Filing Date
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j. Percent Paid and/or Requested Circulation *(15c. divided by 15g. times 100)*	96.4	95.7

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☐ Publication required. Will be printed in the January 2003 issue of this publication. ☐ Publication not required.

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