ELSEVIER

Schizophrenia Research 59 (2002) 211–218

SCHIZOPHRENIA RESEARCH

www.elsevier.com/locate/schres

Audio-visual integration in schizophrenia

Beatrice de Gelder*, Jean Vroomen, Leonie Annen, Erik Masthof, Paul Hodiamont

Cognitive Neuroscience Laboratory, Tilburg University, P.O. Box 90153, 5000 LE, Tilburg, The Netherlands

Received 9 September 2000; accepted 14 September 2001

Abstract

Integration of information provided simultaneously by audition and vision was studied in a group of 18 schizophrenic patients. They were compared to a control group, consisting of 12 normal adults of comparable age and education. By administering two tasks, each focusing on one aspect of audio-visual integration, the study could differentiate between a spatial integration deficit and a speech-based integration deficit. Experiment 1 studied audio-visual interactions in the spatial localisation of sounds. Experiment 2 investigated integration of auditory and visual speech. The schizophrenic group performed as the control group on the sound localisation task, but in the audio-visual speech task, there was an impairment in lipreading as well as a smaller impact of lipreading on auditory speech information. Combined with findings about functional and neuro-anatomical specificity of intersensory integration, the data suggest that there is an integration deficit in the schizophrenic group that is related to the processing of phonetic information.

Keywords: Schizophrenia; Cross-modal integration; Audio-visual perception; Ventriloquism; Speech processes

1. Introduction

In a natural environment the organism receives information though multiple sensory channels. Yet, the world is not perceived as consisting of a juxtaposition of independent sensory experiences in which the integrity of each modality is preserved intact. Rather, inputs from different sensory channels are often combined, providing an information-rich environment, which in turn presents the organism with a complex target for adaptive behaviour. Adaptive responses are thus the product of perceptual integration between different sensory modalities. This situation is found, for example, in spatial orientation, which is often based on a combination of auditory and visual cues, but also in audio-visual speech perception and in perceiving emotional cues provided by the face, the voice as well as by gestures. These cases and others are undoubtedly quite different among themselves, yet it is likely that for all of them continuous integration of multi-sensory inputs is at the basis of successful communicative behaviour. Since schizophrenic patients are known to experience many problems in interacting with the social environment, our goal was to investigate whether some of these difficulties might go back to impairments in processing cues with communicative value and in establishing inter-sensory integration between them.

There are many domains of perception in which inputs from different sensory modalities are combined.

---

* Corresponding author.
E-mail address: b.degelder@kub.nl (B. de Gelder).

0920-9964/02/$ - see front matter © 2002 Elsevier Science B.V. All rights reserved.
PII: S0920-9964(01)00344-9

One type of inter-sensory integration is that between audition and vision. Audio-visual integration has predominantly been studied in two domains of perception: space and speech. A very well known example of audio-visual spatial integration is ventriloquism (see Bertelson, 1998 for an overview). The ventriloquist produces speech without moving his lips, while his puppet seems to be talking. The ventriloquist illusion is very robust and consists in the fact that perceivers attribute the location of a sound to the apparent visual source (the puppet) rather than to its actual source (the ventriloquist). The ventriloquist illusion is a prime example of the general perceptual principle that when two or more sensory events are in close temporal proximity, but in slightly distinct spatial locations, they are generally perceived as emanating from a common source. A well-known experimental paradigm for investigating the ventriloquist effect is immediate cross-modal bias. Participants are asked to point to the location of an auditory stimulus and their pointing is attracted towards the location of a visual stimulus located at different position as the sound. The effect is automatic and mandatory and does not depend on attention to the visual input and even occurs when the viewer does not explicitly notice the presence of a visual stimulus as is for example the case in patients with unilateral neglect (Bertelson et al., 2000a,b; Vroomen et al., 2001, in press).

Audio-visual integration in the domain of speech perception is illustrated most dramatically by an experiment of McGurk and MacDonald (1976). They paired a video of a face articulating /ga/ in synchrony with a soundtrack of /ba/. This resulted in a 'heard' /da/. In the combined audio-visual condition, there were two types of responses: a "fused" response, where information from the two modalities was transformed into something new (e.g., visual/ga/ + auditory/ba/perceived as/da/), and a "combination" response representing a composite solution (e.g., visual/ba/ + auditory/ga/perceived as/bga/). Not only behavioural, but also electrophysiological studies found evidence for cross-modal effects in the perception of speech. Sams et al. (1991) demonstrated, by means of magneto-encephalography (MEG), that the characteristic response of the auditory cortex to heard speech could be modified by the inclusion of visible speech information. This shows that visual information from articulatory movements can have a cross-modal effect on auditory cortex (see de Gelder, 2000 for a model of cross-modal effects). It is also possible to investigate the brain regions involved in multi-modal processing by means of functional magnetic resonance imaging (fMRI). Calvert et al. (1997) used this technique to investigate the brain regions involved in silent lipreading in normal hearing subjects by comparing them with those activated during auditory speech perception in the same individuals. Silent lipreading not only activated visual cortex, but also primary auditory cortex, and activation in the latter region overlapped considerably with the region activated during heard speech.

Only very few studies have looked at audio-visual integration in schizophrenia. A number of neurological studies found impairments in audio-visual integration using cross-modal matching. Heinrichs and Buchanan (1988) reviewed several neurological studies of abnormal signs on clinical neurological examinations. They found that basic mechanisms of sensory input appear to be intact in schizophrenic patients. Impairments were found in three higher-order functional areas: the co-ordination of motor activity, the sequencing of motor patterns and the integration of more complex sensory units. Later results were based on studies of cross-modal matching. Ismail et al. (1998) investigated the prevalence and type of neurological abnormalities in schizophrenic patients and their nonpsychotic siblings. Both patients and siblings scored worse than comparison subjects did on integration of higher sensory functions. Ross et al. (1998) found an association between poor sensory integration and eye tracking disorder. They proposed that a circuit, which includes the posterior parietal cortex, subserves both smooth-pursuit eye movements and audio-visual integration. de Gelder et al. (1997) reported a study of audio-visual integration in schizophrenia. They measured the effect of a voice expression (happy or sad) on a face expression categorisation task using a morphed happy-to-sad face continuum. In normal controls, the recognition of a facial expression was biased towards the direction of the vocal expression, but the schizophrenic group did not show this bias.

The main objectives of our study were to explore whether schizophrenic patients show deficits in the cross-modal integration of audio-visual stimuli, and whether possible deficits are found in more than one domain where audio-visual integration is critical. Two tasks were administered, each focusing on one domain of audio-visual integration. The first task was intended to assess audio-visual interactions in the spatial localisation of sounds. The second task was a variant of the McGurk phenomenon (McGurk and MacDonald, 1976). If schizophrenic patients show a general deficit in audio-visual integration, performance on both tasks will be impaired and there should be a correlation between the two sets of results. But if the integration deficit is more specific, then one task might be impaired, but not the other.

2. Experiment 1

In experiment 1, the question is examined whether schizophrenic patients, like normal perceivers, are biased by a concurrently presented visual stimulus when pointing towards the origin of a sound.

2.1. Method

2.1.1. Participants

Eighteen schizophrenic patients (15 male, 3 female) participated in this experiment (mean age was 36.4 years; sd = 7.37; range = 23–51). All patients were under treatment at the local day care hospital. Only patients completely meeting the criteria for schizophrenia set by the DSM-IV (APA, 1994) were included. Patients differed concerning the characteristic course of symptoms over time. In 1 patient the course was continuous, and in 10 other patients it was characterised by episodes; 5 of them had inter-episode residual symptoms and the other 5 had inter-episode residual symptoms with prominent negative symptoms. The remaining 4 patients had a single episode, 1 of which was in partial remission, 1 in full remission and 2 in partial remission with prominent negative symptoms. All patients were on antipsychotic medication; 4 (27%) were receiving benzisoxasol, 2 (13%) thioxantheen, 4 (27%) thienobenzodiazepine, 3 (20%) butyrofenon, 1 (7%) fenothiazine and 1 (7%) dibenzodiazepine. Diagnoses were established with the Schedules for Clinical Assessment in Neuropsychiatry (SCAN), a standardised interview for diagnosing axe I disorders, conducted by two trained interviewers.

The control group consisted of 12 persons (11 male, 1 female), matched with the schizophrenic group for age and education. Their mean age was 41.2 years old (sd = 11.83; range = 22–57). This group was also screened through the SCAN. Subjects with a psychiatric disorder, a brain dysfunction or a genetic predisposition for schizophrenia were excluded from participation. Both groups were paid a small amount for participation.

2.1.2. Materials and procedure

Auditory stimulus material consisted of series of six pure tones of 1000 Hz, each lasting 190 ms presented through boxes placed next to each other behind the monitor of a microcomputer. The distance between the centre of the speakers was 8 cm at a distance of 115 cm from the subject's head (angle = 4°). The interval between the tones (ISI) was 750 ms. In half the trials the tone came from the left box, in the other half they came from the right box. Visual stimuli consisted of sequences of white squares of 20 × 20 mm, appearing on the left or right side on a 14-in. monitor (angle from centre to centre = 17°). They were synchronised with the tones and thus also appeared for 190 ms each with an ISI of 750 ms.

The experiment consisted of 48 trials, preceded by a small practice block of four trials. The two auditory stimuli (sound right, sound left) were orthogonally combined with three visual stimuli (square left, square right, no square) resulting in six conditions. Each condition was presented eight times. Participants were asked to locate the auditory stimulus in space, by pointing to it with the index finger. The finger was placed on a bow-shaped display of 75 cm that could be read by the experimenter to the nearest centimeter. Subjects were instructed to watch the screen while pointing to the location of the sound.

2.2. Results

Audio-visual integration in spatial localisation was measured by the average shift to the side of the square if compared to the no-square condition (Table 1). The schizophrenic group had a mean shift of 2.48 cm while the control group had a mean shift of 2.22 cm. The raw averaged pointing responses were submitted to a $2 \times 2 \times 2$ ANOVA with Square (left, right) and Sound (left, right) as within-subjects factors, and Group as between-subjects factor. The main effect of Group was not significant, $F(1,28) < 1$. The main effect of Sound was significant, $F(1,28) = 111.79$, $p < 0.001$, as sub-

Table 1
Mean pointing response (in centimeter) in the audio-visual spatial localisation task

		Schizophrenic group Square		Control group Square	
		Left	Right	Left	Right
Sound	Left	20.9	24.9	20.5	25.7
	Right	42.8	48.1	44.1	46.8

jects pointed more to the right when the auditory stimulus came from the right box, and they pointed more to the left when the auditory stimulus came from the left box. The main effect of Square was also significant, $F(1,22) = 11.75$, $p < 0.002$, reflecting the cross-modal bias effect. Subjects pointed more to the right when the square was on the right side of the screen, and they pointed more to the left when the square was on the left side of the screen. Importantly, the Group by Square interaction was not significant, $F(1,28) < 1$, thus showing that the cross-modal bias effect was essentially the same for both groups. All other interactions were nonsignificant (all F's < 1).

2.3. Discussion

When locating a sound in space, both the schizophrenic and the control group were biased towards the location of the visual stimulus, indicating that they showed a normal ventriloquist effect. As the schizophrenic group showed a normal pattern of performance in this task, we can conclude that their audio-visual integration in a spatial task is largely intact.

3. Experiment 2

In Experiment 2 the question was examined whether schizophrenic patients show an effect of lipreading on the recognition of auditory presented syllables. A comparison of these results with Experiment 1 might also allow to address the question whether there is a general as opposed to a domain-specific deficit in audio-visual integration.

3.1. Method

3.1.1. Materials and procedure

The stimuli consisted of a video recording of six different vowel–consonant–vowel utterances (/aba/, /ada/, /ata/, /apa/, /ama/, /ana/), pronounced by a female speaker. The audio was presented at a comfortable loudness level through boxes placed beside the PC screen. The video measured 11 × 9 cm, presented on a 14-in. colour monitor at a distance of approximately 80 cm.

There were three conditions, each containing 36 trials. The auditory-only condition was administered first, followed by the visual-only condition, and finally the audio-visual condition. In the auditory-only condition, only the auditory stimulus material was presented while the computer screen remained black. In the visual-only condition, a short video fragment (2.5 s) of the speaker's face articulating one of the speech tokens was shown. There was no sound, so subjects had to rely entirely on lipreading. In the audio-visual condition, auditory /ada/, /aba/, /ata/, /apa/, /ama/ and /ana/ was combined with visual /aba/, /ada/, /apa/, /ata/, /ana/ and /ama/, respectively. The visible place of articulation feature of the medial consonant thus never matched the auditory place feature. There was always auditory-visual coincidence of the release of the consonant in each utterance. Each of the stimuli was presented six times in random order.

Participants were asked to watch the screen and to repeat what the speaker had said. They were instructed to choose among alternatives given before each condition started. In the auditory-only and visual-only conditions, subjects had to choose between /aba/, /ada/, /ata/, /apa/, /ama/ and /ana/. In the audiovisual condition six more alternatives were added: /abda/, /adba/, /apta/, /atpa/, /amna/ and /anma/.

3.2. Results

A correct response in the auditory-only condition was an accurate repetition of the stimulus. For each subject in each group, the number of correct responses was computed. Both the schizophrenic and the control group had a high mean score of 98% and 99% correct, respectively (see Table 2). When the data of the auditory-only condition were submitted to a t-test with number of correct responses as dependent variable, there was no significant group effect ($t = 1.49$, $p = 0.15$).

Correct responses in the visual-only condition were scored in broader categories than in the auditory-only condition. A correct response in the visual-only condition was a response that fell in the same category of visually distinguishable phonemes (i.e., a viseme cluster) as the stimulus did. There were two categories: bilabials: "p, b, m" or linguals: "t, d, n". The number of correct responses was computed for each subject in each group. The schizophrenic group scored 78% correct versus 92% correct of the control group (see Table 2). In a *t*-test with number of correct responses as dependent variable, the group-effect was significantly different, indicating that the schizophrenic groups performed worse on lipreading ($t = 2.37$, $p < 0.026$).

For the audio-visual condition the number of times the auditory stimulus was biased by the lipread information was counted. This was done by calculating the number of "fused" and "blended" responses. A fused response is one where visual information of the place of articulation is combined with the auditory information into a single phoneme (e.g. auditory/ama/and visual/ana/into an/ana/response). A blended response is a response where the visual place information is added to the auditory information into a two-phoneme composite (e.g. auditory/ana/and visual/ama/into an/amna/response). The schizophrenic group showed a visual bias (fusions or blends) on 61% of the trials (the other 39% responses were exact repetitions of the auditory stimulus), while the controls showed a visual bias on 86% of the trials (the other 14% were exact repetitions of the auditory stimulus; see Table 2). A *t*-test with the percentage of visually-biased responses as dependent variable showed that this difference was also significant ($t = 2.54$, $p < 0.017$), thus indicating that schizophrenics were less influenced by the visual information in audio-visual trials.

In order to rule out the possibility that the smaller impact of the visual information in the audio-visual condition in the schizophrenic group was due to a deficit in lipreading per se, we looked at the relation between the two separate scores. The correlation between visual influence in the audio-visual condition and lipreading was not significant neither in the schizophrenic nor in the normal group, $r(11) = -0.03$, $p = 0.90$ for the control group, and $r(17) = 0.03$, $p = 0.88$ for the schizophrenic group. The correlation between visual influence in spatial localisation (Experiment 1) and visual influence in speech perception (Experiment 2) was calculated to check whether a common factor might underlie the integration of auditory and visual data. In the schizophrenic group as well is in the control group, correlations between the different experiments were not significant, $r(11) = -0.18$, $p = 0.57$ for the control group and $r(17) = 0.13$, $p = 0.58$ for the schizophrenic group.

Table 2
Percentages of correct responses in the auditory-only and visual-only conditions, and percentage of visually biased responses in the audio-visual condition

	Auditory-only (%)	Visual-only (%)	Audio-visual (%)
Schizophrenics	98	78	58
Controls	100	89	83

3.3. Discussion

Experiment 2 investigated whether schizophrenic patients were impaired in the cross-modal integration of audio-visual speech. As expected, schizophrenics and controls were able to repeat syllables presented in the auditory modality. Results of the visual-only condition showed that the schizophrenic patients were significantly worse than the control group in lipreading. Moreover, in the audio-visual condition, the data of the clinical group provide evidence of a reduced effect of lipreading on audio-visual speech perception. This may signal a lack of integration of phonetic information coming from different modalities.

4. General discussion

The goal of this study was to investigate whether schizophrenic patients are impaired in their integration of auditory and visual stimuli and whether a possible integration deficit existed for audio-visual spatial localisation, for audio-visual speech perception or both. In Experiment 1, schizophrenic patients showed a normal pattern of performance, indicating that they have no impairments integrating auditory and visual information when performing a spatial localisation task. In Experiment 2, where audio-visual integration of spoken language was investigated, the schizophrenic group was less influenced by lipreading than the control group. This poor integration was not due to reduced lipreading ability also observed in this group. Previous reports of lipreading ability in schizophrenics provided mixed results (Schonauer et al., 1998; Myslobodsky et al., 1992). Our results favour the notion of an impoverished lipreading ability. Whether or not this is related to the well documented difficulties with perception of social cues is a matter for future research. Our main finding here concerns the dissociation between two kinds of audiovisual integration processes.

The contrast between the results of the two Experiments indicates that schizophrenic patients do not show a *general* deficit in audio-visual integration. Rather, their integration problem is confined to speech processing. Our study used meaningless syllables in order to rule out that higher order semantic factors would one way or the other affect performance. Also, both our Experiments used paradigms in which the integration of auditory and visual information is known to reflect automatic integration processes. Differences in performance are thus not likely to be due to attentional factors that could differentially affect the two experimental situations. What, then, might explain this pattern?

The observed dissociation between audio-visual integration at stake in spatial localisation and that at the basis of audio-visual speech perception is consistent with the neuro-physiological literature. As mentioned before, the different types of inter-sensory processes currently studied have in common that they serve the purpose of adaptive communication, but each of them has its own underlying functional and neuro-anatomical principles (Dolan et al., 2001; Pourtois and de Gelder, submitted for publication). This is illustrated by the fact that different brain areas appear to implement inter-sensory integration. For example, areas in parietal cortex play a role in the integration of cues for spatial orientation, while the left superior temporal sulcus is involved in audio-visual speech integration (Calvert et al., 2000). There is also behavioural evidence indicating that integration of audiovisual speech and spatial information are based on different principles. Bertelson et al. (1994) combined the ventriloquist effect and the McGurk illusion in one experiment. An ambiguous fragment of auditory speech was delivered on one of an array of hidden loudspeakers. A face, either upright of upside-down, was shown on a centrally located screen, articulating one of two different utterances or remaining still. Subjects pointed to the apparent origin of the speech sounds and reported what had been said. The McGurk effect was practically independent of the spatial separation between auditory and visual source, but the ventriloquist illusion was influenced by it. In contrast, face inversion had no effect on ventriloquism, but it did significantly reduce the integration of auditory and visual speech. A similar dissociation as a function of the content of audiovisual pairs was also observed in a study using Transcranial Magnetic Stimulation (TMS). Single-pulse TMS interfered with audiovisual integration of arbitrary image/sound pairings but not of natural pairs (Pourtois and de Gelder, submitted for publication). These experimental dissociation thus also suggests that the two phenomena originate in different components of the cognitive architecture. The results of Experiment 1 and 2 indicate that in the schizophrenic group, the processes underlying ventriloquism are intact, while those at the basis of audio-visual speech integration are impaired.

At present, different explanations can be envisaged for the reduced visual bias that schizophrenics have in audiovisual speech perception. We can be reasonably confident that the observed integration failure is not due to an attentional deficit. It is well known that this kind of integration process is mandatory and does not require that attentional resources be allocated to it (Vroomen et al., in press).

One possibility is that schizophrenics have problems with the perception of movement as reported recently (Chen et al., 1999). This deficit might, in a subtle way, have an impact on lipreading. But since the difficulty manifests itself more at the level of integration than at that of lipreading itself, this explanation is unlikely to be the final word. Therefore it is worth looking into the neural architecture underlying cross-modal effects in more detail. Cross-modal bias effects of the kind typically illustrated by audiovisual speech perception require that both sources of information are taken as related to the same external event. The system thus has to detect a convergence between the information presented in the auditory and visual modality. Moreover, the detection of a multisensorial event typical for audiovisual speech may require feedback to the original input modalities (de Gelder, 2000). This mechanism may explain that visual stimuli can affect auditory cortex (Calvert et al., 1997; de Gelder et al., 1999). A deficit in audiovisual integration can therefore have two possible functional loci:

one is related to detection of sensory convergences, the other to feedback or back-projecting mechanisms that effectuate the kind of intersensory bias measured in behavioral responses. Further research is needed before one can tell which alternative to favour.

In research with schizophrenic patients, one has to be aware of several methodological issues that can influence the results. A number of factors were not examined in this study: First, the effects of medication were not addressed because the heterogeneity of drug regimes made meaningful comparisons difficult. It may be that some neuroleptics have other influences on audio-visual integration abilities than others, even though there is agreement that the effects of neuroleptic medication on test performance of schizophrenic patients are minimal (see Gourovitch and Goldberg, 1996 for an overview). Secondly, schizophrenia is a very heterogeneous syndrome, with very diverse manifestations. Therefore, symptoms are often clustered in subtypes of schizophrenia. Examples are the classification into disorganised, catatonic, paranoid, undifferentiated and residual subtypes by DSM-IV (APA, 1994) and the classification into three distinguishable syndromes: psychomotor poverty, reality distortion, and disorganisation (Liddle, 1987). It might be possible that patients showing the symptoms of one syndrome have more trouble with audio-visual integration than other patients. Unfortunately, during testing we only administered one structural interview, which was unsuitable to make subdivisions in the schizophrenic group. It should therefore be clear that this study presents only the beginning of a line of research, and cannot provide a final answer to the question of audio-visual integration in schizophrenia.

Acknowledgements

We thank an anonymous reviewer for insightful comments. This research was partly supported by a grant from Lundbeck.

References

Bertelson, P., 1988. Starting from the ventriloquist: the perception of multimodal events. In: Sabourin, M., Craik, F.I.M., Robert, M. (Eds.), Advances in Psychological Science. Biological and Cognitive Aspects, vol. 2. Psychology Press, Hove, UK, pp. 4119–4439.

Bertelson, P., Vroomen, J., Wiegeraad, G., de Gelder, B., 1994. Exploring the relation between McGurk interference and ventriloquism. Proceedings of the International Congress on Spoken Language Processing. Acoustical Society of Japan, Yokohama, Japan, pp. 559–562.

Bertelson, P., Pavani, F., Ladavas, E., Vroomen, J., de Gelder, B., 2000a. Ventriloquism in patients with unilateral visual neglect. Neuropsychologia 38, 1634–1642.

Bertelson, P., Vroomen, J., de Gelder, B., Driver, J., 2000b. The ventriloquist effect does not depend on the direction of deliberate visual attention. Perception and Psychophysics 62, 321–332.

Calvert, G.A., Bullmore, E.T., Brammer, M.J., Campbell, R., 1997. Activation of auditory cortex during silent lipreading. Science 276, 593–596.

Calvert, G.A., Campbell, R., Brammer, M.J., 2000. Evidence from functional magnetic resonance imaging of crossmodal binding in the human heteromodal cortex. Current Biology 10, 649–657.

Chen, Y., Levy, D.L., Nakayama, K., Mattthysse, S., Palafox, G., Holzman, P.S., 1999. Dependence of impaired eye tracking on deficient velocity discrimination in schizophrenia. Archives of General Psychiatry 1149 (8), 1062–1069.

Dolan, R., Morris, J., de Gelder, B., 2001. Crossmodal binding of fear in voice and face. Proceedings of the National Academy of Sciences 98, 10006–10010.

de Gelder, B., 2000. More to seeing than meets the eye. Science 289, 1148–1149.

de Gelder, B., Parnas, J., Bovet, P., Vroomen, J., Popelier, T., Innocenti, G.M., 1997. Impaired integration of audition and vision in schizophrenics. Experimental Brain Research 117, 23.

de Gelder, B., Böcker, K., Tuomainen, J., Hensen, M., Vroomen, J., 1999. The combined perception of emotion from voice and face: early interaction revealed by electric brain responses. Neuroscience Letters 260, 133–136.

Gourovitch, M.L., Goldberg, T.E., 1996. Cognitive deficits in schizophrenia: attention, executive functions, memory and language processing. In: Pantelis, C., Nelson, H.E., Barnes, T.R.E. (Eds.), Schizophrenia: A Neuropsychological Perspective. Wiley, Chichester.

Heinrichs, D.W., Buchanan, R.W., 1988. Significance and meaning of neurological signs in schizophrenia. American Journal of Psychiatry 145, 11–18.

Ismail, B., Cantor-graae, E., McNeil, T.F., 1998. Neurological abnormalities in schizophrenic patients and their siblings. American Journal of Psychiatry 155, 84–89.

Liddle, P.F., 1987. The symptoms of chronic schizophrenia: a re-examination of the positive-negative dichotomy. British Journal of Psychiatry 151, 145–151.

McGurk, H., MacDonald, J., 1976. Hearing lips and seeing voices. Nature 264, 746–748.

Myslobodsky, M.S., Goldberg, T.E., Johnson, F., Hicks, L., Weinberger, L., 1992. Lipreading in patients with schizophrenia. Journal of Nervous and Mental Disease 180, 168–171.

Pourtois, de Gelder, B., submitted for publication. Different integration sites for arbitrary and natural audiovisual pairs.

Ross, D.E., Buchanan, R.W., Medoff, D., Lahti, A.C., Thaker, G.K.,

1998. Association between eye tracking disorder in schizophrenia and poor sensory integration. American Journal of Psychiatry 155, 1352–1357.

Sams, M., Aulanko, R., Hämäläinen, M., Hari, R., Lounasmaa, O.V., Lu, S.T., Simola, J., 1991. Seeing speech: visual information from lip movements modifies activity in human auditory cortex. Neuroscience Letters 127, 141–145.

Schonauer, K., Achtergarde, D., Reker, T., 1998. Lipreading in prelingually deaf and hearing patients with schizophrenia. Journal of Nervous and Mental Disease 186, 247–249.

Vroomen, J., Bertelson, P., de Gelder, B., 2001. The ventriloquist effect does not depend on the direction of automatic visual attention. Perception and Psychophysics 63 (4), 651–659.

Vroomen, J., Driver, J., de Gelder, B., in press. Audiovisual integration of face and voice expressions is not under attentional control. Cognitive, Affective and Behavioral neuroscience.