ELSEVIER

Neuropsychologia 44 (2006) 693–710

NEUROPSYCHOLOGIA

www.elsevier.com/locate/neuropsychologia

Is susceptibility to perceptual migration and fusion modality-specific or multimodal?

Anthony Marcel[a,*], Bundy Mackintosh[a,b], Peggy Postma[a], Rhodri Cusack[a], Joseph Vuckovich[a], Ian Nimmo-Smith[a], Sylvia M.L. Cox[a]

[a] *Medical Research Council Cognition and Brain Sciences Unit, 15 Chaucer Road, Cambridge CB2 2EF, UK*

[b] *Psychology Department, The Open University, UK*

Received 7 September 2004; received in revised form 22 July 2005; accepted 16 August 2005

Available online 18 October 2005

Abstract

A previous paper reported high susceptibility to spatial migration (allochiria) of tactile stimuli in about 25% of healthy individuals (High Error subjects). When synchronous stimuli touched the two hands, if the unattended stimulus was temporally modulated when the attended one was not (and was thus more salient than the latter), it "migrated" to and fused with or replaced the stimulus on the attended hand. When subjects rated similarity of the attended stimulus accompanied by a distractor to each stimulus alone, scaling distributions tested against a sampling model showed most High Error subjects experienced fused stimuli, others experienced replacement and Low Error subjects experienced neither. We argued that these migrations are equivalent to allochiria and that this underlies neglect and extinction. This study assessed whether the individual difference is modality-specific or not. In auditory and visual equivalents of the tactile rating experiment, the difference between High and Low Error subjects was replicated in audition, but no migration occurred in vision. However, when two words were briefly presented visually before a mask with cued report of one, letter migrations to equivalent locations did occur and the individual difference was reproduced. This constitutes the first report of individual differences in auditory fusion and visual letter migration. Migration occurred in egocentric coordinates but apparently preserved structural homology. Different migration rates between the modalities paralleled relative salience of the unattended to the attended stimulus. The multimodality of the individual difference suggests that its source is supramodal, in deficient binding of perceptual content to location.

Keywords: Modality; Space; Attention; Neglect; Allochiria; Binding

1. Introduction

Allochiria in neurological patients consists in displacement of the experienced location of stimuli or sensations to the opposite side of the body or space, usually from the contra- to ipsilesional side. In a previous paper, Marcel et al. (2004) reported a high susceptibility to migration of tactile sensation in about 25% of healthy adults. Given several similarities, they argued that this could be equivalent to clinical allochiria, and possibly be a premorbid precursor of this and of neglect and extinction. The present paper assesses the extent to which the phenomenon is specific to touch in the relevant subjects.

* Corresponding author.

E-mail addresses: tony.marcel@mrc-cbu.cam.ac.uk, a.marcel@herts.ac.uk (A. Marcel).

0028-3932/$ – see front matter © 2005 Elsevier Ltd. All rights reserved.

doi:10.1016/j.neuropsychologia.2005.08.004

The migration observed in our previous study occurred when synchronous stimuli were presented to the two hands and the unattended stimulus was made the more salient by being temporally modulated. For our "High Error" subjects, the unattended stimulus representation migrated to the attended hand and fused with or replaced that of the attended stimulus. In a further experiment, subjects were asked to rate the similarity of the attended stimulus when accompanied by a distractor to how they perceived each stimulus alone. Their rating distributions, tested against a sampling model, showed that most High Error (HE) subjects experienced fusion of the stimuli, though some experienced replacement, but Low Error (LE) subjects experienced neither. We suggested that the individual difference is in how tightly unattended stimuli are bound to the representation of their location, and thereby in their susceptibility to be falsely bound to the location of contralateral attended stimuli. Apparently migrating stimuli will fuse experientially with attended stimuli if they can be integrated or, if not, they will replace them.

The question arises whether susceptibility to migration in HE subjects is modality-specific or multimodal, and, if the latter, extending to which modalities.[1] In clinical populations, migration of sensation, whether induced by a stimulus at the resulting location or not, can occur in various sensory modalities, but is mainly reported in somatosensation (Bisiach & Berti, 1995; Kawamura, Hirayama, Shinohara, Watanabe, & Sugishita, 1987; Meador, Allen, Adams, & Loring, 1991). These reviews and that of Bisiach and Vallar (2000) show that while migration of sensation has been reported in more than one modality in single patients, it can be modality-specific, or more evident in one modality. Many reports show dissociation between modalities of neglect and extinction. This does not mean that the susceptibility per se is not multimodal. It may be multimodal and yet be manifest selectively in specific modalities, due to e.g. appropriateness or sensitivity of tests in different modalities.

How neural substrates that represent location of stimuli represent their sensory modality obviously bears on this. Early in processing, spatial location of stimuli is represented specific to their source modality. Location in different modalities is integrated later into multimodal and supramodal spatial representations. These supramodal representations of location allow us to experience a common source of experiences in different modalities and plausibly underlie ventriloquism effects. Macaluso and Driver (2001, 2004) present evidence suggesting that multimodal spatial representation may also be integrated cross-modally at the level of specific modalities via supramodal spatial attention. It is relevant that extinction can be obtained when competing ipsi- and contralesional stimuli are in different modalities (Mattingley, Driver, Beschin, & Robertson, 1997). Thus, spatial location would appear to be represented unimodally, multimodally and supramodally. Indeed, Bisiach and Vallar (2000) indicate on empirical grounds that allochiria, neglect and extinction is each "likely to be symptomatic of dysfunction at different levels of sensory processing" (p. 468). There are many reports of dissociations between modalities for neglect and extinction, and less often for allochiria. But it is unfortunate that what review papers do *not* do is to attempt any meta-analysis of particular patterns or directions of association/dissociation either (a) between modalities, (b) between neglect, extinction and allochiria, or (c) between modality and deficit type. This is difficult, given the specificity of case reports. But it is what is needed if any principled account of the relation of such deficits of spatial attention and modality is to be possible.

We sought to assess the extent to which the difference between High and Low Error subjects obtains across modalities. The original effect was in touch. The other modalities we explored were hearing and vision. If some individuals consistently make migration errors in several modalities, it would indicate that the source of the errors lies at a supramodal level. If they do so in more than one but not all modalities, it might indicate that the source lies at the level of specific modalities, possibly where there is something common to the affected modalities. But if relative migration rate in one modality does not predict relative migration rate in any other modality, it would imply that the source of such migrations is at the level of separate modalities. To tackle this question and assess the extent of consistent patterns of performance, it is crucial to test across different modalities in, as far as possible, the same individuals.

2. Design

2.1. Choosing appropriate auditory and visual analogues

The tactile situation producing individual differences in migration was as follows. Tactors delivered stimuli to the backs of the hands supported in front 55 cm apart. With gaze straight ahead, subjects attended to one hand and discriminated between two stimuli of 250 ms, one a continuous contact ("Tap") and one temporally modulated: three 50 ms contacts separated by 50 ms ("Drum"). Each attended stimulus was accompanied simultaneously on the unattended hand by the congruent, the incongruent or no stimulus. (The terms "Tap–Tap", "Tap–Drum", "Tap–Nil", etc., refer to what is at the attended and unattended locations respectively.) Marcel et al. (2004) examined the extent to which experience of the stimulus at the attended location when accompanied by the other stimulus is a fusion of the two, a replacement by the latter, unaffected, or a mixture. Rated similarity of the attended stimulus when accompanied by a distractor to Tap and Drum when presented alone yielded distributions on an 8-point scale that were tested against a sampling model. This indicated extent of fusion or replacement (both entailing migration) for individual subjects. For details of the procedure, see Marcel et al. (2004).

In choosing appropriate procedures in audition and vision, three aims are relevant: (1) to be analogous to the stimulus situation in the tactile rating experiment; (2) to be analysable in the same way; (3) to be a situation susceptible to migration in the relevant modality. In the tactile studies, stimuli differed only in temporal patterning, and were delivered to each hand held in front. Thus, they were presented at two locations separated both in somatotopic and in external egocentric space, but also laterally homologous (on the two hands), i.e. they were somatotopically equivalent. In audition, these constraints can be met without conflict. (a) When stimuli are delivered to the two ears binaurally with simultaneous onset and offset and the same frequency content, they fuse spatially (perceived at the midline). However, a sufficient difference in frequency reduces fusion, yielding perception of a stimulus at each ear. If the frequency difference is small or there is overlap, there is susceptibility to fusion (Nuetzel & Hafter, 1976, 1981), and thus potentially to individual differences in fusion. (b) The two ears have the same spatial characteristics as the two hands as outlined above.

[1] The term "multimodal" is used here descriptively to mean occurring in more than a single modality, whether or not it occurs in all modalities, and without prejudice as to whether it occurs at the level of modality or at a higher level. The following terms are used conventionally: "supramodal"—occurring at a higher level than modality (and thus affecting all modalities); "unimodal" and "modality-specific"—occurring in one particular modality; "cross-modal"—occurring between modalities at the level of modality-specific representations or processing.

(c) In such situations, rating of stimulus quality and analysis can be conducted in the same way as in the tactile experiment. Finding a visual paradigm which meets all constraints is more difficult. Two situations meeting different constraints can be considered. (1) The direct analogy of the tactile situation, rateable and analysable in the same way, is to present lights each side of a fixation point, with the temporal features of the two tactile stimuli. However, there are no data indicating whether migration occurs in this situation. (2) By contrast, at least two paradigms are known to produce migration in vision. One is that used by Treisman and Schmidt (1982) where features of multidimensional stimuli (e.g. colour or shape) separate and recombine to produce illusory conjunctions. Another paradigm involves brief masked simultaneous presentation of two or more words, where letters from one migrate to and replace letters in the other (Mozer, 1983; Shallice & McGill, 1978). In this latter case, migration is mainly between structurally equivalent locations within words (e.g. balk + buck → back or bulk). These procedures depend on report of what is seen and so do not lend themselves to rating of similarity or to analysis equivalent to that in the tactile experiment. However, confidence ratings can be used and individual differences can be assessed. Although migration in the word recognition paradigm may depend on linguistic factors, the extent of such dependence is moot and its effect is plausibly on visual perception (see Section 4.3).

Given the above, we conducted three experiments: (1) an auditory and (2) a visual equivalent of the tactile rating experiment; (3) a visual word recognition experiment designed to produce an appropriate range of frequency of letter migration. Where possible, we used the same HE and LE subjects as in the tactile rating experiment. In the first stage, in both the auditory and visual experiments, subjects were familiarised with two stimuli in isolation (equivalent to the tactile Tap and Drum), and were then asked to rate similarity of attended stimuli to these two according to an 8-point scale representing a continuum between them. On trials with two different stimuli, several experiential outcomes relative to those of the stimuli in isolation are possible. (i) Subjects may experience attended Tap (or Drum) as an amalgam of the two stimuli or as something between them, and the difference may lie in their response criteria, i.e. when to call a Drum-like Tap "Tap" and vice versa (an attended Drum on Drum–Tap trials may seem more Drum-like than the converse). (ii) Only the HE subjects may have such experience. (iii) The Tap may be experienced as Drum (implying replacement) to a greater extent by HE than by LE subjects. (iv) Individuals may be subject to differing proportional combinations of such experiences.

3. Experiments 1 and 2: auditory and visual rating

3.1. Method

3.1.1. Subjects

Subjects were the same as had performed the tactile rating; all gave informed consent. Five of those with consistently high error rates were available (CG, MK, EG, JB and LS). Five of the LE subjects (RB, KAM, MF, KS and TD) were matched with these subjects for sex and age (mean age: HE Ss = 40.2, S.D.: 12.07; LE Ss = 38.2, S.D.: 15.83), with no age difference between groups on an independent *t*-test ($t(8) = .225$, $p > .05$). However, CG could not participate in the visual experiment.

3.2. Experiment 1: auditory rating

3.2.1. Apparatus, stimuli and set-up

Custom software written in Visual Basic Version 6.0 was run on a portable Dell Pentium III PC. Stimuli were digitally synthesised at a sample rate of 22,050 Hz and delivered via KOSS TD/65 headphones.

Two auditory stimuli with different temporal envelopes were presented at 78 dB SPL. One consisted of a pure tone lasting 250 ms. The other also lasted 250 ms, but consisted of three 50 ms pure tones separated by two 50 ms gaps. These stimuli will be referred to as "Tap" and "Drum" respectively. The frequency of the tones was either 440 or 494 Hz (see below). Linear onset and offset ramps of 10 ms were used.

Subjects focussed on a rating scale directly in front 1 m away slightly below eye level, serving to maintain central fixation. It consisted of a 21 cm vertical line, intersected at 3 cm intervals. The eight letters A–H appeared next to each interval point with A at the top and H at the bottom. The word 'TAP' appeared next to A and the word 'DRUM' appeared next to H. The experimenter keyed subjects' responses in to the PC.

3.2.2. Design

For each of four blocks of 30 trials, subjects were asked to attend to the right or left ear in an ABBA order. The task was to rate the similarity of each stimulus on the attended ear to the Tap and Drum stimuli when presented alone (see below) while ignoring any simultaneous stimulus on the other ear. The scale provided subjects with a means of expressing variations in the perceived stimuli.

In each block, a third of trials served as a control in which target stimuli (50%: Tap; 50%: Drum) were presented alone to the attended ear. On the other trials, a stimulus was presented to the unattended ear simultaneous with the target on the attended ear. To maintain distinguishability of auditory stimuli (which would otherwise fuse; see Section 2), on binaural trials stimuli differed by two semitones, since a frequency difference enhances stream segregation (Steiger & Bregman, 1982). Thus, for simultaneous stimuli, one was 440 Hz and the other 494 Hz. Which ear received the higher frequency was randomised over trials. When a single stimulus was presented, it was randomly selected to be 440 or 494 Hz. On half the binaural trials (10), distractor and target were the same, on half they were different. This yielded six different stimulus combinations (see Table 1). All six conditions occurred in equal proportions in each block, but in random

Table 1
Combinations of stimuli delivered to attended and unattended ear

Stimulus condition	1	2	3	4	5	6
Attended ear	Tap	Tap	Tap	Drum	Drum	Drum
Unattended ear	–	Tap	Drum	–	Drum	Tap

order. In total, there were 120 trials; in half the target stimulus was Tap, and in the other half Drum.

3.2.3. Procedure

The experiment was explained to subjects, and 'Taps' and 'Drums' were demonstrated to the ear that was to be attended first, until subjects were satisfied with the difference between them. Subjects were told to rate only what the stimulus to the attended ear sounded like, and to ignore stimuli on the unattended ear. It was explained that many of the stimuli might sound exactly like the example 'Taps' and 'Drums', in which case they should be rated as A and H respectively. It was also pointed out that some stimuli *might* sound different, in which case the other letters in the scale should be used. Subjects were told this was not a reaction time task, but were asked to respond fairly quickly since the aim was to record their first impressions of stimuli. It was stressed that there was no right or wrong response and the aim was simply to establish how stimuli were perceived.

Subjects were given 18 practice trials, consisting of all conditions in equal proportions presented in random order. The first block of trials was then run. Following this, subjects were told that they were now to attend to the other ear. The demonstration of the two target stimuli was repeated to help identify them in this ear, and 18 practice trials were then given. The second and third blocks of trials were then run without further practice. Subjects then attended to the original ear for the fourth block of trials. The experimenter initiated each block of trials, and entered each response (A–H), which started the next trial. The experiment lasted about 20 min. Subjects were then asked about their experience of the task, with increasingly specific questions, whether they found some stimulus combinations more difficult, and whether they thought they may have made mistakes, and if so on which conditions.

3.3. Experiment 2: visual rating

3.3.1. Apparatus, stimuli and set-up

Custom software was written in MEL Version 2.0 (Schneider, 1988) and run on a portable Dell Pentium III PC. Visual stimuli were delivered via three light-emitting diodes (LEDs) which were mounted in a horizontal arrangement on a box 8 cm high × 12 cm wide. One LED was in the centre; the other two were 4 cm each side of it. Two visual stimuli were programmed. One consisted of a light of 250 ms duration, and was referred to as "Light". The other was also 250 ms duration, but consisted of three 50 ms illuminations separated by two gaps of 50 ms, and was referred to as "Flicker".

Subjects sat at a table with their chin on a padded rest 38 cm above table level. They adjusted the height of the chair to the most comfortable position. The box with the LEDs was fixed to a vertical rod 66 cm in front of the chin rest; the lights were displayed 48 cm above the table, approximately at eye level. With this arrangement, the lateral LEDs were 4° from the central one. A rating scale was mounted on the vertical rod below the light box with its bottom at table level. It consisted of a vertical line of 14 cm, intersected at 2 cm intervals. The letters A–H were displayed next to each interval point with 'A' at the top and 'H' at the bottom. The word 'LIGHT' appeared next to 'A', and the word 'FLICKER' next to 'H'.

3.3.2. Design

The central LED served as a fixation point with the experimental stimuli (Light and Flicker) appearing on the two lateral LEDs. On each trial, the central LED illuminated for 50 ms, and 500 ms after that the stimuli appeared on one or both lateral LEDs. Subjects were asked to attend to one of the two lateral LEDs and ignore the other for each of four blocks of 30 trials, but were asked to maintain fixation on the central LED. The attended side remained constant for each block, but varied across blocks in an ABBA order. The task was to rate each visual stimulus on the attended side according to the scale in terms of how much it resembled either stimulus alone (see above). Trial types followed the same logic as in the auditory experiment, as did their number and order (see Table 1, with Light and Flicker instead of Tap and Drum respectively).

3.3.3. Procedure

The experiment was explained to subjects. They were then asked to place their chins in the chinrest and adjust the chair to a comfortable height. 'Light' and 'Flicker' were demonstrated via the LED on the side that was to be attended first, until the subject was satisfied with the difference between them. Subjects were instructed as in the auditory experiment, substituting visual for auditory terminology. The rest of the procedure, including practice and order of trial blocks, was the same as in the auditory experiment. The experimenter initiated a block of trials by triggering onset of the central fixation light, and entered each response (A–H) on the PC. This initiated the next trial. The experiment lasted about 20 min.

3.4. Results

Fig. 1 shows the mean ratings in three experiments by HE and LE subjects of the similarity to unaccompanied Tap and Drum (or Light and Flicker) of: (a) attended Tap (Light) and (b) attended Drum (Flicker) when accompanied by the congruent, incongruent or no stimulus. The data from the tactile experiment are shown for comparison. (They were displayed in a different arrangement in Fig. 2 in Marcel et al., 2004.) The data for the auditory and visual experiments will be treated separately.

Fig. 1 illustrates how, on Tap–Drum trials in the tactile rating experiment, HE subjects rated Taps differently from LE subjects. As discussed in the previous paper, this indicates that they had a different perceptual experience rather than merely a different response criterion. To reprise our earlier findings, individual analyses, tested against a sampling model (see below), showed two different profiles within the HE group. Response patterns of MK, LS and EG were consistent with Tap on such trials being perceived as a fusion of Tap and Drum. Responses of JB and CG on such trials were predominantly accounted for by sampling from those on Drum–Nil trials, i.e. they were consistent with Tap being experienced on such trials as Drum. LE subjects' responses on such trials all reflected veridical perception of Tap and Drum unaffected by the unattended stimulus.

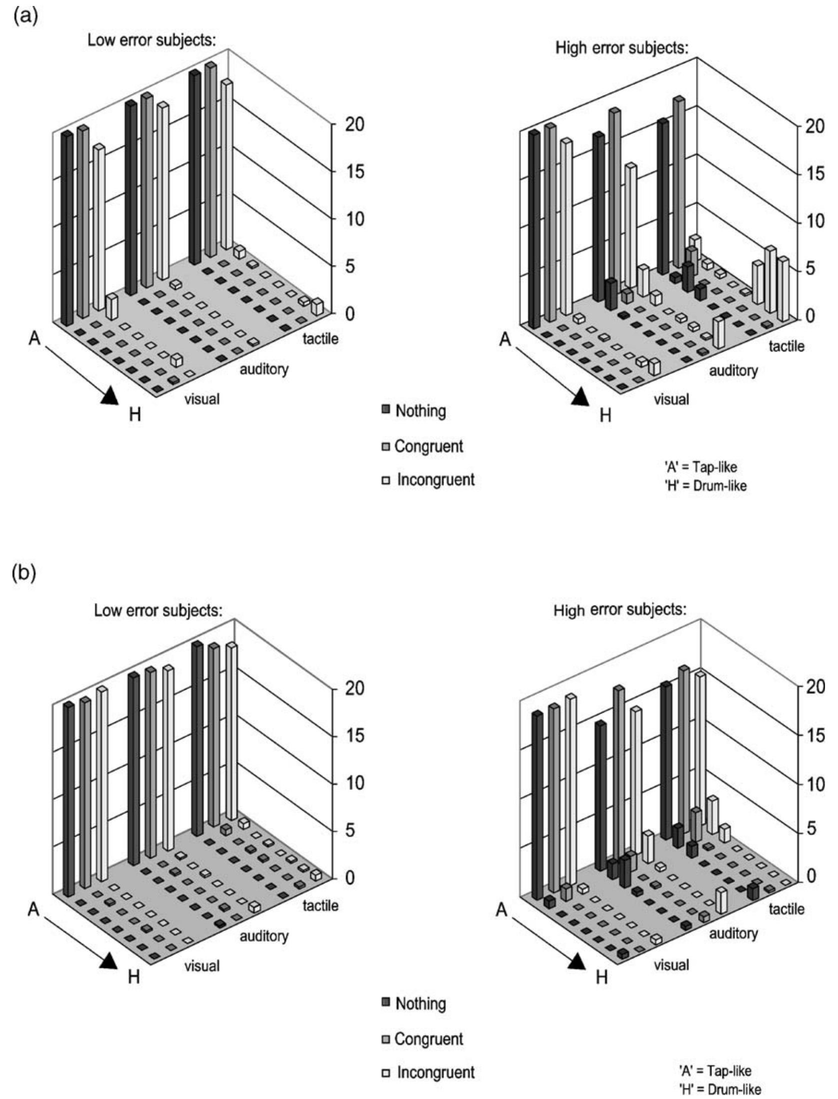

Fig. 1. Mean ratings in the tactile, auditory and visual experiments by High and Low Error subjects of each attended stimulus: (a) Tap and (b) Drum, when accompanied by the congruent, incongruent and no stimulus.

3.4.1. Auditory rating experiment

In this experiment, Fig. 1 shows that on Tap–Drum trials, HE subjects tended to rate Tap at values other than Tap alone, though this tendency is less for the group as a whole than in the tactile experiment. For these subjects, it also appears that Drum on Drum–Tap trials was rated at values other than Drum alone. The LE subjects showed neither of these tendencies. Each subject's data were tested to determine whether rating distributions on Tap–Drum and Drum–Tap trials could be accounted for by a statistical sampling model based on the distributions of ratings observed on Tap–Nil and Drum–Nil trials. This model includes as particular cases three of the possible experiential outcomes outlined above: rating distributions on Tap–Drum trials fitted (a) by those on Tap–Nil trials alone ('unaffected'); (b) by those on Drum–Nil (or Tap–Nil) trials alone ('replacement'); (c) by a mixture of the distributions for both Tap–Nil trials and Drum–Nil trials. (d) A fourth possible outcome is that rating distributions are not fitted by any of (a), (b) or (c) (i.e. 'fusion').

In the sampling model, the data in all four critical conditions (Tap–Nil, Drum–Nil, Tap–Drum and Drum–Tap) are modelled by the response probability distributions for the Tap–Nil and Drum–Nil conditions together with a mixing parameter λ. If $t(k)$ and $d(k)$ represent the probabilities of response k (k = A, B, . . ., H) in the Tap–Nil and Drum–Nil conditions, then the probability of response k in the Tap–Drum condition, $td(k)$, is given by $td(k) = \lambda \cdot t(k) + (1 - \lambda) \cdot d(k)$. Thus, λ and $1 - \lambda$ represent the probability of sampling from the Tap–Nil and Drum–Nil distributions respectively. Cases (a) and (b) above correspond to $\lambda = 1$ and 0; case (c) corresponds to a value of λ strictly between 0 and 1. The model was fitted by means of Monte Carlo Markov Chain (MCMC) methods (Carlin & Louis, 2000) using the WinBugs (Spiegelhalter, Thomas, & Best, 1999) program. Results are given in terms of: (a) the most probable values of λ and (b) the goodness of fit of the model, in terms of the posterior expectation of the deviance statistic (see Carlin & Louis, 2000). Table 2 shows how well the rating distributions on Tap–Drum and Drum–Tap trials are fitted by the sampling model.

Table 2
Assessment of the sampling model and its goodness of fit to ratings of attended Tap on Tap–Drum and Drum on Drum–Tap trials (auditory trials)

Subject	Tap on Tap–Drum trials		Drum on Drum–Tap trials	
	Outcome of fitting a sampling model	Goodness of fit measured by posterior expectation of deviance	Outcome of fitting a sampling model	Goodness of fit measured by posterior expectation of deviance
High Error subjects				
MK	Sampling model rejected	38.0 ($p = .020$)	Drum Tap ⇒ Drum	27.4 ($p = .196$)
LS	95:5 sampling with Tap Drum ⇒ Tap predominating	27.0 ($p = .211$)	30:70 sampling with Drum Tap ⇒ Drum predominating	24.9 ($p = .302$)
EG	75:25 sampling with Tap Drum ⇒ Tap predominating	24.9 ($p = .302$)	10:90 sampling with Drum Tap ⇒ Drum predominating	24.8 ($p = .302$)
CG	Sampling model rejected	34.7 ($p = .033$)	Sampling model rejected	42.5 ($p < .001$)
JB	65:35 sampling with Tap Drum ⇒ Tap predominating	24.9 ($p = .302$)	Drum Tap ⇒ Drum	26.5 ($p = .231$)
Low Error subjects				
KAM	95:5 sampling with Tap Drum ⇒ Tap predominating	27.0 ($p = .211$)	Drum Tap ⇒ Drum	26.5 ($p = .231$)
RB	Tap Drum ⇒ Tap	26.5 ($p = .231$)	10:90 sampling with Drum Tap ⇒ Drum predominating	26.9 ($p = .211$)
MF	Tap Drum ⇒ Tap	28.6 ($p = .157$)	Drum Tap ⇒ Drum	24.9 ($p = .302$)
TD	Tap Drum ⇒ Tap	26.5 ($p = .231$)	Drum Tap ⇒ Drum	26.5 ($p = .231$)
KS	Tap Drum ⇒ Tap	26.5 ($p = .231$)	5:95 sampling with Drum Tap ⇒ Drum predominating	27.0 ($p = .211$)

For all LE subjects, the rating distributions on Tap–Drum and Drum–Tap trials were accounted for by sampling from those on Tap–Nil and Drum–Nil trials respectively, i.e. none of these subjects showed evidence of fusion or replacement. There were no significant deviations in rating responses between Tap–Nil and Tap–Drum conditions nor between Drum–Nil and Drum–Tap conditions (for p-values, see Table 2).

There were differences among the HE subjects. MK showed a response distribution on Tap–Drum trials different from those on Tap–Nil and Drum–Nil trials (for p-values, see Table 2). This profile suggests that the stimulus at the attended ear was perceived as a fusion of Tap and Drum. JB and EG showed response distributions on Tap–Drum trials that were accounted for by sampling from those on Tap–Nil and Drum–Nil trials. These profiles suggest that in these cases, Tap at the attended ear was either replaced by Drum or perceived veridically. The response distributions of LS and CG were accounted for by sampling from Tap–Nil trials alone, though CG's ratings were distributed over intermediate values suggesting a degree of fusion. On Drum–Tap trials, CG's rating distribution showed evidence of fusion. LS and EG mainly responded on such trials as they had on Drum–Nil trials, but also showed evidence of replacement by Tap. The other two HE subjects showed no evidence of fusion or replacement on Drum–Tap trials.

3.4.2. Visual rating experiment

Fig. 1 shows little evidence in HE subjects of Light on Light–Flicker trials being rated as Flicker or as intermediate values. Nor did these subjects show evidence of Flicker being rated as anything else on Flicker–Light trials. The same is true for LE subjects. Each subject's data were tested to determine whether rating distributions on Light–Flicker and Flicker–Light trials could be accounted for by a sampling model based on the rating distributions observed on Light–Nil and Flicker–Nil trials. For the possible outcomes and the sampling model, see Section 3.4. Table 3 shows how well the rating distributions on Light–Flicker and Flicker–Light trials are fitted by the sampling model.

No LE subject showed deviation from the sampling model on either Light–Flicker or Flicker–Light trials, except for MF who showed evidence of fusion on Light–Flicker trials. Of the HE subjects, only EG deviated from the sampling model, showing some replacement on Light–Flicker trials.

3.4.3. Subjects' comments for Experiments 1 and 2

See Appendix A.

3.5. Discussion

The results of these two experiments raise several points. The difference between HE and LE subjects in migration and fusion/replacement established in touch by Marcel et al. (2004) is clearly to *some* extent multimodal. The difference between the HE and LE subjects obtains in audition. As far as we know, this is the first report of an individual difference in susceptibility to auditory dichotic fusion. However, while no LE subjects showed any evidence of migration, it was not shown equally by all five HE subjects. On Tap–Drum trials, two HE subjects showed fusion (though to different extents), two showed some degree of replacement and one showed no migration. On Drum–Tap trials, one HE subject showed some fusion, two showed a degree of replacement, while the other two showed no migration.

Two features of these data are of interest. (a) HE subjects showed less migration than they had in the equivalent tactile situation. (To some extent, this may simply reflect that these stimuli were not as easily fusible as the tactile stimuli since there

Table 3
Assessment of the sampling model and its goodness of fit to ratings of attended Light on Light–Flicker and Flicker on Flicker–Light trials (visual trials)

Subject	Light on Light–Flicker trials		Flicker on Flicker–Light trials	
	Outcome of fitting a sampling model	Goodness of fit measured by posterior expectation of deviance	Outcome of fitting a sampling model	Goodness of fit measured by posterior expectation of deviance
High Error subjects				
MK	Light Flicker ⇒ Light	27.8 (p = .182)	Flicker Light ⇒ Flicker	27.7 (p = .183)
LS	90:10 sampling with Light Flicker ⇒ Light predominating	28.2 (p = .170)	Flicker Light ⇒ Flicker	25.4 (p = .279)
EG	85:15 sampling with Light Flicker ⇒ Light predominating	25.0 (p = .303)	Flicker Light ⇒ Flicker	26.5 (p = .231)
CG	No data			
JB	Light Flicker ⇒ Light	26.5 (p = .231)	Flicker Light ⇒ Flicker	26.5 (p = .231)
Low Error subjects				
KAM	Light Flicker ⇒ Light	28.6 (p = .156)	Flicker Light ⇒ Flicker	26.5 (p = .231)
RB	Light Flicker ⇒ Light	26.5 (p = .231)	Flicker Light ⇒ Flicker	26.5 (p = .231)
MF	Sampling model rejected	35.5 (p = .028)	Flicker Light ⇒ Flicker	26.5 (p = .231)
TD	Light Flicker ⇒ Light	26.5 (p = .231)	Flicker Light ⇒ Flicker	26.5 (p = .231)
KS	Light Flicker ⇒ Light	26.5 (p = .231)	Flicker Light ⇒ Flicker	26.5 (p = .231)

was always a two-semitone difference—introduced to prevent maximal fusion.) (b) Three HE subjects showed some migration on Drum–Tap trials, whereas none had shown this at all in the tactile situation. In touch, all subjects experience the Drum stimulus as more salient. This is not true in audition. Subjects did not spontaneously report it, and, when asked, did not unreservedly find the auditory Drum stimulus more obviously salient. This may be due to the fact that in touch a continuous pressure stimulus is experienced mainly as its start and finish (the brief Pacinian corpuscle response is only to pressure onset and offset; Shepherd, 1994), whereas in audition a continuous sound is experienced continuously, at least for the durations used here. If so, the repeated onsets and offsets of Drum and its vibratory quality would render it *relatively* more salient in touch. It is plausible that this difference in salience accounts for: (a) the less frequent apparent migration on Tap–Drum trials in audition than touch, (b) the smaller asymmetry of migration of the unattended stimulus between Tap–Drum and Drum–Tap trials in the auditory experiment and (c) the fact that unattended Tap migrated to attended Drum in the auditory experiment. If differential salience underlies these data, it suggests that salience per se plays a role in migration. If migration in these experiments is a form of allochiria, as argued in Marcel et al. (2004), then unattended stimuli that are more salient are more likely to migrate to attended locations in clinical allochiria.

In contrast to the auditory experiment, the individual difference does not obtain in the visual analogy of the tactile experiment—because migration errors hardly occurred at all in this situation. Three possible reasons come to mind. First, there may be even less difference in salience between the visual stimuli selected than in audition. Second, a difference in temporal modulation may play a different role in vision than in touch and audition. Third, and more probable, those procedures in vision which produce migration errors involve disruption to focal attention, usually backward masking, which plausibly disrupts binding of perceptual content to spatial location. Since the present visual procedure did not involve such disruption, binding for veridical conscious experience would not be affected. The fact that migration errors did not occur in this visual situation has two implications. First, it suggests, together with reasons given in the earlier paper, that the difference between HE and LE subjects is not merely in response criterion. Our earlier paper cautiously acknowledged that the difference in tactile rating might reflect greater uncertainty coupled with a different response criterion. If this were the underlying difference, it should also affect the equivalent visual situation. Second, the absence of migrations implies that this particular visual paradigm is unsuitable for evaluating the presence of the individual difference in vision. Thus, whether migrations and the individual difference in their rate are restricted to touch and audition, (e.g. because these modalities share certain features; see von Békésy, 1960) cannot be decided on the basis of this visual experiment. This makes it worth investigating a visual paradigm known to produce letter migrations as discussed in Section 1.

4. Experiment 3: visual word recognition

The aim was to assess whether HE and LE subjects differ in susceptibility to letter migration between separated letter strings. Pairs of four-letter words were presented briefly either above and below or to left and right of a fixation point, followed by a pattern mask. The task was to report as much as possible of one of the stimuli and to indicate level of confidence in the report. The word to be reported was cued by a rectangle around its location. While in Mozer's (1983) experiments the stimulus to be reported was cued only after presentation, here it was cued both before and after, in order to be analogous to the other experiments in pre-locating attention. Pilot studies showed that this procedure also produces letter migration. To create liability to migration, word pairs were chosen as follows: if either one of two letters (middle or outer) from one word replaced the corresponding letter in the other word, it produced one of two possible words, both of which were higher frequency than the original words. As examples (with word frequency in a corpus of 17.9 million in brackets), CAPE (292) and CORE (323) yield COPE (782) or CARE (2175); DEAR (1251) and HEAL (265) yield HEAR

(9053) or DEAL (2482). Migration to non-equivalent locations is possible, though for stimuli selected as above this yields words much less frequently (DEAR + HEAL → HEAD (9187)). Since apparent migration errors may not be due to migration per se, especially because most would be higher frequency words, one needs to assess to what extent such errors are produced by presence of the unattended word. Therefore, as a control, the same procedure was carried out with the same stimuli but with only one word presented. No distractors were used, because a string of non-letter symbols may itself induce errors by feature migration. Any individual difference in rate of migration errors in the two-word condition must be greater than the rate of equivalent responses in the single-word condition to be counted as migration.

The aim was to assess individual differences under constant presentation conditions. Therefore, pilot studies with LE subjects not used in the experiment established a stimulus-mask SOA at which errors, including migrations, occurred but at a rate low enough to allow for higher rates by HE subjects. Since SOAs producing comparable error rates for single-word presentation are lower, pilot studies also established a suitable SOA for this condition on the same subjects. The two conditions were run as separate sessions. Since errors in the two-word condition might be primed as responses to the same stimuli shown alone, the control condition was run first on about half the subjects.

4.1. Method

4.1.1. Subjects

As far as possible, the same subjects participated as in the rating experiments. Of the HE subjects, JB was unavailable and was replaced by KST (who had been unavailable during the rating studies). Of the LE subjects, KS and TD were unavailable and were replaced by JL and LB who were the same sex. HE and LE subjects were matched for sex and as closely as possible for age (mean: HE = 50.0, S.D.: 19.5; LE = 52.0, S.D.: 18.5), with no age difference between groups on an independent *t*-test ($t(8) = .17$, $p > .05$).

4.1.2. Stimuli

Forty pairs of four-letter words were selected from the Celex Lexical Database (Baayen, Piepenbrock, & Guilikers, 1995) on the following criteria. No word contained any letter twice. Twenty pairs had the same outer two letters, 20 had the same inner two letters. If either of the other two non-identical letters replaced the corresponding one in the other word, it would form a new word. The two new words were both higher frequency than either of the stimulus words. Based on the Celex Database, the frequency range of stimuli out of 17.9 million was 13–8047, that of the possible words due to equivalent letter migration was 149–23,455. Different word pairs were used for familiarisation and practice and for buffer trials presented before experimental blocks. Not all of these pairs met all the criteria for experimental stimuli. Experimental stimuli were used for the control condition, but displayed singly. Word pairs are listed in Appendix B.

Words were displayed in Verdana font. Letter strokes were 4 pixels wide and each word was adjusted to be 1.5 × .3 cm, subtending 1.5° of visual angle at the 60 cm viewing distance.

4.1.3. Apparatus and set-up

Custom software was written in MEL Version 2.01 (Schneider, 1988) and run on a Pentium III Dell Dimension 4100 Windows PC. Stimuli were presented on a 32 cm × 24 cm Dell colour monitor.

Subjects sat on a height-adjustable chair at a table with their heads against a padded forehead rest 60 cm from the screen. The screen height ensured that stimuli appeared just below eye level. The experimenter sat behind the monitor facing the subject with a keyboard and a second Dell monitor connected to the testing PC, and could thus see what subjects saw and record responses without being in the subject's field of view.

4.1.4. Design and procedure

4.1.4.1. Experimental condition. The trial sequence is shown in Fig. 2. The background field throughout was mid-grey. Stimuli were displayed in a white field (8° × 5.25° visual angle) at the centre of the screen, which appeared at the onset of each trial and disappeared at its end. At the start of each trial, a .3° black fixation cross appeared together with a 2° × .5° rectangle, .25° above, below, to right or left of the centre of the cross. The rectangle, with thinner lines than the cross, indicated position of the word to be reported. The rectangle disappeared after 750 ms, leaving the cross for a further 250 ms. A white numeral (to be reported later) in a black disc .5° in diameter then appeared at fixation for 110 ms. This size and duration, established by pilot studies, necessitated fixation. This was followed by presentation of two words for 230 ms, displayed either above and below or to left and right of fixation, one within the space of the prior rectangle. They were .9° apart both when separated vertically and horizontally. Vertical separation subtended a vertical total of 1.5°; horizontal separation subtended a total of 3.9°. The words were followed for 250 ms by a pattern mask 4.5° wide × 2° high, formed from fragments of letters in the words and covering the area of word pairs. This was followed by the initial fixation cross and the cue rectangle for 750 ms. The screen then returned to blank grey.

Subjects were told that the experiment examined perception of letter strings. Throughout, the experimenter referred to stimuli as "letter strings" and said that not all of them were necessarily words. The trial event sequence was explained, stressing that the rectangle appeared both before and after the letter strings to indicate which was to be reported. Subjects were told that after the rectangle reappeared, they were required to make three responses. First, they should report the numeral. Second, they should try to report the cued letter string by spelling it out (and could also name it). Third, they should indicate their confidence that what they reported was what they had seen by saying "very sure", "sure", "unsure" or "very unsure". Guessing was discouraged, but subjects were told to report any guesses by saying "guess" instead of a confidence rating. It was stressed that the confidence rating applied only to the letter string, not the

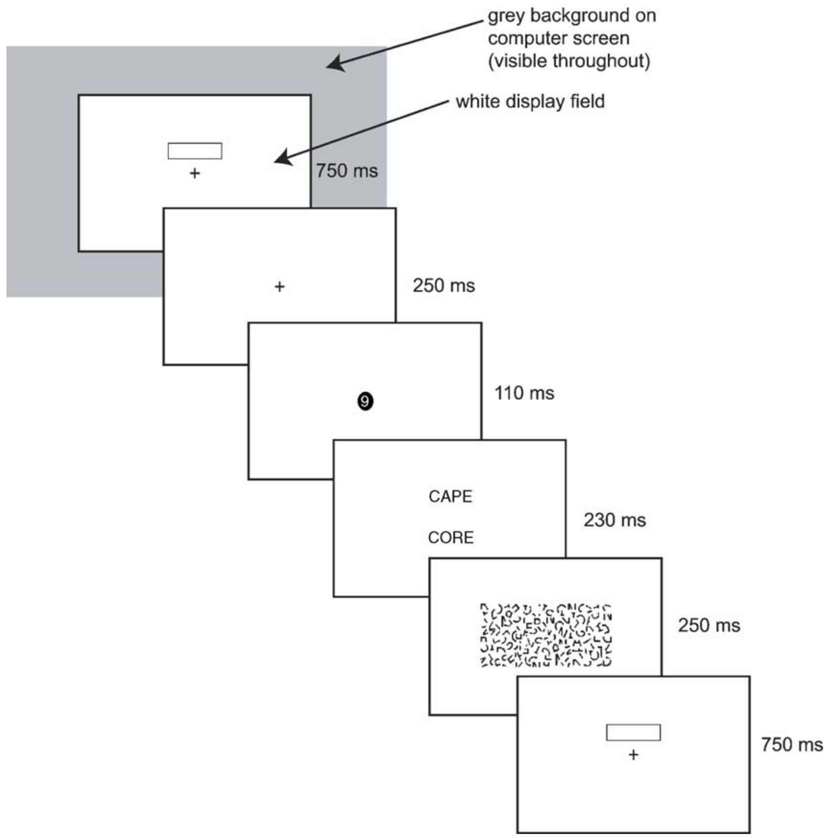

Fig. 2. Sequence on an experimental trial with the words vertically aligned. On trials with the words horizontally aligned, the cueing rectangles would be to the left or to the right of fixation. The control condition was the same except that single words instead of word pairs were displayed. (Figures are not to scale; see text for actual dimensions.)

numeral. The experimenter keyed subjects' responses in to the computer and initiated the next trial.

Subjects were shown four demonstration trials in which the numeral and the words were displayed for 400 ms and 2 s respectively. They were then given practice trials, over which the durations of the numeral and the word pairs were reduced. For the first 4, 200 and 1200 ms; for the next 16, 110 and 500 ms; for the next 16, 110 and 300 ms; for the final 16 trials, 110 and 230 ms, which were the display durations for the following experimental trials. At this point, all subjects were responding as required, and all declined an offer of further practice.

There were eight blocks of 20 trials, each preceded by four buffer trials. Within each block, each word pair was used once. Stimuli at the end and beginning of consecutive blocks were controlled so that presentations of the same word pair were separated by at least three test trials. Each of the four positions to be reported was cued equally often; no position was cued more than twice in succession. Half the word pairs were displayed horizontally aligned and half vertically aligned. Across all blocks, each word was cued four times, once in each position. Each word was probed twice in the first four blocks and twice in the second four. Between consecutive blocks, a given word pair alternated horizontal and vertical alignments. Thus, a word never appeared in the same position in consecutive blocks. Order of blocks was counterbalanced (partially, given the number of subjects) separately across HE and across LE subjects using a Latin Square design, subject to the constraint that each word pair alternated horizontal and vertical alignments. After the second and sixth blocks, subjects were given a 3 min rest. After the fourth block, they were given a 10 min rest. After the experiment, subjects were asked for general comments and then about relative difficulty and whether they believed that they had made mistakes and how many (see Appendix A).

4.1.4.2. Control condition. The design and procedure were the same as in the experimental condition, except that words were presented singly. Their positions were cued by the rectangle, but again report of the numeral ensured fixation at stimulus onset. A pre-mask SOA of 90 ms was used, established in piloting as producing below-ceiling performance in LE subjects. Four blocks of 20 trials were presented. Each stimulus and each stimulus location were tested an equal number of times. Subjects were instructed in the same way as for the experimental condition, except that they were told that single letter strings would be shown. They responded in the same way and were given a single 3 min rest break.

4.2. Results

Trials on which the digit was not reported correctly were discarded from the analysis. In both the experimental and control conditions, median error rate for reporting the numeral was 1.25% of the total number of trials. There was no difference between the two subject groups in numeral error rates in either

Table 4
Percent migrations, pseudo-migrations, true migrations, intrusions, omissions and correct responses made by each subject in the experimental and control conditions

Subjects	Migrations			Intrusions		Omissions		Correct responses	
	Migrations experimental condition (%)	Pseudo-migrations control (%)	True migrations (%)	Experimental condition (%)	Control condition (%)	Experimental condition (%)	Control condition (%)	Experimental condition (%)	Control condition (%)
High Error subjects									
MK	12.66	3.75	8.91	8.23	15.00	.63	0	78.48	81.25
LS	11.39	6.58	4.81	8.23	48.68	0	0	79.75	44.74
EG	7.55	0	7.55	8.18	15.19	.63	12.66	83.65	72.15
CG	4.46	1.27	3.19	2.55	13.92	0	1.27	92.99	83.54
KST	5.16	0	5.16	3.87	5.13	1.94	2.56	89.03	92.31
Mean	8.24	2.32	5.92	6.21	19.58	.64	3.30	84.78	74.80
Low Error subjects									
KAM	1.88	0	1.88	0	0	5.00	10.13	93.13	89.87
RB	5.63	1.25	4.38	3.13	2.50	.63	0	90.63	96.25
MF	1.89	3.45	−1.56	7.55	10.34	3.77	17.24	84.91	68.97
LB	1.94	0	1.94	1.29	0	0	0	96.77	100
JL	3.13	3.75	−.62	5.00	7.50	0	0	91.25	88.75
Mean	2.89	1.69	1.20	3.39	4.07	1.88	5.47	91.34	88.77

True migrations (%) = migrations (%) − pseudo-migrations (%).

the experimental condition (Mann–Whitney $U = 9.5$, $p = .55$) or the control ($U = 10.0$, $p = .69$). All following results reported were calculated only from trials where the numeral was reported correctly.

Reports of the words were classified as follows. Commission errors were of two types: *migrations*, where a letter or letters from the distractor word were included in the report, and *intrusions*, where the report included letters which occurred in neither target nor distractor. Reports including both migrations and intrusions were scored as migrations. *Omissions* were where fewer than four letters were reported (without migrations or intrusions) or where subjects reported seeing nothing in the cued location, and were very infrequent. In the control condition, errors which would have been classed as migrations in the experimental condition (e.g. reporting CARE when only CAPE was displayed) were classified as *pseudo-migrations*. Errors that included letters from neither the single target word nor what would be its experimental partner were classified as *intrusions*. In all other respects, data from control and experimental conditions were scored in the same way. Assuming that the pseudo-migration rate in the control condition represents the frequency of migration-like responses in the absence of a distractor, subtracting the pseudo-migration rate (control condition) from the migration rate (experimental condition) gives the "true" migration rate for each subject (Mozer, 1983; McClelland and Mozer, 1986).

Table 4 shows the percentages of migrations, pseudo-migrations, true migrations, intrusions, omissions and correct responses made by each subject in the experimental and control conditions. An independent *t*-test showed that HE subjects, as a group, made significantly more true migration errors than LE subjects ($t(8) = 3.22$, $p < .01$, one-tailed). The difference in migration rates between experimental and control conditions was significant for HE subjects (mean: 5.92; $t(4) = 5.80$, $p < .01$) but not for LE subjects (mean: 1.2; $t(4) = 1.15$, $p = .315$). The fact that there was no significant difference in pseudo-migrations between groups ($t(8) = .42$) suggests that HE subjects make a specific kind of error, rather than being generally more error prone (though this conclusion should be treated with caution due to the small sample size).

The central issue is whether HE subjects made more migration errors than LE subjects independently of any potential tendency to make more commission errors per se. To ascertain this, each subject's migration rate and pseudo-migration rate in experimental and control conditions respectively, were expressed as a percentage of the total number of commission errors (migrations + intrusions) in each condition. When calculated in this way, the difference in migration rates between experimental and control conditions was significant for HE subjects (mean: 49.43; $t(4) = 16.28$, $p < .001$) but not for LE subjects (mean: 10.37; $t(2) = .97$, $p = .44$). When the migration rates in the control condition were subtracted from those in the experimental condition to obtain true migration rates adjusted for total commission errors, HE subjects had significantly higher true migration rates than LE subjects (mean: 49.43 versus 10.37; $t(6) = 4.44$, $p < .005$). That is, their greater increase in migration errors from control to experimental condition was not due purely to a greater tendency to make commission errors. Table 5

Table 5
Migration and pseudo-migration rates as percentages of total commission error rates in experimental and control conditions for High and Low Error subjects

Subject group	Mean migrations/total commission errors: experimental condition (%)	Mean pseudo-migrations/ total commission errors: control condition (%)
High Error	57.48	8.05
Low Error	40.93	30.56

Table 6
Number of migrations to structurally equivalent and structurally non-equivalent positions in the experimental condition made by High and Low Error subjects

Subjects	Structurally equivalent	Structurally non-equivalent
High Error subjects		
MK	18	2
LS	17	1
EG	12	0
CG	6	1
KST	8	0
Mean	12.20	.80
Low Error subjects		
KAM	3	0
RB	7	2
MF	1	0
LB	3	0
JL	5	0
Mean	3.80	.40

lists mean percent migration and pseudo-migration rates for both subject groups in experimental and control conditions, adjusted as described above.

Migration errors were classified according to whether each involved transposition of a letter or letters from the distractor word to structurally equivalent positions in the target (e.g. CAPE + CORE → CARE) or not (e.g. CAPE + CORE → CPRE). Table 6 shows the number of migrations to structurally equivalent and non-equivalent positions in the experimental condition. Both groups of subjects showed significantly more migrations to structurally equivalent than to structurally non-equivalent positions (HE: $t(8) = 4.74$, $p < .01$; LE: $t(8) = 3.10$, $p < .02$); the groups did not differ in the proportion of structurally equivalent compared to structurally non-equivalent migrations (mean: HE = 94%, LE = 95.6%; $t(8) = -.29$, $p = .78$).

The question arises whether migration errors are more probable when a pair of words is aligned horizontally or vertically. That is, compared to a single-word presentation (control condition), does adding a second horizontally aligned word lead to more migrations than adding a second vertically aligned word (for HE versus LE subjects)? Therefore, the percentage of true migration errors made by HE and LE subjects (i.e. the relative increase) was compared between vertically and horizontally aligned words (see Table 7). Again, it is possible that adding a distractor word can increase commission errors per se (migrations and intrusions). This would not mitigate any difference, since this in itself might bear on whatever produces migrations. Therefore, in addition, the increase in migration errors from control to experimental condition relative to the increase in all commission errors was compared between alignments. For this comparison, the increase in migrations was subtracted from the increase in all commission errors (see Table 7).

For the first analysis, a repeated-measures ANOVA showed a significant main effect of subject group, with HE subjects making significantly more migration errors in both alignments than LE subjects ($F(1,8) = 10.53$, $p < .015$). The interaction between alignment and group approached significance ($F(1,8) = 3.65$,

Table 7
For horizontal and vertical alignments: percentages of migrations, pseudo-migrations and all commission errors in the experimental and control conditions, and the differences for each error type between experimental and control conditions

Subjects	Horizontal						Vertical					
	Migrations			All commissions			Migrations			All commissions		
	Experimental: migrations	Control: pseudo-migrations	Difference: true migrations	Experimental	Control	Difference: experiment − control	Experimental: migrations	Control: pseudo-migrations	Difference: true migrations	Experimental	Control	Difference: experiment − control
High Error subjects												
MK	15.00	5.00	10.00	27.50	27.50	0	10.26	2.50	7.76	14.10	10.00	4.10
LS	16.25	10.00	6.25	28.75	47.50	−18.8	6.41	2.78	3.63	10.26	63.89	−53.6
EG	12.66	0	12.66	25.32	20.00	5.32	2.50	0	2.50	6.25	10.26	−4.01
CG	6.49	2.56	3.93	9.09	12.82	−3.73	2.50	0	2.50	5.00	17.50	−12.5
KST	6.41	0	6.41	8.97	2.56	6.41	3.90	0	3.90	9.09	7.69	1.40
Mean	11.36	3.51	7.85	19.93	22.08	−2.15	5.11	1.06	4.05	8.94	21.87	−12.9
Low Error subjects												
KAM	0	0	0	0	0	0	3.75	0	3.75	3.75	0	3.75
RB	5.00	2.50	2.50	8.75	5.00	3.75	6.25	0	6.25	8.75	2.50	6.25
MF	0	0	0	8.00	6.67	1.33	3.57	7.14	−3.57	10.71	21.43	−10.7
LB	3.90	0	3.90	5.19	0	5.19	0	0	0	1.28	0	1.28
JL	2.50	7.50	−5.00	12.50	17.50	−5.00	3.75	0	3.75	3.75	5.00	−1.25
Mean	2.28	2.00	.28	6.89	5.83	1.06	3.46	1.43	2.03	5.65	5.79	−.14

$p = .093$), with HE subjects tending to show more migrations in the horizontal than in the vertical alignment. Subsequent between-subjects tests showed that the groups did not differ in their rates of true vertical migrations ($t(8) = 1.02$, $p = .34$), but that HE subjects had a higher rate of true horizontal migrations than LE subjects ($t(8) = 3.50$, $p < .01$). For the second analysis, when the increase in commission errors from control to experimental condition was subtracted from the increase in migration errors to produce an "adjusted" migration rate for each alignment, no within-subject differences were found between horizontal and vertical (HE means: $H = 10$, $V = 17$; $t(4) = -1.04$, $p = .36$; LE means: $H = -.8$, $V = 2.7$; $t(4) = -1.78$, $p = .15$). However, between groups, HE subjects had a higher adjusted rate of horizontal migrations than LE subjects ($t(8) = 2.61$, $p < .05$), but the groups did not differ in adjusted rate of vertical migrations ($t(8) = 1.42$, $p = .19$).

Confidence ratings were converted to a 4-point scale, with "very unsure", "unsure", "sure" and "very sure" represented as 1, 2, 3 and 4, respectively. They were treated in two different ways. (a) Analysis of percentage of migration errors rated at each confidence level in the experimental condition showed that HE subjects rated more of their migration errors "very sure" than did LE subjects (mean: HE = 15.82; LE = 0; $t(4.0) = 3.08$, $p < .05$, equal variances not assumed). Indeed, while HE subjects rated 15% of their migration errors as "very sure", LE subjects never rated their migration errors as "very sure". There were no differences between groups in the proportion of migration errors rated at other confidence levels. (b) A single average calculated using the 4-point scale permits one to compare confidence ratings between migration errors and correct responses. Fig. 3 shows mean confidence ratings by HE and LE subjects on migrations and correct responses in the experimental condition and on pseudo-migrations and correct responses in the control condition. The mean difference between confidence ratings on correct responses and migrations did not differ between the two groups (mean: HE = .67; LE = 1.01; $t(8) = -.964$, $p = .36$). However, while LE subjects had significantly higher confidence ratings on correct responses than on migrations ($t(8) = -2.44$, $p < .05$), HE subjects showed no difference between their confidence ratings on migrations and on correct responses ($t(8) = -2.19$, $p > .05$). In the control condition, no within-subjects difference in confidence was found between pseudo-migrations and correct responses (HE: means = 2.64, 3.07; $t(4) = -1.97$, $p > .05$; LE: means = 2.89, 3.13; $t(4) = .10$, $p > .05$).

4.2.1. Subjects' comments

See Appendix A.

4.3. Discussion

The procedure in this experiment was successful in inducing migration errors. This is of interest for two reasons. First, while Mozer (1983) used only post-stimulus cueing, this experiment also used pre-stimulus cueing, in order to be comparable to our other experiments in which subjects knew where to attend before stimulus presentation. Letter migrations clearly occur even when subjects do not have to divide attention between stimuli. It is difficult to tell to what extent this pre-cueing was what produced lower migration rates in the present case than in Mozer's procedure, because we deliberately used a pre-mask SOA where LE subjects made few enough migrations to allow for increases by HE subjects. Second, when compared to the results of the first visual experiment, the finding suggests that brief exposure followed by pattern masking plays a role in induction of migration errors—plausibly by a disruption to binding.

The main results relevant to the central issue are as follows. HE subjects as a group made more true migration errors than LE subjects. In addition, the relative increase in migration errors was still greater in HE than in LE subjects when taking into account the increase in total commission errors from control to experimental condition. It appears, then, that the visual situation and task in Section 3.3 is not sensitive to the individual difference (since it did not produce migrations), but that this paradigm does show that the greater susceptibility to migration in HE subjects occurs also in vision. As far as we know, this is the first report of an individual difference in susceptibility to migration in vision.

It might be argued that letter migration errors between words are not truly a visual effect, but are produced at a lexical level (McClelland & Mozer, 1986; Mozer, 1983). There are reasons (a) to doubt the generality of this, and (b) why it does not mitigate the relevance of the finding to the issue of sensory modality of migration. First, it is unclear why a purely lexical effect should be differential for subjects who differ in susceptibility to migration in tactile and auditory perception. Indeed, HE subjects may

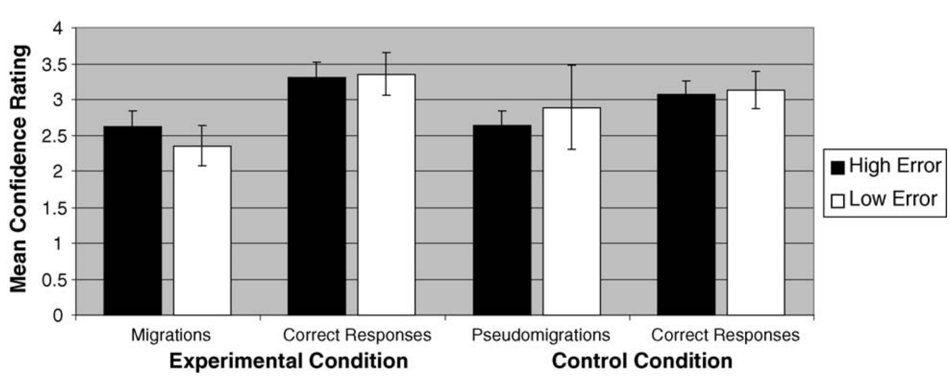

Fig. 3. Mean confidence ratings by High and Low Error subjects on migrations and correct responses in the experimental condition and on pseudo-migrations and correct responses in the control condition. Bars represent standard errors.

be more sensitive to whatever produces a "better" perceptual object on a variety of criteria (e.g. more familiar) via integration of available features at the locus of attention. Second, whatever has a causal influence, its effect on migration of perceptual features must be constrained by the degree to which such features are veridically bound to their original spatial location. Third, in a recent study (Vuckovich, 2004), the same HE subjects also made more letter migrations than LE subjects between *non-word* consonant-strings, especially if the colour of migrating letters produced better colour grouping in the target string. This suggests that letter migration can be produced by factors at different levels (not necessarily lexical) and that the effect itself is at a visual level. Finally, HE subjects' confidence was almost equal on migrations and correct responses, while LE subjects' confidence was significantly lower on migrations. This suggests that HE subjects perceive their migrations as no different from their correct reports. The tactile (Marcel et al., 2004) and auditory rating experiments indicate that migrations reflect what HE subjects experience, rather than merely their response bias. The nature of the letter report task precluded the same kind of data. However, the confidence ratings, especially given the instruction to rate confidence as to what was *seen*, indicate that migration errors reflect subjects' conscious visual experience. Thus, however they were produced, the present migration errors are likely to be a property of visual experience rather than purely of lexical access.

It is of particular interest that HE subjects' greater tendency to make migration errors was much more evident in horizontal than vertical alignment of word pairs. First, there is little reason to assume from previous literature that migrations are more frequent when stimuli are horizontally aligned, and the LE subjects showed no differential tendency in this experiment. Second, and more importantly, the structural equivalence of letter positions is more perceptually evident when two words are aligned vertically than horizontally. This makes the greater horizontal than vertical increase in HE subjects' structurally equivalent migrations noteworthy. Marcel et al. (2004) speculated that HE subjects are showing a subclinical form of allochiria and neglect. They argued that much neglect and extinction is also accounted for by migration of unattended contralesional stimuli to attended ipsilesional locations. These and associated deficits involve primarily a problem in horizontal space (though whether this is mainly in a geocentric or body-centred reference frame is moot; see Ládavas, 1987). Indeed, in the tactile and auditory experiments, the migrations were from laterally homologous locations. Therefore, the greater potential of the horizontal dimension to produce migrations in HE subjects is consistent with their putative relation to patients with allochiria and neglect.

Both groups of subjects made many more structurally equivalent than structurally non-equivalent migrations. This suggests that, in letter migrations, while egocentric or scene based location is weakened, structural location is preserved. However, this may also be due to the constraints of the letter strings and the fact that structurally equivalent migrations had a greater potential for producing higher frequency words.

In the tactile and auditory experiments, migrating stimuli either fused with or replaced the stimuli at the attended location.

Table 8
Tactile, auditory and visual migration rates for High Error subjects in the three relevant experiments

Subject	Tactile migration rate (%)	Auditory migration rate (%)	Visual migration rate (true letter migrations) (%)
MK	75	15	8.91
LS	100	5	4.81
EG	75	25	7.55
CG	100	15	3.19
JB	70	35	N/A

In this experiment, migrating letters overwhelmingly replaced those in structurally equivalent locations. However, it is possible to conceive of each word as an object of which the letters are features. In these terms, one can think of the two words fusing to produce "better solutions", i.e. the non-matching letters in the two words can only compete as integral features rather than fuse. Whole perceptual objects can fuse, but features can only compete. Whether fusion or replacement is occurring may depend on the level of representation one focuses on.

Subjects showed migration to different degrees. It is of interest whether this individual difference is constant across modalities. Since LE subjects showed low migration with little range, the question can only apply to HE subjects. Five performed both tactile and auditory rating and four of these performed the visual word recognition experiment. A single "migration rate" was derived from each subject's responses in each of the auditory and tactile rating (Marcel et al., 2004) studies: the percentage of Tap–Drum trials on which attended Tap was rated as more similar to Drum than to Tap (ratings of E, F, G and H). The equivalent in the visual experiment is the rate of true migrations. These measures are shown for relevant subjects in Table 8. Pearson's correlation coefficient was not significant for the tactile and auditory migration rates ($r = -.79$, $N = 5$, $p = .11$) nor for the tactile and letter rates ($r = -.94$, $N = 4$, $p = .06$) nor for the auditory and letter rates ($r = .43$, $N = 4$, $p = .57$). This lack of consistency over modality of relative degree of migration might be due either to differential modality effects across individuals or to migration susceptibility itself over time. However, the small number of HE subjects common to these studies renders the power of any statistic too low for any firm conclusion. What remains clear is that across all studies in the previous and present paper the difference in migration susceptibility between HE and LE subjects as groups is maintained.

5. General discussion

Apart from the central issue of the specificity or generality of modality in which the difference in susceptibility to migration occurs, these experiments have produced two new findings. This is the first report of individual differences in auditory fusion of dichotic stimuli and in susceptibility to migration in vision. Such individual differences throw light on what underlies these phenomena. Although subjects' comments must be treated with caution, over the three experiments they tended to reflect each subject's behaviour (e.g. fusion or replacement in audition in HE subjects; difference between horizontal and vertical alignment in word recognition; see Appendix A). If anything, LE subjects seemed more aware of the difficulties to be overcome and the possibility of migration.

Regarding the central question, the difference between HE and LE subjects in susceptibility to migration is clearly multimodal, manifesting in touch, audition and vision, though not equally for all subjects nor to the same relative extent across modalities. In touch and audition, we have tested only lateral alignment of the two locations. However, in the visual case, where we tested both lateral and vertical alignments, the lateral alignment is clearly the most prepotent for HE subjects. Since allochiria, neglect and extinction primarily occur in horizontal coordinates, this reinforces our proposed relation between migrations in HE subjects and these spatial deficits, i.e. premorbid susceptibility (see previous paper).

5.1. What underlies multimodality of the individual difference in susceptibility to migration?

Two alternative approaches to what underlies high migration rates in some individuals may be considered. Both account for susceptibility to migration being multimodal. The first approach focuses on the fact that in all the cases where high migration rates have occurred stimuli have been spatially lateralised such that their primary projection would be to separate hemispheres. It is possible that some individuals have more equally bilateral representation, e.g. via interhemispheric connection. In this sense, migration is primarily hemispheric and secondarily spatial. It may not immediately appear that this approach relates to neglect or extinction, with which allochiria is associated (see Marcel et al., 2004). However, one variant, Kinsbourne's (1987) hemispheric theory of spatial attention, provides such a link. In this view, each hemisphere mediates spatial attention toward the contralateral side of space (with the right hemisphere mediating attention to both), and the two are in a form of isometric competitive balance. To the extent that superordinate control of lateral attention is weakened, what is on the side to be ignored would tend to capture attention and in neglect a directional bias would occur toward the ipsilesional side (in healthy people toward the attended side). This would account for greater horizontal than vertical migration in HE subjects in Section 4, but it is not clear how it would account for vertical migration at all.

The second approach relies on a suggestion in our previous paper (Marcel et al., 2004) that has two components. (a) Susceptibility to migration is the result of weak binding of perceptual content to unattended spatial locations. (b) Fusion with or replacement of stimuli at attended locations is mediated by integration of perceptual features or binding of perceptual identity to location, which are aspects of focal attention related to conscious perception. Indeed, (a) and (b) may be independent and only one may be relevant. We argued that normally binding must occur to some extent outside of the target locus of focal attention. If some individuals show particularly weak binding outside of attention (but preserve perceptual identity), then this is due either to their representation of spatial location outside attention or to whatever produces the binding that normally prevents migration. The latter is more probable for the following reason. Since the present experiments show susceptibility to migration to be multimodal, its source must be supramodal. Representation of spatial location is almost certainly modality-specific in these situations. However, binding is held to be produced by spatial attention, which, though it can be applied to each modality, is normally located supramodally (which is why it is difficult to attend simultaneously to different locations in separate modalities; Driver & Spence, 2004).

The individual difference in binding might be independent of attention. However, the similarity of the migration errors to clinical allochiria (see Marcel et al., 2004 for discussion), which tends to occur in patients with pathology of spatial attention, encourages the conjecture that the individual difference is in some aspect of spatial attention. This might seem paradoxical, since we are referring to binding at locations outside of the focus of attention. However, spatial attention cannot be restricted to its focus, and there is no sharp boundary between the spatial extent of focal attention and its background. First, we propose that the extent of focal attention and the difference in allocation of attentional resource between focus and surround depend on task demands, difficulty and the spatio-temporal constraints of the perceptual situation (e.g. discriminability, duration, masking). Second, it has been proposed that selective attention entails not only an operation on its target, but also some (inhibitory) operation on potential distractors (Allport, Tipper, & Chmiel, 1985). Hence, negative priming from ignored competitors (Tipper, 2001). From this perspective, attending to stimuli in one location involves some degree of suppression of stimuli in other locations, entailing some degree of binding to those to-be-ignored locations. We further propose that the greater the focussing of attention, the less the availability of attentional resources for binding those stimuli that lie outside the attentional focus. In neglect and associated phenomena, focal attention is frequently thought to be not only spatially biased, but also narrowed and more "concentrated" (Ládavas, Petronio, & Umiltá, 1990). This would pathologically reduce the availability of attentional resources at unattended locations. In so far as HE subjects are similar to such patients, increased focal attention would leave less resources for minimal extra-attentional binding that would prevent those stimuli from migrating to become attentional candidates. If this attentional process is supramodal, it would lead to a tendency to migrate that is multimodal.

Another factor relevant to differences in migration rates between modalities is stimulus salience. In both the tactile and auditory paradigms, the temporally modulated stimulus (Drum) had the greater tendency to migrate if unattended and paired with an attended unmodulated stimulus (Tap). While in touch this is universally experienced as more salient, in the auditory equivalent the difference in salience is less marked. This modality difference in relative salience is illuminated by Cusack and Carlyon's (2003) analysis of the decomposition of auditory stimuli. According to their analysis, it is probable that the auditory Drum stimulus is represented as an extended tone with the added feature of temporal modulation, whereas the tactile Drum stimulus is represented as a series of temporal modulations or of separate stimuli. While in both cases Tap and Drum are temporally coextensive, the difference between them in relative prominence of the temporal modulation feature is greater in touch than in audition. In the visual letter migration experiment, there was no difference in experienced salience between what migrated and what was replaced, and there is no reason to suppose any such difference. The relative migration rates in the three paradigms parallel these differences.[2] Thus, salience does seem to play some role. It appears to contribute to the competitiveness of spatially unattended stimuli for migration, whereas structural compatibility affects whether a migrating stimulus will fuse with or replace that in the attended location. This further reinforces the hypothesis that the individual difference lies at least partly in an attentional difference.

5.2. *What is the relation of multimodality in healthy subjects to pathology?*

We suggested (Marcel et al., 2004) that HE subjects are those who will predominantly manifest allochiria, neglect and extinction with appropriate brain damage. If this speculation is correct, then one might expect that such deficits will be predominantly multimodal. Unfortunately, clinical studies have often examined only one modality or, at most, two. This is most true of allochiria, which has also been less studied than neglect or extinction. All these deficits can occur both in a single modality and in more than one (see Vallar, Rusconi, Bignamini, Geminiani, & Perani, 1994, for review). The relative predominance of multimodal and unimodal occurrence of such deficits is impossible to derive from the literature. However, the coexistence of multimodal and unimodal cases of such deficits can be due to either of two possibilities. (1) The basic deficit is modality-specific but can occur in more than one modality. (2) The basic deficit is multimodal but can manifest overtly in, or be amplified in, specific modalities. Although all HE subjects show migration in three modalities significantly more than LE subjects, they do not show it equally in all modalities nor in the same order of severity across individuals. Patients whose acute neglect symptoms remit often still exhibit neglect or extinction with more sensitive measures or in more demanding conditions. The same may apply to modality. Thus, a patient with clear allochiria or extinction in only one modality might show symptoms in another if tested appropriately. Of course, susceptibility to such spatial deficits may be modality-specific in some individuals and multimodal in others. As explicated in Section 1, spatial source is represented at both modality-specific and supramodal levels, and spatial attention operates at both levels. Therefore, to fully characterise patients' spatial deficits and what underlies them, different modalities need to be systematically tested with sensitive measures.

5.3. *What is common to the situations producing differences in migration?*

The fact that migrations and the individual difference in susceptibility to them occur in touch, audition and one (though not another) visual situation raises a question. Are there features making a situation appropriate to migration that are peculiar to each modality or is there something uniting the effective situations in the three modalities? For migrations to occur at all, the attended and unattended stimuli must presumably be spatially compatible or temporally coextensive to a sufficient degree to be integratable or for one to replace the other. (However, we have not yet specifically tested variations in non-compatible or non-coextensive stimuli.) Two factors conducive to migration were mentioned in Section 3.5. One is relative salience of the unattended stimulus. This plausibly accounts for the different degree of tactile and auditory migration, because which stimulus migrates and the migration rates are correlated with subjects' spontaneous reports of relative salience. The other factor, especially applicable to the different visual experiments, is disruption to what permits adequate binding (e.g. by pattern masking).

One other feature is common to the situations in the three modalities. In each, the locations between which migrations occur are homologous. The two hands are homologous in a structural description of the body. Marcel, Gillmeister, and Griffin (in preparation) conducted an experiment, using the original Tap and Drum procedure, assessing the spatial frames of reference in which tactile interference operates. Homology of body part produced most interference, even when the relevant body parts (the two hands/feet) were in different postural locations in egocentric external space. We found much less tactile migration in HE subjects between non-homologous bodily locations. In auditory dichotic presentation using earphones, the perceived location of sounds is at the two ears, which are homologous bodily locations. The other locative relation that was effective in the present experiments is structural position of letters in words. Letters migrated overwhelmingly to structurally equivalent locations, while in many cases (see Appendix B) they could have migrated to other locations. Structural equivalence of location is a form of homology. Since in the migration in the present experiments homology of location was preserved, this suggests that the failure in the underlying spatial binding is in an egocentric frame of reference. If such migration is indeed related to allochiria, neglect and extinction, this is also likely to be mainly the case for these deficits.

The present experiments investigated migration only within modalities. In healthy people, there is at least one kind of migration that occurs across modalities. In a variant of the McGurk effect (McGurk & McDonald, 1976), if a particular phoneme in a spoken syllable is produced and the mouth or lip shape on a visually presented face placed elsewhere signals the equivalent phoneme to differ in placing and voicing, one of these latter feature values replaces its equivalent in the consciously heard word (Bertelson, 1998; Bertelson & de Gelder, 2004, p. 168). For this to happen, a phonetic feature must have perceptually migrated across both space and sensory modality, at least at the level of conscious experience. Whether the present susceptibility to migration is not only multimodal but also cross-modal remains to be assessed. Mattingley et al's (1997) findings are suggestive. Patients who showed reliable within-modality extinction for visual and tactile stimuli also showed cross-modal extinction where the stimuli were commensurable. Their data are consistent with evidence for competition between vision and touch

[2] However, the particular stimulus presentation conditions, e.g. degree of pitch separation in audition, SOA in vision, also plausibly affected migration rate.

in spatial attention. This reinforces the notion of migration at a supramodal level.

In summary, the individual difference in migration and fusion/replacement obtains in touch, audition and vision. These and our previous data suggest a common cognitive characteristic in our HE subjects, which causes a multimodal susceptibility to migration, plausibly deriving from a particular feature of their spatial attention. It would be of interest to test our proposal that HE subjects may be predisposed to allochiria, neglect and extinction by assessing their relative vulnerability to procedures mimicking such deficits (e.g. Transcranial Magnetic Stimulation) and by pursuing parallel studies in relevant neurological patients.

Acknowledgements

We are grateful to Bob Carlyon for discussion of auditory fusion, to Christopher Rorden and Karolina Moutsopoulou for comments on an earlier version of the manuscript and to the Editor and referees for helpful suggestions.

These studies were approved by and in accord with the standards of the Cambridge Psychology Research Ethics Committee (Reference No. 2002.24).

Appendix A. Subjects' comments

(Experimenter's clarification, interpretation or remarks are in brackets.)

NB. Subjects' comments on the tactile rating experiment are in Appendix A of Marcel et al. (2004).

A.1. Experiment 1: auditory rating

A.1.1. High Error subjects

MK. "I had some difficulty keeping the stimuli separate when they were on both ears".

LS. "When tap and drum were together it was harder. Sometimes when it was like hearing 'one sound' it was hard to 'hear' something in the attended ear, and so I just assumed it was 'the same' stimulus as the overriding impression. I had difficulty when the sound was 'above me'".

JB. "Very hard when mixed—I was just guessing when tap and drum were together. It was difficult to keep the sounds separate when two stimuli was a cacophony of noise. This was harder than the visual experiment. I said A or H, as I felt very much it was either one or the other".

CG. "When it was the same in both ears I felt like going for extreme A or H, because I felt it was a 'stronger' sound". (This implies experience of fusion on incongruent trials.) "I may have made mistakes rating *within* 'tap' or 'drum' (i.e. e–f–g–h), but not *between* 'tap' and 'drum'".

EG. "The hardest (experiment). The drum overpowered whatever ear I was listening to. I must have made errors saying drum on a few occasions when it was a tap. I had difficulty keeping the stimuli apart when the drum felt like it was merging—but I could keep taps separate. I only heard extremes—no 'fuzzy' ones, i.e. rated 'A' or 'H'". (Replacement)

A.1.2. Low Error subjects

TD. "The distractor felt stronger than (what occurred in) the attended ear. It was like listening to an echo—depended on memory to figure out what had actually happened. Tap would mask out drum more frequently".

RB. "It was hard to hear tap when drum was on other ear". (Implies awareness) "[I made errors] mainly with tap in attended ear, drum on the other. More [difficult to keep stimuli separate] than in any of the other experiments—I had to really concentrate hard on which sound was coming from where, as it seemed a blur of noise". (Aware of fusion)

KAM. "This was easiest [experiment]".

MF. "Much tougher than other experiments. [I was] not sure which ear was I was hearing [stimuli] in. Obviously the drum goes on longer". (!)

KS. "Obviously two different stimuli were more difficult; most difficult when tap on attended combined with drum on ignored ear". (Implies awareness) "Vaguely difficult to keep locations separate; I had to concentrate hard to overcome this".

A.2. Experiment 2: visual rating

A.2.1. High Error subjects

MK. "Light–Flicker trials hard; wanted to say Flicker, I may have made mistakes on these trials.

Difficult to differentiate between stimuli: very few seemed different from the extremes, harder to relate stimuli to the rating scale than in the tactile experiment".

LS. "Not sure if flicker was consistent, as it seemed a different type of stimulus at times—I said 'B' (implies fusion). Easier than the tactile experiment".

JB. "Did not notice any difference in difficulty over the different conditions".

CG. (Could not participate in this experiment.)

EG. "Easier than touch. I was more likely to say H (Flicker) on trials with Light–Flicker". (But she did not do so.) "Not as many errors as on touch".

A.2.2. Low Error subjects

TD. "This was easy".

RB. "Much easier. No difficulty to keep stimuli separate".

KAM. "Hard to tell whether 'light' was not a 'flicker'. Possibly a couple of mistakes: light reported as flicker".

MF. "Generally easier to attend to visual stimuli than auditory ones. Not as much difficulty keeping the stimuli separate as in touch".

KS. "Hard not to divert gaze. When one [stimulus] is flicker, [it is] hard to say what the other (ignored) stimulus is".

A.3. Experiment 3: visual word recognition

A.3.1. High Error subjects

MK. "Horizontal was harder than vertical".

LS. "I might have transposed and made words that were not really there". (Seemed aware of possibility of migrations, but she was not certain that she did this.)

CG. "Sometimes the last letter of a word seemed vague or seemed to fade slightly. A letter from one word could 'superimpose' itself on the other word". (Aware of possibility of migrations. Aware that some of her errors involved "transposing" the last letters of the two words.)

EG. (She did not think she had made many mistakes.)

KST. (She thought she was more likely to make mistakes with words that were "obscure" or not "in normal use".)

A.3.2. Low Error subjects

RB. "If two letter strings started with same letter, I found it hard to distinguish them".

KAM. (Did not think she made any mistakes. Aware of both words.)

MF. On most trials, "not terribly aware of other word" (i.e. of non-cued word). "No difference between horizontal, vertical or among positions".

JL. (She found left position a bit harder. No other relevant comments.)

LB. "Letters from one word could appear in the other word". (Aware of possibility of migrations. She said she was "aware" of the other word, but tried to make a point of not "saying it to herself". She did not think she made many mistakes.)

Appendix B. Word pair stimuli used in Experiment 3

(Word frequency from Celex Lexical Database in brackets.)

Same outer letters		Same inner letters	
BALK (34)	BUCK (160)	BEAD (197)	DEAN (227)
CAPE (292)	CORE (323)	DEAR (1251)	HEAL (265)
WANE (86)	WILE (23)	FAIR (1402)	HAIL (129)
BANE (17)	BORE (568)	LEAK (185)	WEAN (113)
RIPE (173)	ROSE (381)	CAST (737)	LASH (152)
MARE (68)	MOLE (99)	FOUL (171)	SOUR (189)
PARE (33)	PUCE (13)	WARD (550)	HARM (546)
SLAP (295)	SNIP (33)	FORK (266)	WORM (302)
SATE (15)	SINE (53)	DART (151)	PARK (1275)
TACK (49)	TUSK (33)	EVER (8047)	OVEN (353)

References

Allport, D. A., Tipper, S. P., & Chmiel, N. R. J. (1985). Perceptual integration and postcategorical filtering. In M. I. Posner & O. S. M. Marin (Eds.), *Attention & performance: Vol. XI* (pp. 107–133). London: Lawrence Erlbaum Associates.

Baayen, R. H., Piepenbrock, R., & Guilikers, L. (1995). *The CELEX lexical database (CD-ROM) (version v2.5)*. Philadelphia, PA: Linguistic Data Consortium, University of Pennsylvania.

Bertelson, P. (1998). Starting from the ventriloquist: The perception of multimodal events. In M. Sabourin, F. I. M. Craik, & M. Robert (Eds.), *Advances in psychological science, biological and cognitive aspects: Vol. 2* (pp. 419–439). Hove, East Sussex: Psychology Press.

Bertelson, P., & de Gelder, B. (2004). The psychology of multimodal perception. In C. Spence & J. Driver (Eds.), *Crossmodal space and crossmodal attention* (pp. 141–177). Oxford: Oxford University Press.

Bisiach, E., & Berti, A. (1995). Consciousness in dyschiria. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 1331–1340). London: MIT Press.

Bisiach, E., & Vallar, G. (2000). Unilateral neglect in humans. In F. Boller, J. Grafman, & G. Rizzolatti (Eds.), *Handbook of neuropsychology: Vol. 1* (pp. 459–502). Amsterdam: Elsevier.

Carlin, B. P., & Louis, T. A. (2000). *Bayes and empirical Bayes methods for data analysis* (2nd ed.). Boca Raton: Chapman & Hall/CRC.

Cusack, R., & Carlyon, R. P. (2003). Perceptual asymmetries in audition. *Journal of Experimental Psychology: Human Perception and Performance*, *29*, 713–725.

Driver, J., & Spence, C. (2004). Crossmodal spatial attention: Evidence from human performance. In C. Spence & J. Driver (Eds.), *Crossmodal space and crossmodal attention* (pp. 179–220). Oxford: Oxford University Press.

Kawamura, M., Hirayama, K., Shinohara, Y., Watanabe, Y., & Sugishita, M. (1987). Alloaesthesia. *Brain*, *110*, 225–236.

Kinsbourne, M. (1987). Mechanisms of unilateral neglect. In M. Jeannnerod (Ed.), *Neurophysiological and neuropsychological aspects of spatial neglect* (pp. 69–86). Oxford: Elsevier Science.

Ládavas, E. (1987). Is the hemispatial deficit produced by right parietal lobe damage associated with retinal or gravitational coordinates? *Brain*, *110*, 167–180.

Ládavas, E., Petronio, A., & Umiltá, C. (1990). The deployment of visual attention in the intact field of hemineglect patients. *Cortex*, *26*, 307–317.

Macaluso, E., & Driver, J. (2001). Spatial attention and crossmodal interactions between vision and touch. *Neuropsychologia*, *39*, 1304–1316.

Macaluso, E., & Driver, J. (2004). Functional imaging of crossmodal spatial representations and crossmodal spatial attention. In C. Spence & J. Driver (Eds.), *Crossmodal space and crossmodal attention* (pp. 247–275). Oxford: Oxford University Press.

Marcel, A. J., Gillmeister, H., Griffin, H. *Frames of reference and interference in somatic attention*. In preparation.

Marcel, A. J., Postma, P., Gillmeister, H., Cox, S., Rorden, C., & Nimmo-Smith, I. (2004). Tactile migration and fusion in healthy people—Premorbid susceptibility to allochiria, neglect and extinction. *Neuropsychologia*, *42*, 1749–1767.

Mattingley, J. B., Driver, J., Beschin, N., & Robertson, I. (1997). Attentional competition between modalities: Extinction between touch and vision after right hemisphere damage. *Neuropsychologia*, *35*, 867–880.

McClelland, J. L., & Mozer, M. C. (1986). Perceptual interaction in two-word displays: Familiarity and similarity effects. *Journal of Experimental Psychology: Human Perception and Performance*, *12*, 18–35.

McGurk, H., & McDonald, J. (1976). Hearing lips and seeing voices. *Nature*, *264*, 746–748.

Meador, K. J., Allen, M. E., Adams, R. J., & Loring, D. W. (1991). Allochiria vs allesthesia. Is there a misperception? *Archives of Neurology*, *48*, 546–549.

Mozer, M. C. (1983). Letter migration in word perception. *Journal of Experimental Psychology: Human Perception and Performance*, *9*(4), 531–546.

Nuetzel, J. M., & Hafter, E. R. (1976). Lateralization of complex waveforms: Effects of fine structure, amplitude, and duration. *Journal of the Acoustical Society of America*, *60*(6), 1339–1346.

Nuetzel, J. M., & Hafter, E. R. (1981). Discrimination of interaural delays in complex waveforms: Spectral effects. *Journal of the Acoustical Society of America*, *69*(4), 1112–1118.

Schneider, W. (1988). Micro experimental laboratory: An integrated system for IBM-PC compatibles. *Behavior Research Methods, Instruments and Computers*, *20*, 206–217.

Shallice, T., & McGill, J. (1978). The origins of mixed errors. In J. Requin (Ed.), *Attention and performance: Vol. VII* (pp. 193–208). Hillsdale, NJ: Erlbaum.

Shepherd, G. M. (1994). *Neurobiology* (3rd ed., pp. 267–293). Oxford University Press.

Spiegelhalter, D. J., Thomas, A., & Best, N. G. (1999). *WinBUGS Version 1.2 User Manual*. Cambridge, UK: MRC Biostatistics Unit.

Steiger, H., & Bregman, A. S. (1982). Competition among auditory streaming, dichotic fusion, and diotic fusion. *Perception & Psychophysics*, *32*, 153–162.

Tipper, S. P. (2001). Does negative priming reflect inhibitory mechanisms? A review and integration of conflicting views. *Quarterly Journal of Experimental Psychology (A)*, *54*, 321–343.

Treisman, A. M., & Schmidt, H. (1982). Illusory conjunctions in the perception of objects. *Cognitive Psychology*, *14*, 107–141.

Vallar, G., Rusconi, M. L., Bignamini, L., Geminiani, G., & Perani, D. (1994). Anatomical correlates of visual and tactile extinction in humans: A clinical CT scan study. *Journal of Neurology, Neurosurgery and Psychiatry*, *57*, 464–470.

von Békésy, G. (1960). *Experiments in hearing* (translated and edited by E. G. Weaver). London: McGraw-Hill.

Vuckovich, J. (2004). *Individual differences in letter migration: Constraints and relation to allochiria and modality*. Unpublished MPhil thesis. Cambridge University.