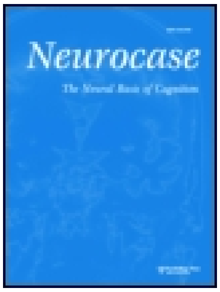

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Strengths and weaknesses of multimodal processing in a group of adults with gliomas

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Strengths and weaknesses of multimodal processing in a group of adults with gliomas

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The present study aimed to analyze the multimodal skills that would be spared, altered, or impaired by gliomas that slowly infiltrate various and diversely localized areas in the cerebral hemispheres. Ten patients and 60 healthy controls were evaluated using four multimodal processing paradigms across 11 tasks. Our objectives were as follows: (a) to describe the strengths and weaknesses of the glioma patients' multimodal processing performance after accounting for task specificity and their individual performances compared to those of the control group; (b) to determine the correlation between lesion localization and impairments; and (c) to identify the tasks that were most sensitive to tumor infiltration and plasticity limits. Our results show that patients as a whole were efficient at most tasks; however, the patients exhibited difficulties in the productive picture-naming task, the receptive verbal judgment task, and the visual/graphic portion of the dual-attention task. The individual case reports show that the difficulties were distributed across the patients and did not correlate with lesion localization and tumor type.

Keywords: Glioma; Cognition; Naming; Multimodal processing; Plasticity.

Due to their slow development and infiltrating characteristics, gliomas dramatically activate brain plasticity and connectivity (Duffau et al., 2003). Patients with glioma are typically diagnosed at approximately 30 years old (Lote et al., 1997), most commonly after sudden epileptic seizures. These patients often present a 'quasi normal' neuropsychological profile when assessed with tests created for the impairments that can follow sudden strokes or neurodegenerative diseases (Le Rhun, Delbeuck, Devos, Pasquier, & Dubois, 2009; Meyers & Brown, 2006; Tucha, Smely, Preier, & Lange, 2000).

Moreover, considering patients with gliomas as one group does not account for the between-patient variability due to age, lesion localization, tumor type and size, presence or absence of epilepsy, neurological status, or quality of life. These factors create substantial heterogeneity between subjects (Duffau, 2006).

Neurosurgical publications have highlighted the importance of assessing the cognitive and emotional functioning of patients with gliomas (Moritz-Gassert & Duffau, 2010). This assessment is important to document the cognitive correlates of gliomas, which can help patients in their daily lives as well as inform the subsequent development of therapeutic approaches and facilitate the determination of the evolution of gliomas. Indeed, cognitive deterioration predicts tumor progression and often precedes the radiographic evidence of

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that progression by more than 3 months (Meyers & Brown, 2006) Gliomas indirectly alter brain functioning by perturbing the integrative networks of regions, which results in discrete impairments of executive function, memory, or attention. This effect implies a largely distributed brain network (Correa, 2010; Douw et al., 2009; Taphoorn & Klein, 2004). Because of the specificity of gliomas, there is a need for tests and tasks that assess integrative cognitive processes and their modular functions (Lageman et al., 2010; Le Rhun et al., 2009; Teixidor et al., 2007). The present exploratory study focused on multimodal visual and verbal processing by examining unimodal and crossmodal processing. We sought to determine which specific skills would be spared, altered, or impaired by tumors that slowly infiltrated various and diversely localized areas of the cerebral hemispheres.

Crossmodal processing, which requires simultaneous processing, designates a specific integration between and above modalities that activates large brain networks. Notably, crossmodal processing activates the left superior sulcus, temporal gyrus, intraparietal sulcus, posterior parietal cortex, superior colliculus, and perirhinal cortex (Calvert, 2001; Calvert & King, 2001; Taylor, Moss, Stamatakis, & Tyler, 2006). We previously studied crossmodal visual–verbal processing in a preoperative condition with direct electrical stimulation applied during 'awakened surgery'; we showed that one discrete area of the left dorsolateral prefrontal cortex was implicated in the judgment of phonological visual–auditory incongruence (Plaza, Gatignol, Cohen, Berger, & Duffau, 2008).

Crossmodal processing, which is used to integrate all sensorial and perceptual information, presents various advantages, such as the reduction of latency times and the detection thresholds, the presentation of coherent and unified world knowledge, and the use of compensatory strategies when sensorial deficits affect one modality. Auditory–visual stimuli generate faster responses than those from one isolated modality. This crossmodal advantage is based on the neuronal co-activation mechanism, which allows enhanced performances (Booth et al., 2002; Calvert, 2001; Molholm et al., 2004, 2006; Ross, Saint-Amour, Leavitt, Javitt, & Foxe, 2007; Saint-Amour, De Sanctis, Molholm, Ritter, & Foxe, 2007; Taylor et al., 2006). Crossmodal visual–verbal competence is a crucial integrative processing strategy that is used in daily life. Consequently, its assessment in patients with gliomas, which affects various brain areas and solicits plasticity and connectivity mechanisms, is of theoretical interest. Clinically, the question is whether and how patients' crossmodal processing compensates for deficits that affect one modality. The answer to this question might enhance recovery during the post-surgical period.

To refine the evaluation of multimodal processing, we used four paradigms and 11 tasks (i.e., 3 matching tasks, 6 learning tasks, 1 dual-attention task, and 1 visual–verbal picture-naming task).

We sought to accomplish the following: (a) describe the strengths and weaknesses of patients' multimodal processing after accounting for the task specificity as well as the individual performances of the patients compared to those of the control group; (b) examine the correlation between lesion localization and impairments; and (c) identify which tasks were most sensitive to tumor infiltration and plasticity limits.

METHOD

Participants

Ten adult patients (5 men, 5 women) who participated in awakened surgery with a direct electrical stimulation technique were recruited from the Neurosurgery Department of the Pitié-Salpêtrière Hospital, Paris, France. All patients presented gliomas (astrocytoma, oligodendrioma, or oligoastrocytoma). Five were diagnosed as Grade II, and five appeared after histology with micro anaplasia infiltration and were classified as Grade III according to OMS classification. A neuropsychologist administered the protocol during the preoperative cognitive and language diagnosis session. Table 1 presents clinical characteristics of the patients.

Sixty control participants (6 per patient) matched on age, gender, laterality, and socio-cultural level were recruited from the Paris community as well as from among the patients' relatives.

All participants provided written informed consent before the testing began. Table 2 presents participant characteristics.

Procedures and materials

Participants were assessed on the capacity: (a) to match stimuli (*matching tasks*) in a visual task (halves of visual objects), an auditory task (halves of spoken words), and a crossmodal task

TABLE 1
Patient clinical characteristics

Patients	*Sex*	*Age (years)*	*Tumor site*	*Tumor type*	*Tumor size 3D/SEGM*
JV	M	29	Right fronto-temporo-parietal	Oligoastrocytoma Grade II–III *	245.5 178.9
AG	F	32	Right fronto-temporo-insular	Astrocytoma Grade II–III*	52.4 56.6
JG	M	29	Left temporal	Oligoastrocytoma Grade II	58.7 69
GT	M	23	Left fronto-temporo-basal	Oligodendrioma Grade II	100.7 59
RL	M	35	Right temporo-insular	Oligoastrocytoma Grade II	28.7 28.2
PL	M	32	Left frontal	Oligodendrioma Grade II	27.5 27.7
CP	F	33	Left fronto-callo-parieto-cingular	Oligoastrocytoma Grade II–III*	359.3 211.4
FR	F	35	Right fronto-temporo-insular	Oligodendrioma Grade II–III*	106.3 105.4
FM	F	35	Right parietal	Oligoastrocytoma Grade II–III*	63.7 66.2
SB	F	35	Right fronto-temporo-insular	Oligodendrioma Grade II	17.2 19.4

*Grade III micro sites infiltration diagnosed with postsurgical histology.

TABLE 2
Group characteristics

	Glioma group (n = 10) Mean (SD)	*Control group (n = 60) Mean (SD)*
Age (years)	31.8 (3.9)	29.3 (4.1)
Male:Female	5:5	30:30
Education (years)	16.3 (2.4)	17.2 (2.8)
Handedness	4 L–6 R	24 L–36 R

(simultaneous picture and spoken word); (b) to recognize meaningful stimuli (*learning-meaningful tasks*) in a visual task (faces), an auditory task (first names), and a crossmodal task (simultaneous faces and first names); (c) to recognize non-meaningful stimuli (*learning-non-meaningful tasks*) in a visual task (graphic signs), an auditory task (pseudo-words), and a crossmodal task (simultaneous graphic signs and pseudo-words); (d) to retrieve cues (*dual-attentional task)* simultaneously in visual and auditory condition; and (e) to name picture of objects (*picture-naming task*).

The experimental protocol was created with E-Prime 1.1 (Psychology Software Tools, Inc., Pittsburgh, PA). Participants were seated in front of a 17-inch computer at a viewing distance of approximately 70 cm. Participants were tested individually in a single session that lasted approximately 45 minutes. Tasks order was counterbalanced across participants and preceded by a training phase, allowing the participant to be familiarized with the task principles before the test session.

Unimodal and crossmodal matching tasks

In the unimodal conditions, participants were presented two halves of stimuli. In the visual condition, these were presented simultaneously (one on the left and one on the right), and in the auditory condition, the two halves were presented sequentially to both ears, separated by 750 ms of silence. Pictures in the crossmodal condition and the visual unimodal condition were displayed for 2000 ms, and the mean duration of the unimodal auditory condition was 600 ms. Participants were instructed to decide whether the two stimuli ‘went together’ and to press the ‘S’ or the ‘L’ keys of a French keyboard, respectively, to indicate whether the two stimuli were congruent or incongruent. These keys were identified by two colored labels (green for ‘same’ and red for ‘different’) and were counterbalanced across participants. Correct responses (CR) were recorded and corresponding response times (RTs) were measured from the onset of the

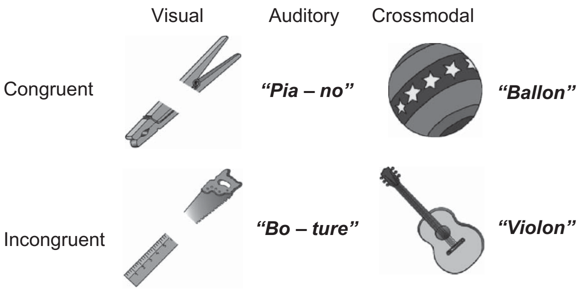

Figure 1. Example stimuli belonging to the matching task.

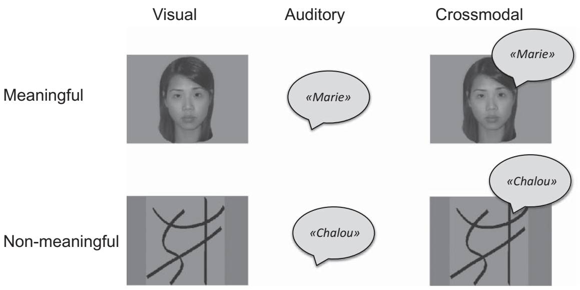

Figure 2. Example stimuli belonging to learning task.

presentation of the picture or picture halves and in the unimodal auditory condition, at the onset of the second sound half.

Stimuli in the unimodal visual and unimodal auditory conditions were constructed by halving stimuli from the respective modality in the crossmodal conditions (i.e., visual and auditory), and presenting two stimuli halves for congruency decisions. Half the trials in each condition were congruent (e.g., the two visual halves constituted a real object, such as a clothespin and the two auditory halves constituted a real word, such as 'pia-no') and half were incongruent (e.g., the two visual halves were parts of two objects and the two auditory stimuli were parts of two words). The crossmodal stimuli consisted of 70 color pictures of objects (Rossion & Pourtois, 2004), each simultaneously paired with a spoken word. Half of the trials were congruent (e.g., the sound 'ball' and picture of a ball) and half were semantically ('violon' and picture of a guitar) or phonologically ('elevant' and picture of an elephant) incongruent (see Figure 1).

Unimodal and crossmodal learning tasks

During each of the 6 tasks, we presented eight sequences of stimuli. Three were meaningful, and three were non-meaningful. After displaying a black screen for 3000 ms participants briefly observed a target stimulus (2000 ms for visual, 600 ms for auditory). The target appeared two or three times within three or four distracters. There were 20 matched targets in each task. Subjects determined whether – in each sequence – the meaningful stimuli (a face, a first name, or a face/first name pair) and the non-meaningful ones (a graphic sign, a pseudo-word, or a graphic sign/pseudo word pair) matched the target by pressing the 'S' or the 'L' keys of a French keyboard, respectively. These keys were identified by two colored labels (green for 'same' and red for 'different'). The two-unimodal conditions were presented before the crossmodal one. CR and RTs were recorded from the stimuli onset until the participant's manual response.

In the meaningful condition, the visual stimuli consisted of black and white photographs of neutral faces (36: 18 female, 18 male), extracted from the CAL/PAL face database (Minear & Park, 2004) and constructed with Adobe Photosphop; the auditory stimuli consisted of 36 frequent disyllabic first names registered by a feminine voice with Adobe Audition, and the crossmodal stimuli consisted of 36 photographs of faces that were each simultaneously paired with a first name (see Figure 2).

In the non-meaningful condition, the visual stimuli consisted of 36 black and white pictures of abstract graphic signs constructed using Adobe Photoshop; the auditory stimuli consisted of 36 disyllabic pseudo-word spoken by a feminine voice using Adobe Audition and the crossmodal stimuli consisted of 36 pictures of abstract graphic signs, which were each simultaneously paired with a disyllabic pseudo-word.

Dual-attentional task

The subjects listened to a story while crossing service stations on a road card, and then orally recalled the story. In case of poor recall, 10 questions about the story were asked. The scores include the number of crossed service stations (requiring visual attention and graphic activity) and the number (maximum 10) of recalled story elements (auditory attention and working memory).

The visual stimuli consisted of a color picture of a road sign with 80 targets symbols (e.g., a gas station). The auditory stimuli consisted of a story (narrated by a feminine voice and registered using Adobe Audition) that included 10 salient auditory events. Both visual and auditory stimuli were presented in the dual-attentional task.

Picture-naming task

The participants were instructed to name the 70 color pictures of objects (Rossion & Pourtois, 2004). A total processing time was calculated, including hesitations, corrections, and latencies.

Statistical analyses

We compared performances using non-parametric tests due to the small sample size. The Mann–Whitney *U*-test compared: (a) the mean performance of the control group to that of the group of patients; (b) the mean performance of patients with Grade II vs. Grade III gliomas; and (c) the mean performance of right vs. left tumors. The level of statistical significance was set at $\alpha = .05$. Furthermore, the *Z*-score of each patient was compared to that of his or her control group counterparts.

RESULTS

Group performance comparisons

Patients vs. controls

The non-parametric analyses showed the following characteristics of patients with gliomas: (a) performed similar to the control group with regard to the unimodal visual and crossmodal conditions within the *matching tasks* but were significantly weaker than controls in the unimodal auditory condition; (b) performed similar to the control group with regard to unimodal and crossmodal *learning tasks*; (c) performed significantly worse than the control group with regard to the visual portion of the *dual-attentional task* and were slightly weaker than controls for auditory recall; and (d) performed significantly worse than the control group with regard to the *picture-naming task* (see Table 3). The differences were minimal for accuracy but more significant for time, which demonstrates a slower lexical access.

Grade II vs. Grade III

There were no significant differences.

Left vs. right tumors

There were no significant differences.

Individual profiles

Each patient's performance was compared to a normal performance by converting their data to *Z*-scores (i.e., standardized scores), which represent the magnitude of the difference between patient performance and control participant performance in terms of control-participant standard deviations,

TABLE 3
The means (±*SD*) of patient and control participant scores (and RTs when required) as well as their Mann–Whitney *U*-test statistics and *p* values on the unimodal and crossmodal integration

Task	*Condition*	*Patients* *(n = 10)*	*Control group* *(n = 60)*	*Mann–Whitney* U-*test*	*p-Value*
Matching tasks	Visual unimodal: Picture (P)	22.5 (1.2)	22.7 (1.1)	52.5	*ns*
	Auditory unimodal: Word (W)	22.1 (1.5)	23.0 (1.1)	185	<.05
	Crossmodal: Picture/Word (P/W)	68.8 (0.1)	69.0 (0.9)	288.5	*ns*
Learning-meaningful tasks	Visual unimodal: Face (F)	62.0 (2.9)	62.8 (1.5)	279.5	*ns*
	Auditory unimodal: First Name (N)	63.9 (0.3)	62.8 (1.5)	264.5	*ns*
	Crossmodal face/first name (F/N)	63.2 (1.3)	63.1 (1.3)	288.5	*ns*
Learning-non-meaningful tasks	Visual unimodal: Graphic sign (GS)	60.3 (4.5)	61.9 (1.9)	293.5	*ns*
	Auditory unimodal: Pseudo-word (PW)	63.5 (1.0)	63.6 (0.6)	305.0	*ns*
	Crossmodal: sign/pseudo-word (GS/PW)	61.9 (2.4)	62.4 (1, 4)	291.0	*ns*
Dual-attentional task	Visual processing (ATTvis)	49.9 (12.5)	69.8 (6, 8)	90.0	<.001
	Auditory processing (ATTaud)	5.8 (1.3)	6.0 (1.4)	202.7	*ns*
Picture-naming task	Picture naming score (PN)	68.8 (0.7)	69.6 (0.6)	128	<.01
	Processing time in sec (PN time)	145.1 (28.2)	111.6 (16.6)	89	<.001

TABLE 4
Patients' individual *Z*-scores

	P	*W*	*P/W*	*F*	*N*	*F/N*	*GS*	*PW*	*GS/PW*	*ATTvis*	*ATTaud*	*PN*	*PN time*
JV*	−1.4	0	0	0	0	0	0	0	0	−1.6	0	0	−1.9
AG*	−1.4	−3.2	−2.9	0	0	0	0	0	0	−3.4	0	−4	−3.7
JG	0	0	0	0	0	0	0	0	0	−2.4	−1.4	0	−1.3
GT	0	0	0	0	0	0	0	0	0	−3.5	−1.4	0	0
RL	0	0	−3.8	0	0	0	0	0	0	−2.3	−1.4	−1.7	0
PL	0	−8.4	0	−8.4	0	−1.6	−1.4	0	−2.6	−1	1.4	0	0
CP*	0	−2.9	0	0	0	0	0	0	0	−0.7	0	0	−2
FR*	0	0	0	−9.4	0	−2.6	−6.9	−2.7	0	−1.8	0	0	0
FM*	0	−1.7	0	−3.8	−1	0	−1.5	0	−3.2	−2.9	0.7	−2.9	−3.8
SB	0	0	0	0	0	0	0	0	0	−1.5	−0.3	0	−1.7

*Grade III micro sites infiltration diagnosed with postsurgical histology.
P, Picture; W, Word; P/W, Picture/Word; F, face; N, First name; F/N, Face/First name; GS, Graphic sign; PW, Pseudo-word; GS/PW, Graphic sign/Pseudo-word; ATTvis, visual processing; ATTaud, auditory processing; PN, Picture naming score; PN time, picture naming time.

e.g. [(mean control participant performance)–(mean patient performance):(standard deviation of control participant performance)]. We considered all scores under −1 *SD* as 'weak' and under −1.6 *SD* as 'impaired' (see Table 4).

Patient 1: J.V. The patient, a 29-year-old, left-handed man, was diagnosed with a right Grade III temporo-fronto-parietal oligoastrocytoma. J.V. showed an average or above average performance on the auditory and crossmodal matching tasks but performed poorly on the visual matching task (−1.43 *SD*). He performed accurately on all learning tasks. He was deficient on the visual portion of the crossmodal attention task (−1.6 *SD*) but average on the verbal portion. He was significantly slow (−1.91 *SD*) but accurate at naming pictures.

Patient 2: A.G. The patient, a 32-year-old, right-handed woman, had a right Grade III fronto-temporal astrocytoma that partially included the insula. A.G. showed a significantly impaired performance on the unimodal auditory (−3.28 *SD*) and crossmodal (−2.91 *SD*) matching tasks and was weak on the visual matching task (−1.41 *SD*). She performed similar to controls on all learning tasks. She showed an impaired performance on the visual portion of the crossmodal attention task (−3.4 *SD*) but an average performance on the visual portion. She demonstrated an impaired performance on naming accuracy (−4 *SD*) and speed (−3.73 *SD*).

Patient 3: J.G. The patient, a 29-year-old, right-handed man, had a left Grade II temporal oligoastrocytoma. He performed similar to controls on the matching and learning tasks. He demonstrated an impaired performance on the visual portion of the attention task (−2.4 *SD*) and a weak performance on the verbal portion (−1.4 *SD*). He was slightly slower than average (−1.33 *SD*) but accurate at naming pictures.

Patient 4: G.T. The patient, a 23-year-old, right-handed man, had a left Grade II fronto-temporal and fronto-basal oligodendrioma. G.T. performed similar to controls on the matching and learning tasks. He showed an impaired performance on the visual portion of the attention task (−3.5 *SD*) and was weak on the verbal portion (−1.4 *SD*). He was accurate at naming pictures.

Patient 5: R.L. The patient, a 35-year-old, right-handed man, had a right Grade II temporal oligoastrocytoma that included the insula. R.L. showed an average performance on the auditory and visual conditions but an impaired performance on the crossmodal condition (−3.81 *SD*) of the matching tasks. He performed all learning tasks similar to controls. He showed an impaired performance on the visual portion (−2.3 *SD*) and a weak performance on the verbal portion (−1.4 *SD*) of the attention task. He was slow at naming pictures (−14.77 *SD*), and his naming score was deficient (−1.78 *SD*).

Patient 6: P.L. The patient, a 32-year-old, right-handed man, had a left frontal Grade II oligodendrioma. P.L. showed an impaired performance in the auditory condition (−8.44 *SD*) but an average performance in the visual and crossmodal conditions of the matching tasks. He showed impaired performances for faces (−8.44 *SD*), crossmodal face/first name (−1.65 *SD*), and crossmodal signs/pseudo-words (−2.62 *SD*) as well as slightly weak performances for signs (−1.46 *SD*). He had average scores on the two auditory learning tasks (first names and pseudo-words). His attention scores were slightly weak (−1 *SD* for the visual portion and −1.4 *SD* for the auditory portion). He was accurate but slightly slow at naming pictures (−1.2 *SD*).

Patient 7: C.P. The patient, a 33-year-old, right-handed woman, had a left frontal Grade III parietal cingular oligoastrocytoma. C.P. showed an impaired performance in the auditory condition (−2.9 *SD*) but an average performance on the visual and crossmodal conditions of the matching task. He was accurate on the learning tasks, his attention scores were average, and his picture naming was accurate but slow (−2 *SD*).

Patient 8: F.R. The patient, a 35-year-old, right-handed woman, had a right Grade III fronto-temporo-insular oligodendrioma. F.R. showed an average performance on all matching tasks. Although she demonstrated an impaired performance on the visual (−9.44 *SD* for faces and −6.94 *SD* for signs), auditory (−2.7 *SD* for pseudo-words), and crossmodal face/first name (−2.62 *SD*) learning tasks, her crossmodal sign/pseudo word task score was average. FR also was deficient on the visual portion (−1.8 *SD*) but accurate on the verbal portion of the attention task. She was slow at naming pictures (−4 *SD*).

Patient 9: F.M. The patient, a 35-year-old, right-handed woman, had a right Grade III parietal oligoastrocytoma. F.M. showed a deficient performance on the auditory judgment task (−1.78 *SD*). She had an average performance on the visual and crossmodal matching tasks. In the learning tasks, she demonstrated impaired performances for faces (−3.8 *SD*) and crossmodal signs/pseudo words (−3.24 *SD*), weak performances for first names (−1 *SD*) and signs (−1.54 *SD*), and average performances for pseudo words and crossmodal faces/first names. She showed an impaired performance in the visual portion of the attention task (−2.9 *SD*) but an above average performance in its verbal portion. She showed an impaired performance in picture naming accuracy (−2.9 *SD*) and speed (−3.82 *SD*).

Patient 10: S.B. The patient, a 35-year-old, right-handed woman, had a right Grade II oligodendroma that affected her frontal lobe, amygdala, insula, and the ventral part of the striatum. S.B. showed an average performance on all matching tasks. She performed the learning tasks similar to controls. She showed a weak performance on the visual portion of the attention task (−1.5 *SD*) but an average one on its verbal portion. She was significantly slow (−1.78 *SD*) but accurate at naming pictures.

DISCUSSION

We preoperatively compared the multimodal processing of 10 patients with gliomas to 60 control participants. Although the patients as a whole performed efficiently on most tasks, our results show that they also exhibited difficulties on the productive picture-naming task, the receptive verbal judgment task, and visual/graphic portion of the dual-attention task. Their case reports show that these difficulties were distributed across the patients.

Matching tasks

The matching tasks required successive or simultaneous visual and auditory attention. Participants must decide whether two auditory (words), visual (pictures), and crossmodal (pictures and words) stimuli are related to an object (congruence) or different from an object (incongruence). Areas of the heteromodal cortex, including the STS, are consistently implicated in the integration of identity and spatial information. The insula might affect the detection of crossmodal coincidences and participate in crossmodal matching. Regions of the frontal cortex might have a more task-dependent role in the perception of inputs across multiple modalities in normal subjects (Calvert, 2001).

Four patients (J.G., G.T., F.R., and S.B.) showed average performances on the 3 tasks, whereas the others had dissociated performances. Auditory judgment was the most impaired perception of the 3 tasks, being difficult for 4 patients. This task requires listening to portions of two words and deciding whether they form a real word. It solicits auditory attention and encoding, phonological processing, judgments of congruence and incongruence, as well as semantic decision. The patient who showed the most impairment on this task, P.L. (−8.44 *SD*), had a Grade II glioma that infiltrated his left frontal lobe. This structure is implicated in phonological and judgment skills. In contrast, he performed normally on the visual and crossmodal judgment tasks and was slightly slow at picture naming. The 4 patients who performed poorly on this task (A.G., P.L., C.P., and F.M.)

had right fronto-temporal, left frontal, or right parietal gliomas. These impairments suggest *a fine-grain 'gnosis' difficulty in phonological analysis and blending*, which contrasts with the superior phonological encoding of pseudo-words and the semantic encoding of first names during the auditory learning tasks. R.L., who had a right temporal Grade II glioma that included the insula, had efficient unimodal skills but an impaired crossmodal task performance. He was also slow at picture naming (−14.77 *SD*) and deficient on accuracy (−1.78 *SD*). A.G., who had a right fronto-temporal Grade II–III glioma that partially included the insula, had a significantly weak or impaired performance on the unimodal auditory, visual and crossmodal tasks as well as an impaired performance on naming accuracy (−4 *SD*) and speed (−3.73 *SD*).

The weak accuracy and speed of picture naming bounded with crossmodal judgment difficulty suggests a *vulnerability in the bridge between pictures and words, which results in longer latency times during multimodal naming (from pictures to verbal labels) and greater uncertainty during visual/verbal integration.*

Thus, judgment impairments in auditory and phonological congruence were more frequent than within visual and crossmodal conditions; moreover, they were independent of lesion localization, tumor type, and laterality. In 4 patients (J.V., P.L., C.P., and F.M.), crossmodal processing compensated for impairments that affected one modality. According to the inverse efficiency principle, unimodal processing is less efficient and crossmodal integration responses are stronger due to multimodal neuron intervention.

Learning tasks

The learning paradigm requires successive or simultaneous visual and auditory attention. In addition, this paradigm solicits working memory and flexibility as the targets change. The participants must decide whether visual (graphic signs, faces), auditory (pseudo words, first names), and crossmodal (graphic signs/pseudo words; faces/first names) stimuli are the same (congruence condition) or different (incongruence condition).

Gonzalo, Shallice, and Dolan (2000) attempted to identify the time-dependent neural changes related to associative learning across sensory modalities. Control participants were exposed to consistently and inconsistently paired audiovisual inputs as well as to single visual and auditory stimuli. They learned which audiovisual pairs were consistent over the training period. Time-dependent effects during the acquisition of these crossmodal associations were identified in the posterior hippocampus and the superior frontal gyrus. Additional activations associated with the learning of consistent pairs included the medial parietal cortex and the right DLPFC.

Five patients with gliomas in the right, temporal, parietal, insular (J.V., A.G., R.L., and S.B.), the left temporal (J.G. and C.P.), or the fronto-temporal and fronto-basal regions (G.T.), normally performed all 6 tasks. A patient (F.R.) with a Grade III right fronto-temporo-insular glioma showed an impaired performance on 4 of the 6 tasks. In other words, she compensated for unimodal impairments via crossmodal processing both visual stimuli (faces and signs) and one auditory stimulus type (first names). In this case, the learning paradigm refined difficulties and suggested a remediation axis.

Thus, learning unimodal and crossmodal tasks that solicit complex skills were relatively spared in these patients and appeared independent of lesion localization, tumor type and laterality. The learning paradigm was easier than the judgment paradigm probably because *novel* pairs of stimuli are *unrelated to daily life*, whereas picture/word *obligatory* associations are under semantic and phonological constraints. The learning paradigm requires working memory matching, whereas the judgment paradigm requires long-term memory matching.

The contrasting results between the judgment and learning paradigms confirms that the most prominent difficulties concern the *vulnerability in the bridge between pictures and words as well as access to long-term memory.*

Dual-attentional tasks

The double-task attention paradigm solicits simultaneous visual and verbal attention, which is resistance to interference, auditory/verbal working memory, semantic processing, as well as motor (graphic crossing) and verbal production (story recall). We sought to investigate whether visual processing and visual selectivity in a concurrent attention task affected the requirement to encode and maintain a spoken auditory story. When 2 tasks must be performed simultaneously, performance frequently declines. These dual-task costs are ascribed to attentional limitations (e.g., Pashler & Johnston, 1998).

The results show that the visual portion of the dual-attention task was impaired in 5 patients (A.G., J.G., G.T., R.L., and F.M.) and weak in all others (S.B., B.R., J.V., F.R., and P.L.). The double task constrained cognitive processing, which resulted in a reduced allocation of resources to visual activity. Specifically, the latter was slowed, erratic, or both, whereas verbal activity was correctly processed.

Gherri and Eimer (2010) conducted an ERP study in which healthy participants performed a visual search task and concurrently encoded and maintained an auditory story. Their results revealed a significant slowing of visual search targets in encoding relative to the control condition, which suggests that the memorization of verbal material might have adverse effects on the attentional processing of visual information and impair performance in concurrent visual search tasks. Our results have theoretical implications that are consistent with the findings of Strayer and Drews (2007). Specifically, our results contradict the hypothesis that attentional resources are modality-specific and provide evidence for the existence of crossmodal attentional links between audition and vision (see also Eimer & Driver, 2001; Strayer, Drews, & Johnston, 2003). These links can result in dual-task costs when attention is divided between auditory and visual tasks.

In our study, the active processing and maintenance of auditory information produced heavier costs in the visual search task for patients with gliomas compared to the control group. Thus, the dual-attentional task appears to be a relevant method to assess divided attention across modalities, regardless of the location or the type of the tumor. *This result fits with the common patient complaint of having difficulty with performing multiple tasks.*

Picture-naming task

Picture naming requires successive multimodal processing: visual identification to verbal production. The naming sub-processes involve the following: (i) visual object recognition and conceptualization at 0–175 ms post-stimulus (requiring the occipital and ventrotemporal regions); (ii) the selection of a corresponding semantic–syntactic representation (a lemma) from the mental lexicon at 175–250 ms, which is associated with the midsection of the left middle temporal gyrus; (iii) phonological code retrieval at 250–330 ms (requiring the posterior portions of the left middle and superior temporal gyri; i.e., Wernicke's area); and (iv) preparation of an oral output after 330 ms (engaging Broca's area in the left inferior frontal gyrus and bilateral sensorimotor areas; Vihla, Laine, & Salmelin, 2006). Thus, picture naming solicits various right and left regions simultaneously.

Within the overall network of regions activated, distinct sub-networks are observed for concept familiarity, word frequency, word length, or reaction time (Wilson, Isenberg, & Hickok, 2009). Familiarity modulates the signal in the occipital cortex and the fusiform gyrus bilaterally. Less frequent words lead to a larger signal in the left posterior ITG and the left temporoparietal cortex. Longer words are associated with larger signals in the primary auditory areas bilaterally, the STG and STS in the left hemisphere, and the cerebellum. Reaction time modulates some of these regions (e.g., the occipitotemporal cortex bilaterally and the left STS). In addition, a wide network of regions involved in executive and attentional processes includes the left IFG, left premotor cortex, bilateral anterior insula, and the pre-SMA (Wilson et al., 2009).

All but two patients demonstrated weak or impaired in naming performance, especially with regard to processing time. *The lexical access (from visual/semantic processing to phonological/motor production) was significantly slowed, although usually accurate*. In this regard, the weakest patients were R.L. (right temporal insular glioma), A.G. (right fronto-temporal glioma), and F.M. (right parietal glioma), who were impaired in both accuracy (-14.7 *SD*, -4 *SD*, and -2.9 *SD*, respectively) and speed (-1.7 *SD*, -3.73 *SD,* and -3.82 *SD*, respectively). F.R. (right fronto-temporo-insular glioma) and C.P. (left frontal glioma) were accurate but slow (-4 *SD* and -2 *SD*, respectively). Four of the 5 patients whose naming skill was weak or impaired had *right* gliomas. The glioma of the slowest patient, R.L. (-14.7 *SD*), infiltrated his right temporal insular region.

The implication of the right hemisphere in naming is controversial; some authors suggest that it merely compensates in cases of left lesions. In a recent study, Raboyeau et al. (2008) found a pattern of activity induced by lexical retrieval that involved two right hemispheric regions (i.e., the insular and the inferior frontal cortex) in both patients and control participants.

These results confirm the literature's observation regarding gliomas, which state that picture naming, especially naming processing time, is a significant marker of pathology that corresponds to the language difficulty that most patients complain about in their daily lives. In our sample, this marker had diverse locations but was particularly found in patients with right gliomas, whatever the tumor type.

CONCLUSION

Among the multimodal tasks, the sequential visual–verbal naming task and the double visual–auditory attentional task appear to be the best markers of pathology in patients with gliomas. Picture naming is classically included in clinical assessments; however, the addition of the dual-attentional task might be useful.

Performances on the unimodal and crossmodal matching and learning tasks are subject to high individual variation. They could be used to diagnose patients' perceptual difficulties and compensatory strategies and thus define a therapy axis.

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