Is Alzheimer's disease a disconnection syndrome? Evidence from a crossmodal audio-visual illusory experiment

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Abstract

In Alzheimer's disease (AD), loss of connectivity in the patient's brain has been evidenced by a range of electrophysiological and neuroimaging studies. However, few neuropsychological research projects have sought to interpret the cognitive modifications following the appearance of AD in terms of a disconnection syndrome. In this paper, we sought to investigate brain connectivity in AD via the study of a crossmodal effect. More precisely, we examined the integration of auditory and visual speech information (the McGurk effect) in AD patients and matched control subjects. Our results revealed impaired crossmodal integration during speech perception in AD, which was not associated with disturbances in the separate processing of auditory and visual speech stimuli. In conclusion, our data suggest the occurrence of a specific, audio-visual integration deficit in AD, which might be the consequence of a connectivity breakdown and corroborate the observation from other studies of crossmodal deficits between the auditory and visual modalities in this population.

Keywords : Alzheimer's disease ; crossmodal integration ; brain connectivity

1. Introduction

The disconnection hypothesis has been documented in Alzheimer's disease (AD) by a wide range of neuropathological, electrophysiological and neuroimaging studies (for a review, see Delbeuck, Van der Linden, & Collette, 2003). These studies have suggested that brain dysfunction in AD is better explained by a disturbance of the interactions between different brain areas rather than by alteration of a specific brain area.

Likewise, neuropathological studies have shown that the association cortices are particularly vulnerable in AD, leading to "deafferentation" and "deeefferentation" of associative brain areas from the rest of the brain (Damasio, Van Hoesen, & Hyman, 1990; Van Hoesen, 1990, 1997). For example, Gòmez-Isla et al. (1997) demonstrated that neuronal loss in higher-order association cortex (such as the superior temporal sulcus) parallels the chronological progression of dementia in AD (as evidenced by the correlation of changes in this area with disease duration and the severity of cognitive impairment).

Other evidence for a "disconnection view" of AD has also been obtained in the electrophysiological field. The initial work of Leuchter et al. (1992) - based on an electroencephalographic (EEG) coherence paradigm - demonstrated a decrease in electrophysiological synchrony between areas linked by corticocortical tracts crossing the Rolandic fissure (e.g., the superior longitudinal fasciculus) in AD. This decrease in EEG coherence has been confirmed in a number of other studies (Besthorn et al., 1994; Koenig et al., 2005; Le Roc'h, Rancurel, Poitrenaud, Bourgin, & Sebban, 1993; Locatelli, Cursi, Liberati, Franceschi, & Comi, 1998; Wada, Nanbu, Kikuchi, et al., 1998). In the neuroimaging field, a number of magnetic resonance imaging (MRI) or positron emission tomography (PET) studies also support the disconnection hypothesis. For example, Rose et al. (2000) used magnetic resonance diffusion tensor imaging techniques to show a significant decrease in associative white matter fibres (such as the superior longitudinal fasciculus, the cingulum or the splenium of the corpus callosum) in mild to moderate AD patients.

Hemisphere disconnection processes in AD patients' brains have also been documented in neuropathological (Tomimoto et al., 2004) andMRI (Wiltshire, Foster, Kaye, Small, & Camicioli, 2005) studies showing a reduction in the size of the corpus callosum. Moreover, loss of interhemispheric connectivity has also been observed in electroencephalographic coherence measurements and in PET studies (Azari et al., 1992; Horwitz, Grady, Schlageter, Duara, & Rapoport, 1987; Wada, Nanbu, Koshino, Yamaguchi, & Hashimoto, 1998). Taken as a whole, these data reveal disturbances in brain connectivity in AD (either between or within the hemispheres).

Despite this growing body of evidence from a variety of domains, the disconnection hypothesis in AD has only recently been studied from a neuropsychological viewpoint. Lakmache, Lassonde, Gauthier, Frigon, and Lepore (1998) examined the interhemispheric transfer of information through the corpus callosum in 10 mild to

moderate AD patients, to whom a set of tasks specifically designed to assess the transfer of motor, somesthesic and visual information (therefore attempting to cover different parts of the corpus callosum) was administered. On the whole, this study suggested a callosal deficit in AD, in view of the patients' worse performance in tasks where coactivation of both hemispheres was necessary. However, these results should be interpreted cautiously, considering (i) the small number of AD patients (n = 10), (ii) the inclusion of mild as well as moderately demented patients and (iii) a number of methodological problems (see Delbeuck et al., 2003). Recently, another study investigated the question of potentially disturbed, interhemispheric transfer in 23 AD patients (Reuter-Lorenz & Mikels, 2005) by using two visual experiments. The first paradigm was the Poffenberger task (evaluating the speed of a motor response to a stimulus displayed either in the right or left visual hemifield) and the second was a visual letter-matching and format-processing task performed either in an interhemispheric mode (where the stimuli for comparison are presented in different visual hemifields) or intrahemispheric mode (where both the stimuli are in the same visual hemifield). Apart from an overall impairment of performance in the AD group, the authors did not evidence a disproportionate alteration in interhemispheric processing (relative to intrahemispheric processing) in the AD patient group, compared with controls. This latter result reopens the debate as to whether interhemispheric disturbance is indeed present in AD; however, Reuter-Lorenz and Mikel's study only featured visual material and so does not necessarily contradict the above-cited study by Lakmache, which additionally identified motor and somatosensory impairments.

In addition to interhemispheric connectivity, Golob, Miranda, Johnson, and Starr (2001) investigated cortical connectivity in AD by means of the refractory effect. This consists in a reduced amplitude and latency of electrophysiological components observed for a stimulus when another has been presented just beforehand. The refractory effect has been observed for two consecutive stimuli belonging to the same sensory modality (visual stimuli, for example), as well as the case where the presented stimuli differ in their modality (more specifically, when an auditory stimulus is preceded by the presentation of a visual item; Davis, Mast, Yoshie, & Zerlin, 1966; Davis, Osterhammel, Wier, & Gjerdingen, 1972). Golob et al. (2001) demonstrated the presence of a refractory effect for intramodal situations (pairs of flashes of light or auditory stimuli) in young and elderly healthy participants, as well as in a group of AD sufferers and patients with mild cognitive impairment. However, when considering crossmodal situations (an auditory stimulus followed the presentation of a visual one), the authors noted the absence of a refractory effect for the AD patients, compared with the other groups. According to Golob et al., this observation might be the consequence of cortical disconnection between sensory areas in AD. Cortical connectivity in AD was also explored by Festa et al. (2005) in a behavioural procedure designed to evaluate the integration of information between cortical areas within a single hemisphere. The authors observed that the binding of two distinct visual features was possible in AD (i.e., motion and luminance) but was disturbed when this process necessitated greater cross-cortical interactions—for instance, when a cue that is usually processed by the dorsal visual stream (such as motion) was combined with a cue usually dealt with by the ventral visual stream (such as colour).

In the present paper, information integration and combination is also investigated; we sought to explore the disconnection hypothesis by using tasks calling on different sensory modalities In an everyday environment, people are confronted with information with differing sensory modalities but generated by the same event; these have to be integrated by associative areas of the brain in order to be correctly processed. To perform this information integration, connectivity within the brain is essential. A crossmodal effect was therefore explored in our first study via a paradigm involving audio-visual integration and administered to a population of AD patients and control participants, in order to assess potential McGurk effect. The McGurk effect (McGurk & MacDonald, 1976) is an audio-visual speech perception paradigm in which a visual input (an actor's lip movement) changes the auditory experience of the receptor. To observe this effect, participants are invited to discriminate between syllables on the basis of auditory and visual information. In the original experiment by McGurk and MacDonald, this was performed in the following manner; when the syllable /ba/ was presented on the auditory channel and the actor's lip movement formed the syllable /ga/, participants tended to produce the syllable /da/ as an answer, which is a fusion of the two syllables presented. On the other hand, when the syllable /ba/ was presented on the visual channel and the syllable /ga/ was transmitted on the auditory channel, participants combined both syllables (/bga/). One thus expects crossmodal illusion effects for these presentations of non-congruent syllable on the auditory and visual channel.

The McGurk paradigm involves processing of information from different modalities, and communications between different groups of neurons are necessary to produce the illusory effect. Considering the loss of connectivity that is postulated in Alzheimer's disease, a disturbance of this effect might be observed in this population, compared with controls.

2. Study 1

2.1. Method

2.1.1. Population

Two groups of participants (patients with AD and matched, elderly, non-AD control subjects) took part in this study and performed the McGurk experiment. The AD group consisted of 16 patients (4 men and 12 women) who met the NINCDS-ADRDA criteria for probable Alzheimer's disease (McKhann et al., 1984). The diagnosis of AD was based on extensive medical, neurological and neuropsychological examinations.

Sixteen elderly non-AD participants (matched for age, gender and time spent in education) served as controls. These participants were without behavioural or cognitive complaints and did not have any impairment in daily life functioning. The groups' demographic characteristics and overall cognitive function scores (on the Mattis Dementia Rating Scale, MDRS, Mattis, 1973) are presented in Table 1. The groups did not differ in terms of age (ranging from 50 to 84 for AD patients and from 51 to 82 for controls; $t(30) = 0.04$, $p = 0.96$) or education level (ranging from 4 to 17 years for the AD group and from 4 to 16 years for the controls; $t(30) = 0.16$, $p = 0.8$). The overall cognitive level for AD patients was significantly lower than for control participants (ranging from 99 to 136 for AD patients and from 131 to 144 for controls; $t(30) = -5.89$, $p < 0.01$).

Table 1 *Demographic characteristics and levels of overall cognitive function for AD patients and controls in study 1*

	AD	Controls
N (male/female)	16 (4/12)	16 (4/12)
Age (S.D.)	7.9 (8.2)	7.8 (8.3)
Years of education (S.D.)	9.3 (3.2)	9.1 (3.2)
MDRS (S.D.)	119.5 (9.8)	136.8 (3.9)

S.D.: standard deviation; MDRS: Mattis Dementia Rating Scale (Mattis, 1973).

2.1.2. Material and procedure

To elicit the illusion known as the McGurk effect, we used material which has been adapted (Colin, Radeau, & Deltenre, 1998) to induce a larger effect in French-speaking populations than the original material cited above. This material consists of four consonant-vowel monosyllables (bi, gi, pi, ki) articulated by a 24-year-old actor. Only the lower part of his face was filmed (from the top of the nose down to the chin). The material was built on a Panasonic AG-A770 editing controller.

The syllables were presented in pairs in two different blocks of trials (bi-gi and pi-ki). Congruent and incongruent combinations of these pairs of syllables on the visual and auditory channels were presented in each block; during congruent presentation, the syllable formed by the actor's lips is the one that is heard (the control situation), whereas in incongruent trials, the syllable heard is not the one that is seen (the McGurk condition). In total, 48 congruent and 48 McGurk trials (i.e., 24 using the syllables bi-gi and 24 with pi-ki) were presented to the participants, in random order. Half of the McGurk trials were situations eliciting a fusion illusion (which emerges when an auditory bilabial is dubbed with a visual non-bilabial; for example, a participant hearing "bi" and seeing "gi" will tend to report having perceived "di") and the other half corresponded to a combination illusion (for example, the answer "bgi" is observed when the bilabial "bi" is presented on the visual channel and the non-bilabial "gi" is presented on the auditory channel; see Table 2 for a summary of the illusory responses). Two different versions of the task were created and the order of presentation of the stimuli was counterbalanced in the two versions.

During the experiment, participants were seated in front of a table and approximately 50 cm from a 17-in. colour monitor. The audio signal was presented at an average level of 75 dB through two loudspeakers (one on each side of the screen). Participants were asked to watch the screen and report on what the speaker said by choosing from a list of alternatives written on a piece of paper placed in front of them (bi-gi-bgi-di for the bi-gi block of trials and pi-ki-pki-ti for the pi-ki block). The participants were also informed that if none of the proposition corresponded to what he/she had perceived, they could choose another response type which was called "other". Note also that the alternative answers were presented in a different order in each trial. Each trial ended with the participant responded—no time limit was set on answering.

Half of the participants began with the bi-gi block and half began with the pi-ki block. In order to familiarize the participant with the material, each block began with the presentation of two situations: a congruent trial and an

incongruent trial. Of course, participants were not informed that incongruent trials would appear throughout the experiment.

The results were analyzed separately for the congruent (control) and incongruent trials. In control trials (where the same syllable is heard and seen), the accuracy of the answer was the primary criterion, whereas the number of illusory answers (fusion or combination) was the variable of interest in incongruent trials.

Table 2 *Illusory responses expected in the different incongruent situations in the McGurk effect experiment*

Auditory channel	Visual channel	Illusory response
bi	gi	di (fusion)
gi	bi	bgi (combination)
Pi	ki	ti (fusion)
ki	pi	pki (combination)

3. Results

Performance in the control condition (congruent trials; see Table 3) was assessed using non-parametric statistics, taking into account the ceiling effect for scores in this condition. Mann-Whitney U tests were used to compare the groups' respective abilities (AD versus controls) to identify the syllables (bi, gi, pi, ki). No inter-group differences were observed ($p > 0.05$). Syllable identification accuracy was then compared using Wilcoxon's matched pairs test. These comparisons revealed that only the /gi/ syllable was less accurately identified than the other syllables (and mostly misidentified as "di"), in both groups.

In the McGurk condition (incongruent trials), the number of times the auditory stimulus was biased by the lip-reading information was counted and the number of fusion and combination answers was calculated (see Table 3). At first, we applied an analysis of variance (ANOVA) with group (AD, controls) as a between-subject factor and type of syllable pair (bi-gi, pi-ki) and type of illusion (combination, fusion) as within-subject factors. This analysis revealed a main effect of group ($F(1,30) = 1.47$, $p < 0.01$), with controls reporting more illusions than AD patients. We did not observe any significant interactions between group and the within-subject factors (type of illusion elicited and pairs of syllables used). However, the ANOVA revealed significant main effects for the type of syllable pair ($F(1,30) = 9.31$, $p < 0.01$; with more illusions using pi-ki than bi-gi) and the type of illusions ($F(1,30) = 4.21$, $p < 0.05$; combination illusions were observed more often than fusion illusions). There was also a significant interaction between these two factors ($F(1,30) = 17.78$, $p < 0.01$). We conducted further comparisons in order to investigate this interaction; there were no significant differences in the number of fusions for both types of syllable pair ($p > 0.05$) but there were significant differences in the number of combinations ($p < 0.01$), with more combination illusions elicited by the pi-ki material than by the bi-gi pair. Moreover, equal proportions of fusion and combination illusions were obtained with the bi-gi material ($p > 0.05$) whereas combination illusions were observed more frequently than fusion illusions with the pi-ki pair ($p < 0.01$). These observations of the number of illusions according to the conditions were generally similar to those observed by Colin et al. (1998) in a group of 36 university students.

In addition, we have compared the pattern of errors for the fusion and combination situation between the groups for incongruent trials. In both groups, when a fusion answer was expected (i.e., when an auditory bilabial syllable is dubbed with a visual non-bilabial syllable), other observed answers were mainly auditory based answers, i.e., participant answer was not influenced by the visual stimuli (e.g., when participants did not select the answer /di/ for fusion situations with the bi-gi material - the syllable /bi/ was presented on the auditory channel and the actor's lip movement formed the syllable /gi/ - they tended mainly to choose the syllable /bi/ as the perceived answer). Auditory-based answer for fusion situation were more frequent in AD patients than in controls (in fusion situation, proportion of AD patients' auditory based answers = 0.79 ± 0.26; proportion for controls of auditory based answers = 0.45 ± 0.4; $U = 6.5$, $p < 0.05$). Other kinds of answers (e.g., visually based answers) for fusion situations were less frequent and did not differ between the groups. When a combination answer was expected, the same pattern of result was observed, i.e., auditory based answers were the most frequent error and were more frequent in AD patients than in controls (in combination situation, proportion of AD patients' auditory based answers = 0.35 ± 0.36; proportion for controls of auditory based answers = 0.09 ± 0.12; $U = 61.5$, $p < 0.05$).

Table 3 *Proportions (and standard deviations) of expected answers for the congruent and incongruent presentation of stimuli during the McGurk experiment (study 1) for AD patients and matched controls*

	AD patients	Controls
Bimodal congruent presentation		
bi	0.98 (0.04)	1 (0)
gi	0.73 (0.38)	0.69 (0.37)
pi	0.99 (0.02)	0.99 (0.02)
ki	0.90 (0.22)	0.98 (0.04)
Bimodal incongruent presentation		
Fusion	0.14 (0.21)	0.49 (0.40)
Combination	0.42 (0.34)	0.57 (0.32)

4. Discussion

Results of this first study showed that the McGurk effect was less frequently observed in AD patients than in a matched control group - suggesting that speech perception is less influenced by lip-reading in AD. This observation was made on the basis of similar performance in congruent trials for both AD patients and age-matched controls.

However, this lesser visual influence on auditory stimuli during speech perception in AD might be related to this group's inability to process the visual information (i.e., the actor's lip movements) correctly. In their study on the McGurk effect in schizophrenia, de Gelder, Vroomen, Annen, Masthof, and Hodiamont (2002) checked this aspect by also examining the participants' lip-reading ability. They observed decreased lip-reading efficacy in schizophrenia. However, this difficulty was not correlated with the subjects' performance in the audiovisual integration condition, which led the authors to conclude that the impairment in the latter condition revealed an integration difficulty during speech processing in schizophrenia. However, this lip-reading condition might not be the most appropriate control condition to test for the ability to process visual stimuli. Indeed, lip-reading might also recruit a network involving multimodal areas that are involved in the integration of audio-visual speech. In this respect, Calvert et al. (1997) used functional MRI (fMRI) to show response amplification in the auditory cortex while participants were watching lip movements. This enhancement of the response of the auditory cortex might be mediated by a back-projection mechanism from a multimodal brain area. Impairment of this multimodal area might therefore lead to impairment of lip-reading, as well as difficulties in audio-visual speech perception. To test the independence of the reduced McGurk effect relative to a visual processing defect, control conditions other than lip-reading should be defined—for example, a condition in which different lip movements must be discriminated between but not identified.

For this reason, our second study involved a deeper examination of the McGurk effect in AD by considering the potential role of disturbance of visual unimodal processing on the occurrence of illusory answers. In addition to evaluation in the McGurk condition, AD patients and their matched controls were administered various control conditions, in order to evaluate their capacity to treat visual and auditory speech stimuli in isolation.

5. Study 2

5.1. Method

5.1.1. Population

A total of 38 right-handed subjects (19 patients with AD and 19 elderly, non-AD subjects) participated in this study. None of the participants were previously included in the first study. The AD group consisted of 4 men and 15 women who met the NINCDS-ADRDA criteria for probable Alzheimer's disease (McKhann et al., 1984). The diagnosis of AD was based on extensive medical, neurological and neuropsychological examinations.

Nineteen elderly, non-AD participants (matched for age, gender and time spent in education) served as controls. These participants were without behavioural or cognitive complaints and did not have any impairment in daily life functioning. The groups' demographic characteristics and overall cognitive function scores are presented in Table 4. The two groups did not differ in terms of age (ranging from 61 to 89 for AD patients and from 61 to 90 for controls; $t(36) = 0.12$, p = 0.91) or educational level (ranging from 8 to 18 years of education for the AD group and from 9 to 17 for the controls; $t(36) = -0.32$, $p = 0.75$). The overall cognitive performance of AD

patients (on the MDRS) was significantly worse than for control participants ($t(36) = -7.45$, $p < 0.01$).

Table 4 *Demographic characteristics and levels of overall cognitive function for AD patients and controls in the second study*

	AD	Controls
N (male/female)	19 (4/15)	19 (4/15)
Age (S.D.)	78.2 (7)	77.9 (6.8)
Years of education (S.D.)	11.6 (2.7)	11.3 (2.3)
MDRS (S.D.)	116 (9.8)	135.5 (5.7)

S.D.: standard deviation; MDRS: Mattis Dementia Rating Scale (Mattis, 1973).

5.1.2. Material and procedure

The material consisted of 4 different situations (one experimental condition and 3 control conditions). In the experimental condition, auditory and visual syllables (an actor's lip movements) were simultaneously presented to the participant. The syllables were either congruent (the syllable formed by the actor's lips is the one that is heard) or incongruent (the syllable heard is not the one that is seen, and so an illusory effect - the McGurk effect - might occur). The control conditions were designed to investigate the participant's performance under unimodal stimuli presentation conditions. The first condition consisted of the presentation of auditory syllables and the two others used visual presentation of the stimuli, which had to be either identified (lip-reading) or discriminated between (participants were asked to judge whether or not two lips movements were the same).

5.1.3. Experimental condition

The same procedure was used to elicit the McGurk effect as in the first study. Again, the results of the congruent and incongruent trials in this experimental condition were analyzed separately. For the bimodal congruent trials (where the same syllable is heard and seen), the accuracy of the participant's answer was scored. Incongruent presentations of the syllables on the auditory and visual channels were scored in terms of whether or not they elicited the expected illusory answer (i.e., fusion or combination answers).

5.1.4. Control conditions

The experimental condition was always administered first to the participants, in order to avoid a potential influence of the processing required during the control conditions (which might have affected participants in the McGurk condition by drawing their attention to the visual stimulus and its occasional incongruence with the auditory syllable). The control conditions were presented in a fixed sequence: visual discrimination, the auditory condition and lastly the lip-reading condition.

5.1.5. The visual discrimination condition

This situation was designed to assess the participant's ability to analyse lip movements in a discrimination task. In each trial, two lips movements forming a syllable (recorded on video, as in the experimental condition) were successively presented, and participants were asked to judge whether or not they were the same. The syllables to be discriminated were either bilabial (bi-pi) or non-bilabial (gi-ki) and were presented in two different blocks (the first block contained the syllables bi-gi and the second featured the syllables pi-ki). Forty-eight trials were performed and the accuracy of the discrimination judgment (same/different) was scored.

5.1.6. The auditory condition

Auditory processing was monitored by playing a syllable to the participants and then asking them to choose the heard syllable from a list. One of the syllables /bi/, /gi/, /pi/ or /ki/ (i.e., those used in the experimental setting) was presented through loudspeakers (at 75 dB) and participants then had to choose one of four alternative answers on a paper list. Forty-eight syllables (12 of each kind) were displayed in all, and the response accuracy was scored.

5.1.7. The lip-reading condition

Video presentations of articulated syllables were again used in this condition. Participants were requested to identify the syllable articulated by the actor, on the basis of a two-choice question. Half of the trials were performed with the syllables /bi/ and /gi/ (block 1), and the other half used /pi/ and /ki/ (block 2). Before the beginning of each block, the experimenter demonstrated to the participant that the articulation of each syllable

implies different lips movements and also asked them to articulate the two syllables themselves (/bi/-/gi/ for block 1 and /pi/-/ki/ for block 2). Next, the syllables were presented on the computer screen and participants had to state which of the two they had seen (a total of 48 trials were performed). Response accuracy was scored and then analyzed in the next section.

6. Results

The performance levels of the AD patients and their matched controls in the various conditions are presented in Table 5. In order to analyse the results from the experimental condition, we first examined the answers from both groups in the congruent trials and then performed a separate analysis of the illusions elicited by incongruent, bimodal presentation of auditory and visual stimuli. We analyzed bimodal, congruent presentation of the stimuli using non-parametric statistical tests, taking into account potential ceiling effects for the scores in both groups. Mann-Whitney U tests performed on the recognition scores for congruent presentation of the syllables (/bi/, /gi/, /pi/ and /ki/) did not reveal any significant ($p > 0.05$) differences between the AD patients and the controls. As in our first study, Wilcoxon matched pairs tests on syllable identification accuracy only revealed a difference for the syllable /gi/, which was less accurately identified than the other syllables by both groups.

For the McGurk situations, we carried out an ANOVA with group (AD, controls) as a between-subject factor and type of syllable pair (bi-gi, pi-ki) and type of illusion (combination, fusion) as within-subject factors. This revealed a main effect of group ($F(1, 36) = 4.25$, $p < 0.05$), with controls reporting more illusions in the incongruent trials than AD patients. Furthermore, a main effect of the type of syllable pair was observed ($F(1, 36) = 73.92$, $p < 0.01$), as well as a significant interaction between this factor and group ($F(1, 36) = 48.66$, $p < 0.0 1$). Additional comparisons highlighted fewer illusory answers with the /bi/-/gi/ material than with /pi/-/ki/ ($F(1, 36) = 2.31$, $p < 0.01$) in control subjects, although this was not observed in AD ($F(1, 36) = 0.22$, $p = 0.64$). Furthermore, this interaction also revealed that inter-group differences in terms of the number of illusions was significant for the pi-ki ($F(1, 36) = 9.36$, $p < 0.01$) material but not for bi-gi ($F(1, 36) = 0.64$, $p = 0.43$). This lack of effect might be due to the fact that the bi-gi material does not elicit many illusory answers (even in controls) and, consequently, might be less likely to reveal inter-group differences. As also reported above for our first study, a significant interaction between the material (syllable pairs) and the type of illusion (combination-fusion) was observed ($F(1, 36) = 25.66$, p < 0.01). This could be explained by the fact that the bi-gi material elicited fewer combination illusory answers in both groups than did pi-ki ($F(1, 36) = 28.88$, $p < 0.01$). No other significant ($p < 0.05$) effects were observed in this analysis.

Due to the low number of errors observed, the groups' performance levels in the three control conditions were investigated using a non-parametric Mann-Whitney U test. There were no significant inter-group differences in the visual discrimination condition ($U = 93$, $p < 0.08$), the auditory condition ($U = 120$, $p < 0.41$) or the lip-reading condition ($U = 95$, $p = 0.09$). Moreover, no effect of material (bi-gi versus pi-ki) was observed in any of the group for the lip-reading and discrimination condition ($p < 0.05$) but statistical analyses revealed that, in the auditory condition, the pi-ki material was more often accurately identified than the bi-gi stimuli ($Z = 2.84$, $p < 0.01$), although AD patients and controls performed equivalently with both kinds of material ($p < 0.05$).

Considering that there were statistical trends for differences between AD patients and controls in conditions involving visual stimuli, we consequently ran correlation analysis on order to guarantee that results in the McGurk condition were not a consequence of disturbed processing of unimodal information (either visual or auditory). These correlation analysis (using Kendall's tau coefficient) were applied to the total number of illusions for each AD patient (and to the number of either combination or fusion illusions) and their corresponding performance levels in the control conditions. No significant correlations were observed (see Table 6).

Table 5 *Proportions (and standard deviations) of expected answers in the different conditions of study 2, for AD patients and matched controls*

Condition	AD patients	Controls
Bimodal congruent presentation	0.88 (0.1)	0.88 (0.12)
Bimodal incongruent presentation (McGurk condition)		
Fusion	0.41 (0.37)	0.48 (0.35)
Combination	0.32 (0.34)	0.59 (0.27)
Visual discrimination	0.91 (0.12)	0.96 (0.09)
Auditory	0.95 (0.08)	0.97 (0.07)
Lip-reading	0.97 (0.04)	0.99 (0.02)

Table 6 *Correlations between the number of McGurk illusions (total, fusion and combination) in the AD group during study 2, together with the performance levels of these patients in the control conditions (correlations were expressed in terms of Kendall's tau coefficient)*

	Visual discrimination	Auditory	Lip-reading
Total number of illusions	$\tau = 0.14, p = 0.37$	$\tau = 0.07, p = 0.68$	$\tau = 0.016, p = 0.35$
Fusion	$\tau = 0.2, p = 0.24$	$\tau = 0.13, p = 0.42$	$\tau = 0.2, p = 0.22$
Combination	$\tau = 0.01, p = 0.97$	$\tau = -0.21, p = 0.22$	$\tau = 0.04, p = 0.79$

7. Discussion

As evidenced in the first study presented here, results in the incongruent audiovisual situation (the McGurk condition) showed a decreased number of illusions (fusion and combination) in AD patients compared with controls—especially with the pi-ki material. Nevertheless, AD patients discriminated congruent audiovisual presentation of syllables as accurately as control subjects did. Moreover, no significant inter-group differences were observed in terms of the ability to repeat syllables presented in an auditory modality, to discriminate lip movements or to read the syllables on an actor's lips. Concerning these two latter capacities, we did see some statistical trends to suggest that AD patients might have more difficulty processing visual speech stimuli than controls do. However, for the AD group, there was no association between the number of illusory answers observed in the McGurk condition and performance in the unimodal control condition (auditory, visual discrimination and lip-reading conditions).

These results confirm and extend our results from study 1, since they indicate decreased integration of crossmodal information during speech perception in AD. Furthermore, this observation appears to be independent of inter-group differences in the ability to process each sensory modality separately.

8. General discussion

The aim of this work was to investigate crossmodal processing in Alzheimer's disease with respect to a disconnection hypothesis. To explore this issue, we assessed the integration of auditory and visual stimuli for speech perception, by exploring the McGurk effect. Studies 1 and 2 demonstrated a decreased McGurk effect in a group of AD patients (compared with controls), even though both groups showed similar performance for congruent trials. Moreover, a deeper examination of this reduced crossmodal illusory effect (study 2) did not evidence an association between the effect and deficits in processing visual and auditory information separately, and consequently argues in favour of a specific alteration in an AD patient's ability to integrate these two sensory channels. The present results recall those obtained by de Gelder et al. (2002), who studied the question of audio-visual integration in a schizophrenic group using both a variant of the McGurk phenomenon and a task designed to assess audio-visual integration in the spatial localisation of sounds. As in our study, they observed an impairment of crossmodal integration for speech perception in schizophrenia, which was selective to the verbal task. Interestingly, schizophrenia has also been interpreted in terms of a disconnection process (see Friston, 1999; Peled, 1999).

This observation of a failure in audio-visual integration is also in accordance with previous works in AD patients showing disturbances of the interactions between the visual and auditory modalities. Indeed, as discussed above, Golob et al. (2001) have demonstrated that the presentation of a visual stimulus did not modify the electrophysiological response to a subsequent auditory stimulus in AD patients. Moreover, Drzezga et al. (2005) have showed more recently a crossmodal inhibition disturbance in AD patients. In this study, values of regional cerebral metabolic rate for glucose consumption were observed using PET, while participants were exploring a visual 3D virtual maze. In healthy participants, a crossmodal inhibition was observed during the task since a deactivation of auditory cortical areas was found (crossmodal inhibition), which might be the consequence of the strictly visual nature of the task performed. However, no deactivation in auditory areas was observed in the AD patients group, suggesting a lack of crossmodal inhibition in this group. These data thus argue for a disturbance in the interactions between the sensory modalities in AD in agreement with the decreased McGurk illusions in AD patients observed in our study.

Looking at the neural basis of McGurk might clarify why crossmodal processing of speech is impaired in AD patients. Activation of multisensory, integrative neurons (in heteromodal, associative brain areas) has been observed when participants are confronted with McGurk' situation. For instance, Calvert, Campbell, and Brammer (2000) used fMRI to show that the ventral bank of the superior temporal sulcus in the left hemisphere

showed the properties of a multisensory integration site during speech perception. Indeed, these authors observed a greater blood oxygen level-dependent (BOLD) response in this area for congruent audio-visual inputs (congruent and simultaneous presentation of speech stimuli on the auditory and visual channels) than for the sum of the unimodal presentation responses (auditory or visual presentation of a speech stimulus). Moreover, this brain area showed decreased BOLD responses when incongruent auditory and visual inputs were presented. More recently, Sekiyama, Kanno, Miura, and Sugita (2003) used fMRI and PET experiments to demonstrate a major role of the superior temporal sulcus in audio-visual integration during speech perception (see also Macaluso, George, Dolan, Spence, & Driver, 2004). In AD, a range of neuropathological studies have evidenced significant changes in this heteromodal area. For example, Gòmez-Isla et al. (1997) found that neuronal loss in the superior temporal sulcus parallels the chronological progression of dementia in AD and, furthermore, correlates with neurofibrillary tangle formation. Likewise, Buldyrev et al. (2000) identified dramatic disruptions to a cytoarchitectural feature (the so-called microcolumnar ensembles) within higher-order association cortex (in the superior temporal sulcus) of AD patients, compared with controls. From a neuroimaging view, the latter areas have also prompted interest as a means of predicting whether or not a given individual will develop Alzheimer's disease. Killiany et al. (2000) observed that MRI measurement of the banks of the superior temporal sulcus was a good discriminator between patients presenting memory problems that did not develop AD during a 3-year follow-up period and those who indeed developed AD (see also El Fakhri et al., 2003).

Taken as a whole, these data suggest that disturbance of audiovisual integration in speech perception in AD might be related to changes in the superior temporal sulcus. A disturbance in this heteromodal area of the brain might lead to disconnection of this area from other cortices (such as the auditory and visual areas) and disturb the audio-visual integration process. An explanation in terms of a loss of connectivity might also be formulated on the basis of a recent study conducted by Fingelkurts, Fingelkurts, Krause, Möttönen, and Sams (2003). On the basis of magnetoencephalographic experiments, these authors reported that temporal synchronization between different cortical sites underlies the phenomenon of audio-visual speech integration. Functional interactions between various cortical brain sites are therefore necessary to produce the McGurk effect. In AD, a loss of connectivity within this network of brain areas might therefore disturb integration and actually lead to observation of a weaker McGurk effect in patients, compared with controls.

An alternative hypothesis about the neuronal network impairment responsible for the McGurk effect disturbances in AD patients is an interhemispheric dysfunction. As reported in the introduction, different studies have highlighted the presence of disturbances of interhemispheric connectivity in AD (for a review, see Delbeuck et al., 2003). This loss of connectivity might affect the expression of this speech perception illusion in AD patients considering that a work by Baynes, Funnell, and Fowler (1994) has documented a decreased McGurk illusion in a case of callosotomy patient. In Baynes et al.'s study, a contribution of both hemispheres for the McGurk effect was also suggested from observations in control participants as for example, a more pronounced McGurk illusion was obtained when the speaker's face was projected in the left visual field (and thus projected to the right hemisphere) than in the right visual field. In the same vein, Diesch (1995) showed that fusion responses were more frequent when the material was presented in the left than in the right visual field, and that more combination responses arose from a right visual field presentation. Consequently, interactions and connectivity between the cerebral hemispheres play a part in the McGurk effect and a disturbance at this level could be another explanation for the decrease of the McGurk illusion in our AD samples. Further studies are thus necessary to disentangle the connectivity breakdown (either intrahemispheric or interhemispheric) that might be responsible for the decreased McGurk illusion observed in AD patients (this question might be clarified by the use of electrophysiological or neuroimaging techniques in combination to behavioural data). These future works should also considered the possibility that a decrease of the McGurk's illusion might not be a specific sign of AD but might also be present in other condition of cognitive disorders. In this perspective, future works should include patients with subcortical pathology such as patients with Huntington's disease, or brain-damaged patients with very focal cortical damage (such as stroke or traumatic brain patients).

However, these explanations of the participants' performance in terms of a cerebral connectivity disturbance should not prevent us from considering the possibility that an attentional factor might be involved. Indeed, early-stage AD is characterized by attentional deficits, which more specifically concern selective attention than sustained or divided attention (see Perry, Watson, & Hodges, 2000). However, a number of studies have suggested that audiovisual speech integration is a relatively automatic process which occurs before attention processes can intervene. Various behavioural data argue in favour of this automaticity (for example Massaro, 1987; Soto-Faraco, Navarra, & Alsius, 2004). Massaro (1987) showed similar response patterns regardless of whether subjects were explicitly instructed to focus attention on one of two information sources (visual or auditory) or on both. The independence of the McGurk effect vis-à-vis attentional focus might argue in favour of automaticity of the McGurk effect. Furthermore, electrophysiological studies also provide support for pre-attentive integration (see Colin et al., 2002) and suggest that the presentation of incongruent syllables on the auditory and visual channels is detected early on in the perceptual process. Nevertheless, a recent experiment

conducted by Alsius, Navarra, Campbell, and Soto-Faraco (2005) evidenced a decrease in the McGurk effect in participants under high attention demands (a dual task condition: the participants were concurrently performing an unrelated visual or auditory task). However, this decrease was observed using concurrent stimuli on the visual and auditory channels (which are also recruited for the McGurk effect) and therefore the participants' capacity to resist interference was evaluated - which was not the case for the AD patients in our present study. Here, patients and controls were in a focused attention situation which protected them from additional load on attention, consequently, this was a similar context to those used in the above-mentioned electrophysiological studies showing early multisensory integration.

In conclusion, our results indicate a deficit in audio-visual integration for speech perception in AD. In view of neuroanatomical findings on crossmodal integration effects (like the McGurk effect) showing that interactions between a wide range of cortical areas are necessary for this effect, one might hypothesize that this effect is disturbed by the loss of cortical connectivity observed in AD.

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