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Brain and Cognition 61 (2006) 159–171

Brain and Cognition

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A left-ear disadvantage for the presentation of irrelevant sound: Manipulations of task requirements and changing state ☆

Lee J. Hadlington [a,*], Andrew M. Bridges [a], C. Philip Beaman [b]

[a] *Department of Psychology, University of Wolverhampton, 243 Willenhall Road, WV1 2HY Wolverhampton, UK*
[b] *Department of Psychology, University of Reading, Earley Gate, Whiteknights, Reading RG6 6AL, UK*

Accepted 22 November 2005
Available online 14 February 2006

Abstract

Three experiments attempted to clarify the effect of altering the spatial presentation of irrelevant auditory information. Previous research using serial recall tasks demonstrated a left-ear disadvantage for the presentation of irrelevant sounds (Hadlington, Bridges, & Darby, 2004). Experiments 1 and 2 examined the effects of manipulating the location of irrelevant sound on either a mental arithmetic task (Banbury & Berry, 1998) or a missing-item task (Jones & Macken, 1993; Experiment 4). Experiment 3 altered the amount of change in the irrelevant stream to assess how this affected the level of interference elicited. Two prerequisites appear necessary to produce the left-ear disadvantage; the presence of ordered structural changes in the irrelevant sound and the requirement for serial order processing of the attended information. The existence of a left-ear disadvantage highlights the role of the right hemisphere in the obligatory processing of auditory information.

Keywords: Irrelevant sound effect; Left-ear disadvantage

1. Introduction

It is now well established that a variety of irrelevant auditory information can have a deleterious effect on cognitive performance, particularly upon immediate serial recall of a verbal sequence (Colle, 1980; Colle & Welsh, 1976; Jones, Alford, Bridges, Tremblay, & Macken, 1999; Jones & Macken, 1993; Jones, Madden, & Miles, 1992). Research has focused on a variety of explanations for the irrelevant sound effect. These explanations usually link interference to confusions between phonological elements of the to-be-remembered and to-be-ignored material in immediate memory (Salamé & Baddeley, 1982, 1989). However, phonological similarity is not always critical in eliciting the irrelevant sound effect (Beaman & Jones, 1997; Bridges & Jones, 1996; Jones & Macken, 1993; Larsen, Baddeley, & Andrade, 2000; LeCompte & Shaibe, 1997; Neath, 2000).

Robust interference effects are generally noted for tasks that include a requirement to hold serial order in memory (Beaman & Jones, 1997, 1998; Henson, Hartley, Burgess, Hitch, & Flude, 2003). Jones, Beaman, and Macken (1996) suggested that the irrelevant sound effect could be viewed as the clash between two simultaneous processes of seriation taking place within memory. One process concerned with retaining item-order information for the to-be-remembered material, the other via the obligatory processing of irrelevant sound that contains abrupt "changes in state" between one auditory object and the next (e.g., changes in pitch). Jones et al. (1996) suggested that it should be possible to demonstrate an irrelevant sound effect for tasks that require the coding of serial order information, even if the requirement is not explicit for the task.

The suggestion that the irrelevant sound effect has a direct basis on the representation of order in memory has

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☆ The experiments reported here were conducted during a studentship at the University of Wolverhampton. Thanks are forwarded to Jacqueline Bestwick for reading an earlier draft of this report.

[*] Corresponding author.
E-mail address: l.hadlington2@btinternet.com (L.J. Hadlington).

0278-2626/$ - see front matter © 2006 Published by Elsevier Inc.
doi:10.1016/j.bandc.2005.11.006

gained further support from recent research into lateralisation of function. Hadlington et al. (2004) demonstrated an original finding related to the irrelevant sound effect and hemispheric specialisation. They showed that the errors produced by irrelevant sound were increased when the irrelevant sound was presented monaurally to the left ear only. This finding contrasts with previous research examining the notion of hemispheric lateralisation that would predict a pattern of errors related to the sound type being presented such that playing speech to the right ear would be most disruptive (Kimura, 1961a, 1961b). This idea is based upon extant behavioural and neural data. Behavioural data shows that phonological targets presented monaurally during a dichotic listening task are more readily detected when presented to the right ear (Kimura, 1961b; Kinsbourne, 1970). It has been noted in more recent PET studies that increased right ear detection is true for phonological and not musical stimuli (Hugdahl et al., 1999).

Neuropsychological patient and neuroimaging data converge upon the conclusion that immediate verbal memory is primarily a left hemisphere process (see Baddeley, 2003 and Henson, 2001 for reviews). Since connectivity between the senses and the hemispheres in audition, like vision, is predominantly contra lateral rather than ipsilateral (Jäncke, Wustenberg, Schulze, & Heinze, 2002) speech played to the right ear is "fed" more-or-less directly to verbal memory. Given this background, the finding that errors were most frequent when irrelevant sound was played to the left ear is particularly perplexing.

Termed the "left-ear disadvantage," Hadlington et al. (2004) suggested a possible mechanism for this unexpected phenomenon. They proposed that the right hemisphere may be responsible for the obligatory processing of "changing-state" information necessary to observe an irrelevant sound effect as well as seriation processes involved in serial rehearsal (Hadlington et al., 2004; Jones et al., 1996; Jones & Tremblay, 2000). Hadlington et al. also suggested that a right hemisphere processing system analyses auditory information on an obligatory basis as all participants are instructed to ignore any and all sounds they may hear. The processing system analyses information irrespective of the type of irrelevant sound being presented, with equivalent interference effects for both speech and non-speech material (Hadlington et al., 2004).

Other neuropsychological data concerning hemispheric specialisation serve to support some aspects of the above claim. It has been noted that the right hemisphere plays a dominant role in the processing of information containing distinct prosodic and melodic changes, the perception and identification of environmental and non-verbal sounds and certain elements of music perception and comprehension (Fries & Swihart, 1990; Joseph, 1988; Mazzucchi, Parma, & Cattelani, 1981; Zatorre, Evans, & Meyer, 1994). For example, Zatorre et al. (1994) observed that the right superior temporal lobe and right occipital cortices displayed increased activity associated with the analysis of melodies. This evidence supports the idea that the right hemisphere also has a role in the perception and processing of changing-state information, a function it may continue to carry out even when the information is task-irrelevant and participants are asked to ignore it. Therefore, the left-ear disadvantage may be symptomatic of an increased processing load on this hemisphere during the presentation of the information to the left-ear, coupled with a joint requirement (from the primary task) for serial recall.

The current experimental series aimed to explore the impact of task requirements and the presence of changing-state information in the irrelevant sound stream on the presence of the left-ear disadvantage. The primary aim was to determine if the left-ear disadvantage was confined to serial recall tasks, or could be extended to include tasks requiring serial rehearsal without verbatim serial recall. Second, the research was designed to explore whether a left-ear irrelevant sound effect could be elicited on a task that, arguably, does not require memory for serial order. Third, the experimental series aimed to determine whether the left-ear disadvantage was indeed reliant upon the degree of changing state information contained in the irrelevant auditory stream. In previous research (e.g., Jones et al., 1999), it was demonstrated that changing-state could be manipulated through a number of factors. However, the left-ear disadvantage has only been elicited using an irrelevant stream that utilises gross changes in token identity to produce a changing state effect (Hadlington et al., 2004). A finding that the left-ear disadvantage is also dependent on a variety of changes in the irrelevant stream would add support to previous conclusions drawn by Hadlington et al. (2004). In essence, these further experiments could provide evidence that the right hemisphere may be the locus for the obligatory processing of change in the auditory streams.

2. Experiment 1

The initial experiments in this series examine performance on a task that is seen as more complex than the serial recall tasks used by Hadlington et al. (2004). The first experiment uses a simple mental arithmetic task as used by Banbury and Berry (1998). The task requires participants to perform a series of mental arithmetic calculations whilst under stimulation from irrelevant sound. A series of digits are presented on screen for a brief period, each followed by a numeric operator. After a brief retention period participants are then required to respond with the correct answer to the previously presented calculation. As Banbury and Berry (1998) indicate, the successful completion of the task requires the maintenance of serial order so that figures and operator remain in sequence. From this respect, this task relies on memory for serial order without a specific requirement for verbatim serial recall. The results from Banbury and Berry (1998) demonstrated that the mental arithmetic task was highly susceptible to the effects of irrelevant sound. It should be noted that serial order, not numeric processing, is the key feature of interest here. The irrelevant sound effect is not limited to numeric processing tasks (see

Beaman, 2005, for a review), however, tasks requiring the recall of serial order appear to be particularly susceptible (Beaman & Jones, 1997, 1998; Farley, Neath, Allbritton, & Surprenant, submitted; Henson et al., 2003).

This experiment was necessary in order to test a main assumption regarding the nature of the left-ear disadvantage. This was that the left-ear disadvantage was a general result of a clash between two processes of seriation, rather than being an artefact of the specific requirement for serial recall. As the left-ear disadvantage has only been demonstrated using tasks that required some form of serial recall response (Hadlington et al., 2004), it is unclear what aspect of the serial recall requirement is responsible for the left-ear disadvantage phenomenon. A second reason for conducting this experiment is to ascertain whether the left-ear disadvantage can be extended to include a task more complex than those generic serial recall tasks used by Hadlington et al. (2004). If the left-ear disadvantage is shown to be a robust feature for a number of tasks, this will have implications for the way in which the processing of irrelevant sound is currently viewed.

The experiment used irrelevant speech utterances and sine-wave tones identical to those used in the series of experiments conducted by Hadlington et al. (2004), in order for direct comparisons to be made between the two sets of data. Previous research has demonstrated that both irrelevant sine-wave tones and speech have an equivalent capability to disrupt performance (e.g., Jones & Macken, 1993). Findings which support this view in terms of the left-ear disadvantage would further the notion that speech is not critical for this effect.

As detailed in previous research (Voyer & Flight, 2001), there is the strong possibility that handedness can serve to produce an attentional bias (see also Hadlington et al., 2004). Therefore, in order to maintain consistency between experiments, and to counter the effects of such attentional bias, all participants in this series of experiments were right-handed. Additionally, for all experiments, the participants were students of the University of Wolverhampton who received course credit for taking part and reported normal hearing and normal (or corrected to normal) vision.

2.1. Experiment 1a

2.1.1. Method

2.1.1.1. Participants. Fifteen female and six male participants, all aged between 18 and 31, took part in the experiment.

2.1.1.2. Materials. The experiment was scripted using Superlab Pro (v. 1.75, Cedrus, USA). Visual stimuli were designed using Appleworks (Apple Macintosh, USA). Auditory stimuli was recorded via microphone and manipulated to conform to a specified length using SndSampler Shareware (Alan Glenn; Midland USA). Sound was presented via a computer sound card through Sennheiser EH200 evolution headphones (Sennheiser, Germany). Values of intensity adopted in this experiment were between 50 and 70 dB (A) (Colle, 1980; Webster, 1984). Acoustic levels delivered via the headphones were measured using a Metrosonics db-3100 Metrologger (Metrosonics, Rochester, NY) that had been previously calibrated using a Metrosonics 304a acoustical calibrator. Auditory lists consisted of five speech utterances, manipulated to last 250 ms in duration. The speech utterances were B, I, J, N, and Z were recorded in a male voice.

Visual lists were based on the mental arithmetic calculations previously used by Banbury and Berry (1998). These initial 12 calculations were randomised for presentation across 40 experimental trials, with the only proviso that the same calculation did not appear in a consecutive trial. The experiment itself was run on a Power Macintosh 8600/250 PowerPC and was presented on an Apple Macintosh Monitor (640 × 480 pixels at 67 Hz). Participants were also supplied with a set of standardised instructions and a response sheet on which to record information in the recall phase.

2.1.1.3. Design. A repeated measures design was employed in the experiment. Participants took part in all four levels of the independent variable; speech to both ears, speech to the left ear only, speech to the right ear only, and a silent control condition with no auditory stimuli.

2.1.1.4. Procedure. At the onset of the experiment, all participants were explicitly instructed to ignore all auditory stimuli presented to them via the headphones. Participants were also instructed to make responses in the recall phase as accurately as possible, and attempt to provide an answer to all calculations. The sequence of each auditory condition (e.g., left, both, right, and quiet) was counterbalanced; such order manipulation was necessary to counter fatigue and practice effects.

The main experimental session lasted for approximately 45 min. The session comprised of 40 individual trials, each of which contained one of the mental arithmetic calculations taken from Banbury and Berry (1998). These 40 trials were divided up into 10 trials for each of the auditory conditions (10 right ear only, 10 left ear only, 10 both ears, and 10 with no sound at all). The presentation of auditory conditions was counterbalanced across participants. For each experimental session, participants were given a short practice session before they began the main experiment. This practice session consisted of five trials unique to the practice session, but contained the same elements from the main experimental series. Once participants had completed the practice session, they were allowed to move on to the main experiment.

Each trial began with a blank screen, with an onscreen duration of 500 ms; a warning tone was presented binaurally at the end of this 500 ms period to signify the beginning of the experiment. After the initial 500 ms blank screen, the first number from the mental arithmetic calculation was presented, with an onscreen duration of 500 ms followed by an inter-stimulus period of 500 ms for which the screen remained blank. Then a numeric operator was presented with the same onscreen duration. This pattern of presenting numeric information and then a numeric operator was repeated until all operators and numbers had been presented for the calculation.

Auditory stimulus began at the presentation of the first item, with each irrelevant utterance lasting precisely 250ms in duration, with a 250ms inter-stimulus break between utterances where no sound was presented. After the presentation of the last visual stimulus, a five-second-retention period was given where the screen remained blank, but auditory stimulus continued playing. After this five-second-retention period, a warning tone was played, immediately after which a screen displaying the words "write down the answer now" was presented. Participants were given a five-second-period in which to write down the answer to the calculation that had previously been presented. A warning tone indicated the end of the recall phase and the beginning of the next experimental trial.

2.1.2. Results

Errors for mental arithmetic calculations were collected for each participant. Mean error rates for the mental arithmetic task with speech utterances as the irrelevant stimuli are shown in Table 1.

A one-way repeated measures ANOVA was used to analyse the data. For irrelevant speech, a significant main effect was found for errors rates according to acoustic condition ($F(3,20) = 7.17$, $MS_e = 2.63$, $p < .0005$; $\eta^2 = .265$), with planned means comparisons showing significant differences between both ears vs. left ear ($F(1,20) = 8.72$, $p < .005$; $MS_{\text{condition}} = 22.88$), left ear vs. right ($F(1,20) = 5.67$, $p < .05$; $MS_{\text{condition}} = 14.88$) and left ear vs. quiet ($F(1,20) = 20.90$, $p < .0001$; $MS_{\text{condition}} = 54.86$). Further means comparisons between both ears vs. quiet, both ears vs. right and right ear vs. quiet failed to reach significance ($p > 0.05$). A power analysis for the primary comparison of interest, the left vs. right ear comparison, shows an estimated effect size of Cohen's $d = .833$ (conventionally defined as a large effect size, see Cohen, 1988) returning power of .73 for a two-tailed t test of difference of means (equivalent to a planned means comparison) with α set to .05 and $n = 21$.

Table 1
Results from Experiment 1, comparing mean error rates for the mental arithmetic task between a quiet (control) condition and conditions where irrelevant speech or tones were presented to both ears, left ear only, or right ear only

Condition	Mean error (max = 10)	Standard deviation
Experiment 1a: speech		
Quiet	5.286	2.028
Both ears	6.095	3.270
Left ear only	7.571	2.336
Right ear only	6.381	2.655
Experiment 1b: tones		
Quiet	5.095	2.143
Both ears	5.905	2.385
Left ear only	7.000	2.258
Right ear only	5.381	2.418

2.2. Experiment 1b

2.2.1. Method

2.2.1.1. Participants. Nineteen female and two male participants, all aged between 18 and 34, took part in the experiment.

2.2.1.2. Materials. Identical materials were used in Experiment 1a, with the exception of the use of simple sine-wave tones that were constructed using SndSampler Shareware. Each tone was manipulated to last 250ms in order to fit exactly with in the space previously occupied by the irrelevant speech utterances. The sine-wave tones used were 87, 174, 348, 696, and 1302Hz.

2.2.1.3. Design. The design was identical to that of Experiment 1a.

2.2.1.4. Procedure. Procedure was identical to that of Experiment 1a, with the substitution of the irrelevant speech utterances /b, i, j, n, z/ with the simple sine-wave tones 87, 174, 348, 696, and 1302Hz.

2.2.2. Results

Mean error rates for the mental arithmetic task with tones as the irrelevant stimuli are shown in Table 1. Repeated measures ANOVA revealed a significant main effect was found for errors rates according to acoustic condition ($F(3,20) = 8.85$, $MS_e = 1.67$, $p = .0001$; $\eta^2 = .307$), with planned means comparisons showing significant differences between both ears vs. left ear ($F(1,20) = 7.53$, $p = .008$; $MS_{\text{condition}} = 12.60$), left ear vs. right ($F(1,20) = 16.46$, $p = .0001$; $MS_{\text{condition}} = 27.52$) and left ear vs. quiet ($F(1,20) = 22.78$, $p = .0001$; $MS_{\text{condition}} = 38.10$). Further means comparisons between right ear vs. both and right ear vs. quiet failed to reach significance ($p > 0.05$). A power analysis for the left vs. right ear comparison, shows an estimated effect size of Cohen's $d = 1.22$, returning power of .97 for a two-tailed t test of difference of means with α set to .05 and $n = 21$.

2.3. Discussion

The results from Experiment 1 demonstrate several key aspects of both the left-ear disadvantage and the wider irrelevant sound effect. Increased errors rates are consistently noted for the mental arithmetic task where irrelevant sound is played directly to the left ear. These effects are also noted as being significantly higher than any other mode of auditory presentation, irrespective of the type of irrelevant sound being presented, with effect sizes in the range conventionally defined as "large," (Cohen, 1988; pp. 24–27). These results also serve to expand effect beyond the serial recall tasks previously used by Hadlington et al. (2004). Such a finding suggests that the left-ear disadvantage is applicable to a variety of everyday tasks where there is an appreciable requirement for the retention of serial order information.

The results also demonstrate that the phenomenon is not directly related to the type of sound being presented. Error rates for left-ear presentation of both irrelevant sound and sine-wave tones for the mental arithmetic task are very similar in magnitude. This finding also complements those from Hadlington et al. (2004) who also demonstrated the equivalence of both speech and non-speech in eliciting the left-ear disadvantage.

Based on findings from these and previous experiments (Hadlington et al., 2004) it seems that the phenomenon relies upon at least two factors. The need for serial rehearsal or memory for serial order is common to the mental arithmetic and serial recall tasks. An irrelevant auditory stream conforming to the notion of changing-state (Jones et al., 1996) is also apparent in the tests of the left-ear disadvantage so far conducted. These two task characteristics (serial order and changing-state) may be more readily processed by the right hemisphere, hence the increased level of errors evoked via this method of presenting irrelevant sound to the left ear.

The results further demonstrate the equivalence of both irrelevant speech and irrelevant sine-wave tones in disruption of retaining serial order information. Previous research, which considered the disruptive effect of irrelevant sound due to phonological similarities between the to-be-remembered and to-be-ignored sounds, fails to provide a suitable explanation for these findings (e.g., LeCompte, 1996; Neath, 2000; Salamé & Baddeley, 1982, 1989). If phonological representations were necessary to disrupt short-term memory processes, the results should reflect this with a lack of an effect for irrelevant sine-wave tones. The equivalence of these two types of stimuli is not only a feature of the irrelevant sound effect (Jones & Macken, 1993) but also a robust feature of the left-ear disadvantage, which is evident irrespective of the type of sound used.

A suitable contrast to the requirement for memory for serial order in the mental arithmetic task is necessary in order to assess the importance of such a process to the left-ear disadvantage. The missing-item task was introduced by Jones and Macken (1993) as a method of exploring the effects of deleterious sound on memory without the need for participants to engage in a serial rehearsal process. As such, this task is ideal for comparing the effects of altering the spatial location of sound between tasks that require serial recall/serial rehearsal and those that do not.

3. Experiment 2

Experiment 2 was designed to determine whether a robust left-ear disadvantage for the presentation of irrelevant sound effect could be identified using a task that contained no appreciable requirement for memory using serial order. If, as suggested by previous research conducted into this phenomenon, it has a direct reliance on the requirement for retaining information in serial order memory, there should be no effect for altering the spatial location of irrelevant sound. However, if the left-ear disadvantage is additional to the "standard" binaural irrelevant sound effect, then it may elicit a left ear only irrelevant sound effect on a task that, within the literature, rarely displays any effect of auditory distraction (Beaman & Jones, 1997; Jones & Macken, 1993; LeCompte, 1996; Macken & Jones, 1995).

The missing-item task (Buschke, 1963) is a test of memory for lists assumed to be well established within the participants' long-term memory. Participants are required to identify the one item omitted from a list (days of the week, months of the year, and digits one through nine) when the order of presentation of the list is randomised (Beaman & Jones, 1997). As reported by Buschke (1963), the memory processes conducted during the missing-item task rely on the retrieval and identification of the item missing from the previously presented sequence. As Beaman and Jones (1997) noted, participants often report using a method of mentally "checking off" which items in a well-learned sequence have been presented. Identification of the missing-item involves scanning this mental representation of the list for the item that has not been checked. The search is done only on the basis of the natural sequence in which the items have been learned, and does not require the rehearsal of items in their order of presentation (Beaman & Jones, 1997).

Several lines of research reinforce the view that the missing-item task is substantially different to that of serial recall. Articulatory suppression, grouping strategies and item repetition all fail to affect the missing-item task (Klapp, Marshburn, & Lester, 1983; Macken & Jones, 1995). These factors have, however, been shown to influence performance on traditional serial recall tasks (Nairne, 1990). Previous research on the impact of irrelevant sound on the missing-item task has produced a variety of results. Beaman and Jones (1997) and LeCompte (1996) found a small effect of irrelevant speech on a missing-item task, smaller than observed with a probed recall task which requires retention of order information and Beaman and Jones (1997) reported a second experiment that failed to display any such effect of irrelevant speech on the missing-item task An experiment by Jones and Macken (1993) similarly showed no effects of irrelevant sound upon the missing-item task. There has been no direct test of the effect of altering the spatial location of irrelevant sound on performance for the missing-item task, which Experiment 2 was designed to explore. As with Experiment 1, two versions of the experiment were undertaken. Experiment 2a utilised irrelevant speech as auditory stimuli, and Experiment 2b used irrelevant tones.

3.1. Experiment 2a

3.1.1. Method

3.1.1.1. Participants. Seven male and twenty-eight female participants, all aged between 18 and 46, took part in the experiment.

3.1.1.2. Materials. These were identical to Experiment 1a with the exception of the visual lists. Visual lists consisted of 48 lists of 11-items. Each list initially contained 12 months of the year, been abbreviated to three letters in length in order to aid recall and presentation (Jones & Macken, 1993). For each of the 48 lists, one item from the list was excluded at random, thus becoming the missing-item; the order of presentation was also randomised, so that familiar sequences (e.g., may, jun, and jul) were avoided during the list presentation. The missing-item could be the same in consecutive lists, as there was no requirement for serial position recall.

3.1.1.3. Design. The design was identical to Experiment 1, with one dependent measure; the number of errors in response to the missing-item task.

3.1.1.4. Procedure. The session itself comprised of 48 individual trials, divided into twelve trials for each of the auditory conditions of the experiment (12 right ear only, 12 left ear only, 12 both ear, and 12 with no sound at all). Each trial consisted of presenting a randomised list of 11 months of the year. Participants were required to identify which month (or item) was missing from this sequence, and to write this missing-item down in the recall phase of the trial. The experimental session lasted for approximately 40 min. All other elements of the procedure were identical to that of Experiment 1a.

For each experimental session, participants were given a short practice session before they began the main experiment. This practice session consisted of five trial sessions unique to the practice, but contained the same elements from the main experimental series. Once participants had completed the practice session, they were then allowed to move on to the main experiment. Each trial began with a blank screen, with an onscreen duration of 500 ms; a warning tone was presented binaurally at the end of this 500 ms period to signify the commencement of the experiment. After the initial 500 ms blank screen, the first item from the 11-item list was presented, with an onscreen duration of 500 ms, followed by an inter-stimulus period of 500 ms, for which the screen remained blank. Auditory stimuli began at the presentation of the first item. Each irrelevant utterance lasted 250 ms, with a 250 ms inter-stimulus break between utterances where no sound was presented. After the visual presentation of the last item from the list, a five-second-retention period was given, where the screen remained blank but the auditory stimuli continued to be presented. After this five-second-retention period, a warning tone was played, immediately after which a "recall now" prompt was presented onscreen. Participants were given a five-second-period in which to write down the missing-item from the preceding list. A warning tone indicated the end of the recall phase and the beginning of the next experimental trial. Participants were required to record their responses on the sheet provided.

3.1.2. Results

Errors in identifying the missing-item were collected for each participant. Mean error rates for the missing-item task with speech utterances as the irrelevant stimuli are shown in Table 2.

A one-way repeated measures ANOVA (factor = sound condition; four levels = both, left, right, and quiet) was used to analyse the data. For irrelevant sound input, no significant main effect was found for error rates according to acoustic condition ($F(3,34) = 2.04$, $MS_e = 3.76, p > 0.1; \eta^2 = .057$). Using the estimate of effect size for left–right ear comparisons derived from Experiment 1a, the power of a paired-sample t test (two-tailed) to detect a "large" left–right difference ($d = .8$) with $n = 35$ and $\alpha = .05$ is .91. When analysed in this way, the left–right comparison just reached significance, $t = 2.09$, df = 34, $p = .044$.

3.2. Experiment 2b

3.2.1. Method

3.2.1.1. Participants. Four male and twenty female participants, all aged between 18 and 30, took part in the experiment.

3.2.1.2. Materials. Identical materials were used to Experiment 2a, with the exception of the use of simple sine-wave tones that were constructed using SndSampler Shareware. Each tone was manipulated to last 250 ms in order to fit exactly within the space previously occupied by the irrelevant speech utterances. The sine-wave tones used were 87, 174, 348, 696, and 1302 Hz.

3.2.1.3. Design. The design was identical to that of Experiment 2a.

3.2.1.4. Procedure. The procedure was identical to that of Experiment 2a, with the substitution of the irrelevant speech utterances /b, i, j, n, z/ with the simple sine-wave tones 87, 174, 348, 696, and 1302 Hz.

Table 2
Results from Experiment 2, comparing mean error rates in identifying a missing-item from a previously presented list between a quiet (control) condition and conditions where irrelevant speech or tones were presented to both ears, left ear only, or right ear only

Condition	Mean errors (max = 12)	Standard deviation
Experiment 2a: speech		
Quiet	8.371	2.030
Both ears	7.886	2.805
Left ear only	8.829	2.561
Right ear only	7.829	2.823
Experiment 2b: tones		
Quiet	8.250	2.027
Both ears	8.625	2.374
Left ear only	7.792	2.265
Right ear only	7.625	2.961

3.2.2. Results

Mean error rates for the missing-item task using simple sine-wave tones as the irrelevant stimuli are shown in Table 2. For irrelevant sine-wave tones, repeated measures ANOVA found no significant main effect was found for error rates according to acoustic condition ($F(3,23)=0.96$, $MS_e=5.14$, $p>0.1$; $\eta^2=.040$). The power of a paired-sample *t* test (two-tailed) to detect a "large" left–right difference ($d=.8$) with $n=24$ and $\alpha=.05$ is .77, rising to .98 when the observed $d=1.22$ from Experiment 1b is used. When analysed in this way, the left–right comparison fails to reach significance, $t=.277$, df = 23, $p=.78$.

3.3. Discussion

The results from the above experiments provide a first step in understanding the pattern of processing underlying the left-ear disadvantage phenomenon. Previous experiments (e.g., Hadlington et al., 2004) have demonstrated a robust left-ear disadvantage for tasks which either require the participant to serially recall information, or the use of memory for serial order. Experiments 2a and b show no sign of an overall effect of irrelevant sound and Experiment 2b also shows no left–right ear difference when examined in detail despite sufficient statistical power. With the lack of a reliable left-ear irrelevant sound disadvantage for the missing-item task, it appears that the phenomenon is linked to specific demands placed upon memory. Although only an initial exploration of this component to the left-ear disadvantage, Experiment 2 provides a preliminary basis for identifying those task components that may elicit the phenomenon, and more specifically the processing mechanisms that could be at the core of this effect.

The results from Experiments 2a and b support the view that, lacking any conflicting processes of seriation between the primary task and the irrelevant sound, the missing-item task is not greatly susceptible to the deleterious effects of irrelevant speech. This finding harmonises with previous research conducted by Jones and Macken (1993); Experiment 4 and Beaman and Jones (1997). The issue is not completely clear-cut, however. LeCompte (1996) argued that one primary reason for the failure of Jones and Macken (1993), Experiment 4 to show a disruptive effect of irrelevant sound on a missing-item task was because irrelevant tones (rather than speech) were used as the to-be-ignored stimuli. Speech appears to be a particularly disruptive irrelevant sound stimulus, although in most comparisons it is qualitatively equivalent to non-speech sounds (such as sine-wave tones) in eliciting an irrelevant sound effect for a variety of tasks (Jones & Tremblay, 2000).

In Experiment 2a where irrelevant speech utterances were used as the to-be-ignored stimuli, there was no significant main effect of irrelevant sound effect for the missing-item task but a pairwise comparison showed a marginally significant left-ear disadvantage. In Experiment 2b, there was neither a significant main effect nor a left-ear disadvantage. The results of Experiment 2a could plausibly be a consequence of a type 1 error given that a pairwise comparison was carried out in the absence of a significant main effect of sound condition in the analysis of variance, and that the error levels for sound presentation conditions were not noticeably higher than those of the quiet control. In Experiments 2a and b there was an increase errors in left ear presentation relative to right ear presentation (by 8 and 1%, respectively) but this was lower than in the mental arithmetic task of Experiments 1a and b (error increase in the region of 12–16%) and marginally significant only in Experiment 2a, thus any effect of ear of presentation in a missing-item task is smaller and less reliable than in other tasks. In this respect, the left-ear disadvantage mimics the basic effect of irrelevant sound which is sometimes significantly disruptive of performance on a missing-item task (Beaman & Jones, 1997; Experiment 1; LeCompte, 1996) and sometimes not (Beaman & Jones, 1997; Experiment 1 supplementary, Experiment 2; Jones & Macken, 1993).

We conclude that the left-ear disadvantage reflects an amplification of the basic irrelevant sound effect observed with binaural presentation, rather than an additional, independent factor unique to that ear. An additional contribution from another (left-ear specific) factor is unlikely to respond in the same idiosyncratic way to primary task requirements as does the basic effect. Like the basic effect, however, the left-ear disadvantage is difficult to observe under conditions where the primary task does not require serial order processing. Both Jones and Macken's (1993) results and those reported here are consistent with the conceptualisation of the irrelevant sound effect as a confusion between processes of a similar nature, rather than on the basis of content (Jones et al., 1996; Jones & Tremblay, 2000). A further series of experiments explores the impact of changing-state information contained in the irrelevant auditory stream on the presence of the left-ear disadvantage.

4. Experiment 3

The focus of Experiment 3 is directly on the level of changing-state information contained in the irrelevant stream. Jones and Macken (1995) previously demonstrated that the notion of changing state does not simply apply to gross changes in the irrelevant stream, i.e., changes in item-identity. They showed that the notion of changing state includes changes of within-stream elements. One aspect of this was explored by Jones and Macken (1995), Experiment 2, who altered the interval between each successive utterance. This produced a varying auditory stream, where the inter-utterance interval was randomly changed or an unvarying stream in which the inter-utterance interval was held at a constant. In each case, the irrelevant sound was the same repeating sequence of the utterance "Ah" (Jones & Macken, 1995). Results demonstrated a significant decrement in performance for the varying sequence in comparison to the repeated, unvarying irrelevant sound. This research demonstrated that changing-state could also be a feature of within-stream elements not directly connected to gross changes in token identity (Jones & Macken, 1995).

Although the notion of changing state in its initial format was proposed to be additive in nature (e.g., Bridges & Jones, 1996; Jones et al., 1996), later research conducted by Jones et al. (1999) suggested a degree of caution should be exercised before making such an assumption. Where irrelevant tones varied on two individual dimensions (pitch and timbre), they were observed to produce much less disruption in comparison to those tones varying on only one of these dimensions. Jones et al. (1999) explained these results in terms of an eroding of the order information in the irrelevant sound. As tokens become more distinct from each other, the sound ceases to be a single coherent series or "stream" extended over time and instead becomes a collection of distinct tokens each with limited connections to their neighbours and no phenomenally clear temporal sequence. Hence, the conflict between order information in the irrelevant sound and that in the to-be-remembered items is attenuated. As we are suggesting that the observed left-ear disadvantage is a product of the processing of prosodic, temporal information, we would predict that reducing order information in this way should reduce the difference between presenting irrelevant sound to the right or left ear.

In this series of experiments changing state information in the irrelevant stream was manipulated on a number of continua. Experiment 3a utilised an irrelevant sound source consisting solely of the repeated utterance "B." Therefore, changing-state information was absent from the irrelevant stream. Experiments 3b and c used the same utterance, with changing-state information manipulated along only one dimension in each case. Experiment 3b altered the pitch from utterance to utterance; Experiment 3c altered the inter-stimulus interval. Experiment 3d manipulated changing-state information on two dimensions to investigate if an increase in stimulus mismatch would result in an attenuation of the effect.

4.1. Experiment 3a

4.1.1. Method

4.1.1.1. Participants. Nine male and sixteen female participants, all aged between 18 and 35, took part in the experiment.

4.1.1.2. Materials. The experiment was scripted using Superlab Pro. Visual stimuli were designed using Appleworks. Auditory stimuli were recorded via microphone and manipulated to conform to a specified length using SndSampler Shareware. Sounds were presented via a computer sound card through Sennheiser EH200 evolution headphones. Values of intensity adopted in this experiment were at levels between 50 and 70 db (A), as used in previous research of this nature (e.g., Colle, 1980; Hadlington et al., 2004; Neath, 2000). Acoustic levels delivered via the headphones were measured using a Metrosonics db-3100 Metrologger to ensure mean intensity levels were matched between auditory conditions.

The auditory list consisted of a repeating sequence of the speech utterance "B," spoken in a male voice. Each utterance lasted exactly 250 ms, followed by a 500 ms interstimulus interval.

Visual stimuli consisted of a series of twenty lists, each containing a random sequence of nine consonants (s, t, r, y, m, l, f, q, k), the order of which was manipulated so that no two sequences were identical. As in previous experiments of this nature, care was taken to ensure that consonant sequences did not contain alphabetic sequences, well-known abbreviation and common acronyms. The same twenty consonant sequences were used in their original order for the other conditions of the experiment.

The experiment itself was run on a Power Macintosh 8600/250 PowerPC and was presented on an Apple Macintosh Monitor (640 × 480 pixels at 67 Hz). Participants were also supplied with a set of standardised instructions, a response sheet and a pen so that they could record the to-be-remembered information.

4.1.1.3. Design. A repeated measures design was employed in the experiment. Participants took part in all four levels of the independent variable; speech to both ears, speech to the left ear only, speech to the right ear only and a silent, control condition with no auditory stimuli.

4.1.1.4. Procedure. The main experimental session lasted for approximately 45 min. The session comprised of eighty individual trials, divided into twenty trials for each of the auditory conditions of the experiment (20 both ears, 20 left ear only, 20 right ear only, and 20 with no sound at all). Each trial consisted of a presentation of a series of nine consonants, which participants were instructed to remember in the correct order, a short retention phase and a recall phase. All other elements of the procedure were identical to that of Experiment 1a.

4.1.2. Results

Errors for serial recall were collected for each participant. A two-way repeated measures ANOVA with sound condition (four levels) and serial position (nine levels) was used to analyse the data. No significant main effect was found for error rates according to acoustic condition ($F(3,24) = .10$, $MS_e = 24.31$, $p = 0.96$; $\eta^2 = .004$). A significant main effect was noted for serial position ($F(8,24) = 22.93$, $MS_e = 36.73$, $p = 0.0001$), this is illustrated in Fig. 1. A significant interaction between serial position and sound presentation was also noted ($F(3,24) = 1.57$, $MS_e = 4.50$, $p < 0.05$).

4.2. Experiment 3b

4.2.1. Method

4.2.1.1. Participants. Seven male and eighteen female participants, all aged between 18 and 31, took part in the experiment.

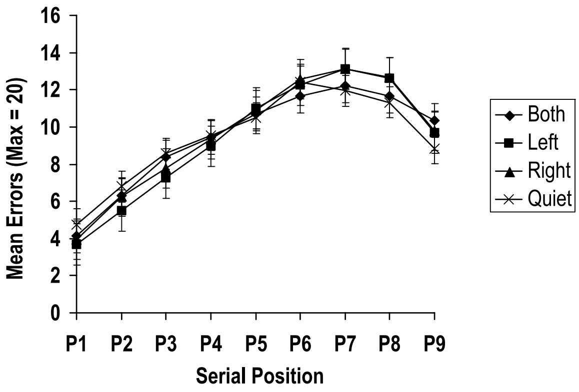

Fig. 1. Results of Experiment 3a, showing mean errors of serial recall with respect to sound location and serial position. Performance in a quiet (control) condition is contrasted with performance when a repeated irrelevant sound is presented to the left ear, the right ear, or to both ears.

4.2.1.2. Materials. Visual stimuli were identical to those used in Experiment 3a. The inter-stimulus interval was the original 500 ms used in Experiment 3a, but the original “B” utterance was manipulated using SoundEdit 16 (v.2: Macromedia) software. The frequency of the utterance was changed to coincide with the frequencies of five sine-wave tones used in Experiments 1 and 2. From the original ‘B’ utterance, five new utterances were formed at 87, 174, 348, 696, and 1302 Hz; where the manipulation caused the new utterance to be longer than 250 ms, it was cropped to last exactly 250 ms.

4.2.1.3. Design. The design of the experiment was identical to that of Experiment 3a.

4.2.1.4. Procedure. Identical to that of Experiment 3a, but with the substitution of the irrelevant speech utterance “B” with the frequency-manipulated speech utterances outlined in Section 4.2.1.2.

4.2.2. Results

Errors for serial recall were collected for each participant. A two-way repeated measures ANOVA was used to analyse the data. For the frequency-varying speech utterance with a unvarying inter-stimulus interval, a significant main effect was found for error rates according to acoustic condition ($F(3,24)=5.64$, $MS_e=28.68$, $p<.005$; $\eta^2=.190$), with planned means comparisons showing significant differences between both ears vs. quiet ($F(1,24)=6.29$, $p<.05$; $MS_{\text{condition}}=180.50$), left ear vs. quiet ($F(1,24)=16.61$, $p=.0001$; $MS_{\text{condition}}=476.38$), right vs. quiet ($F(1,24)=4.39$, $p<.05$; $MS_{\text{condition}}=125.88$) and left vs. right ($F(1,24)=3.92$, $p<.05$; $MS_{\text{condition}}=112.50$). Further means comparisons between both ears vs. right and both ears vs. left failed to reach a suitable level of significance ($p. > 0.05$). A significant main effect was noted for serial position ($F(8,24)=27.68$, $MS_e=27.55$, $p.=0.0001$), this is illustrated in Fig. 2. A significant interaction was also noted for serial position and sound presentation ($F(3,24)=1.80$, $MS_e=4.48$, $p<0.05$).

4.3. Experiment 3c

4.3.1. Method

4.3.1.1. Participants. Five male and twenty female participants, all aged between 18 and 34, took part in the experiment.

4.3.1.2. Materials. Visual stimuli were identical to those used in Experiment 3a.

The irrelevant stimulus was the speech utterance ‘B’ as used in Experiment 3a. The inter-stimulus interval was varied between each repeated utterance with the interval being randomly selected from the range of 0, 100, 200, 800, 900, and 1000 ms. The average offset-to-onset interval for each trial being 500 ms.

4.3.1.3. Design. The design of the experiment was identical to that of Experiment 3a.

4.3.1.4. Procedure. Identical to that of Experiment 3a, but with the inclusion of randomly chosen inter-stimulus intervals as outlined in Section 4.3.1.2.

4.3.2. Results

A two-way repeated measures ANOVA was used to analyse the data. For a repeated speech utterance with a varying inter-stimulus interval, a significant main effect was found for error rates according to acoustic condition ($F(3,24)=7.86$, $MS_e=23.49$, $p=.0001$; $\eta^2=.247$), with planned means comparisons showing significant differences between both ears vs. left ear ($F(1,24)=8.57$, $p<.005$; $MS_{\text{condition}}=201.34$), left ear vs. right ear ($F(1,24)=10.05$, $p<.005$; $MS_{\text{condition}}=236.17$) and left ear vs. quiet ($F(1,24)=22.62$, $p=.0001$; $MS_{\text{condition}}=531.38$). Further means comparisons between both ears vs. right, both ears vs. quiet and right ear vs. quiet failed to reach a suitable level of significance ($p. > 0.05$). A significant main effect was noted for serial position ($F(8,24)=23.78$, $p=0.0001$; $MS_e=27.87$). The serial position curves are presented in

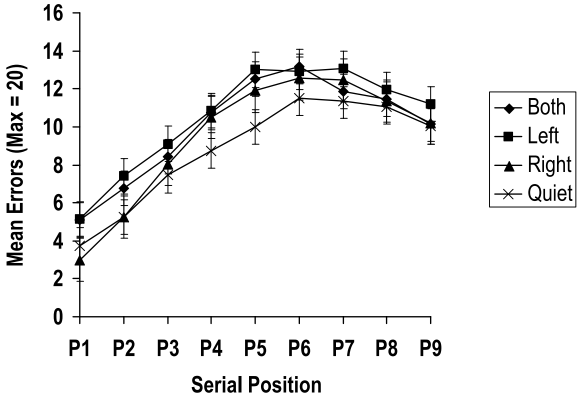

Fig. 2. Results of Experiment 3b, showing mean errors of serial recall with respect to sound location and serial position. Performance in a quiet (control) condition is contrasted with performance when a frequency-manipulated irrelevant sound with a constant inter-stimulus interval is presented to the left ear, the right ear, or to both ears.

Fig. 3. The interaction between serial position and sound presentation failed to reach significance ($F(3,24)=0.95$, $p>0.05$; $MS_e=3.772$).

4.4. Experiment 3d

4.4.1. Method

4.4.1.1. Participants. Five male and twenty female participants, all aged between 18 and 39, took part in the experiment.

4.4.1.2. Materials. Visual stimuli were identical to those used in the previous three experiments. The auditory stimuli used in Experiment 3d combined the inter-utterance intervals used in Experiment 3c and the frequency-manipulated irrelevant utterances used in Experiment 3b. Each trial consisted of a randomly changing pattern of inter-stimulus intervals, inter-spersed with the frequency-manipulated irrelevant speech utterances as used in Experiment 3c. No two trials in the same twenty-block condition contained the same pattern of intervals.

4.4.1.3. Design. The design of the experiment was identical to that of experiment 3a.

4.4.1.4. Procedure. Identical to that of Experiment 3a, but with the inclusion of randomly chosen inter-stimulus intervals and the frequency-manipulated irrelevant speech utterances, as outlined in Section 4.4.1.2.

4.4.2. Results

Repeated measures ANOVA was used to analyse the data. For a frequency-varying speech utterance with a varying inter-stimulus interval, a significant main effect was found for error rates according to acoustic condition ($F(3,24)=7.73$, $MS_e=16.97$, $p=.0002$; $\eta^2=.244$), with planned means comparisons showing significant differences between both ear vs. right ear ($F(1,24)=5.78$, $p<.05$; $MS_{\text{condition}}=98.00$), both ears vs. quiet ($F(1,24)=20.02$, $p=.0001$; $MS_{\text{condition}}=339.74$), left ear vs. quiet ($F(1,24)=13.16$, $p=.0005$; $MS_{\text{condition}}=223.31$) and right ear vs. quiet ($F(1,24)=4.29$, $p<.05$; $MS_{\text{condition}}=72.80$). Further means comparisons between both ears vs. left and left ear vs. right failed to reach a suitable level of significance ($p.>0.05$). A significant main effect was noted for serial position ($F(8,24)=10.25$, $MS_e=41.45$, $p=0.0001$), and the serial position curves are presented in Fig. 4. The interaction between serial position and sound presentation failed to reach a suitable level of significance ($F(3,24)=1.34$, $MS_e=2.82, p>0.05$).

4.4.3. Overall effects of sound type on serial recall errors

The data from Experiments 3a–d was combined to investigate patterns across the series. A mixed design ANOVA with one between subjects factor; sound type (four levels: repeated, frequency-varied, time-varied, and frequency + time-varied) and two within subjects factors; sound location (four levels: left, right, binaural, and absent) and serial position (nine levels) was used to analyse the data. No significant main effect was found for sound type ($F(3,96)=1.64$, $MS_e=380.82$, $p>.05$). A significant overall main effect was found for sound location ($F(3,96)=13.18$, $MS_e=23.36$, $p=.0001$) and for serial position ($F(8,96)=77.72$, $MS_e=33.40$, $p=.0001$). A significant two-way interaction was noted for sound location × sound type ($F(9,288)=2.46$, $MS_e=33.40$, $p<.05$), and a significant three-way interaction was noted for sound location × serial position × sound type ($F(72,2304)=1.60$, $MS_e=3.90$, $p<.005$). The mean number of errors across the factors of sound type and sound location is presented in Fig. 5.

4.4.4. Discussion

The results from Experiment 3 provide a new perspective from which to view the left-ear disadvantage phenomenon. Findings have demonstrated that where the irrelevant sound stream contains little changing-state information (Experiment 3a), or is manipulated on more

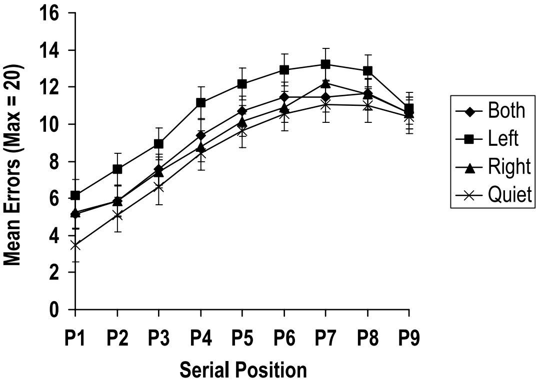

Fig. 3. Results of Experiment 3c, showing mean errors of serial recall with respect to sound location and serial position. Performance in a quiet (control) condition is contrasted with performance when a repeated irrelevant sound with a varied inter-stimulus interval is presented to the left ear, the right ear, or to both ears.

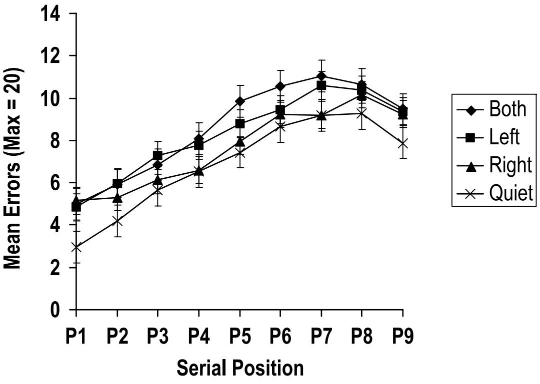

Fig. 4. Results of Experiment 3d, showing mean errors of serial recall with respect to sound location and serial position. Performance in a quiet (control) condition is contrasted with performance when a frequency-manipulated irrelevant sound with a varied inter-stimulus interval is presented to the left ear, the right ear, or to both ears.

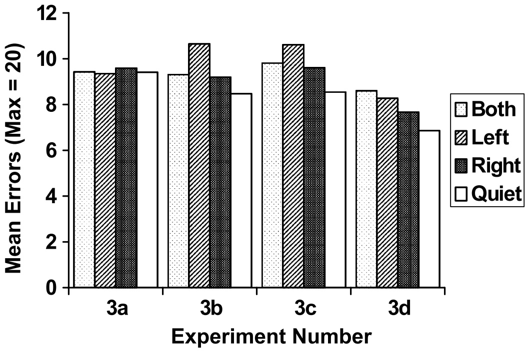

Fig. 5. Overall results of Experiment 3, showing mean errors with respect to sound location and sound type. Performance in each sound condition is shown in relation to the presentation of each irrelevant sound type to the left ear, the right ear or to both ears, and a quiet (control).

than one continuum (Experiment 3d) to produce, despite the common spatial location, a fission of changing-state, the left-ear disadvantage is attenuated. Conversely, where the irrelevant sound stream contains significant changing-state information (Experiments 3b and c) the left-ear disadvantage is a key trend of the disruption noted. This phenomenon is present irrespective of whether changing-state is related to distinct changes in item-identity or discrete temporal changes. This must suggest the main factor for the observed left-ear disadvantage is the presence of discrete changes in the irrelevant stream but that extreme changes (in identity, as signalled by frequency, and timing) break up the perceptual unity of the auditory stream and the signal is therefore dealt with differently, in a manner that attenuates the left-ear disadvantage.

Such findings strongly suggest that the right hemisphere plays a significant role in the obligatory processing of irrelevant auditory information. Up until this point, previous research had only explored the notion of changing-state in relation to the presence of distinct changes in the identity of items in the irrelevant stream (Hadlington et al., 2004). The present research moves away from this static view of changing state and its effect on the left-ear disadvantage. Instead, the findings suggest that the right hemisphere is responsible for processing auditory information that displays change on a number of continua.

The results from Experiment 3d harmonise well with those of Jones et al. (1999). They found that by increasing the stimulus mismatch beyond a certain level the irrelevant speech effect was attenuated, although not to the level of steady state sound (Jones et al., 1999) Experiment 3. This was explained in terms of a reduction in the amount of order information in the irrelevant sound. As we have proposed that the observed left-ear disadvantage is a product of processing prosodic temporal information, reducing order information would necessarily reduce the magnitude of the observed difference between presentation to the right and left ear. This position is supported in the results of Experiment 3d and in the observation of an interaction between sound type and sound location in the analysis conducted across the four sub-experiments.

5. General discussion

The experiments reported here provide an extension to several main strands of previous research. Primarily, the work here adds more detail to the initial conceptualisations of the left-ear disadvantage provided by Hadlington et al. (2004), and provides further information regarding the nature of hemispheric specialisation and the processing of irrelevant sound. Second, the results also provide further empirical support for the notion of an irrelevant sound effect, particularly with regards to the specific mechanism of interference proposed by Jones et al. (1996). The results of this series of experiments will be discussed in relation to the left-ear disadvantage and the wider irrelevant sound effect.

5.1. *The left-ear disadvantage: A further analysis*

At first blush, findings from the current series of experiments, and those previously conducted by Hadlington et al. (2004), could be attributed to an attentional bias. However, such a notion does not equate with previous views of hemispheric specialisation. As Kinsbourne (1970) suggested, information presented to one hemisphere of the brain serves as a "prime" for further information from the same point in auditory space. Therefore, attentional biasing would result in the level of decrement shifting from ear to ear as does the mode of presentation, e.g., a right-ear disadvantage for information "primed" to be presented to the right ear of a similar magnitude to the left-ear disadvantage. Given the robust nature of the left-ear disadvantage throughout the presentation conditions in this series of experiments, it seems implausible to suggest that the left-ear disadvantage is due to the artefact of attentional bias. The findings rather suggest that the sound stream is being processed by the right hemisphere at a more fundamental or basic level than that of phonology, possibly at the level of structural or temporal characteristics (see also Beaman, Bridges, & Scott, in press) which could be identified with the notion of changing-state (Jones et al., 1996).

The possibility that the right hemisphere of the brain is responsible for the processing of unattended changing-state auditory information, while attention is focussed elsewhere upon a different (visually-presented) primary task, gains support from the present research. Experiment 1 demonstrated that both irrelevant tones and irrelevant speech produced a significant decrement on the mental arithmetic task previously used by Banbury and Berry (1998). This decrement was matched by a significant left-ear disadvantage for both types of sound stimuli. However, there was no significant main effect for any type of auditory presentation in the missing-item task used in Experiment 2, and a marginally significant left-ear disadvantage (on a left–right pairwise comparison) only in Experiment 2a.

As noted previously, the only substantial difference between these two tasks is the requirement for retention of information in serial order memory. Even where changing-state auditory information is being presented directly to the right hemisphere via the left-ear, there is a failure to reliably produce an irrelevant sound effect. This is consistent with the idea that the right hemisphere is the locus of obligatory processes of changing-state information and also of voluntary processing of serial order information in the primary task. A further alternative that cannot be ruled out by these data, however, is that right hemisphere activity associated with the irrelevant sound effect inhibits left hemisphere processes required for the primary task through some form of inter-hemispheric competition (Gisslegård, Petersson, Baddeley, & Ingvar, 2003). In this case, one must assume that serial recall and mental arithmetic require left hemisphere processing whereas the missing-item task calls upon right hemisphere or bilateral processing resources in its demands. Further research in this area, and in particular, neuroimaging research, is obviously necessary to settle this question.

Experiment 3 determined how much the left-ear disadvantage was dependent upon the presence of changing-state information in the irrelevant stream. As noted above, previous explorations have demonstrated an effect using static changing-state information that alters on one main continuum, namely the change in item-identity. The results from Experiment 3 provide a series of important clarifications regarding the left-ear disadvantage which have been unexplored in previous research. Primarily, it has been demonstrated that there is an obvious link between the presence of changing-state information and the left-ear disadvantage. Where changing-state information is absent from the irrelevant auditory stream (Experiment 3a), or where the phenomenological connections between tokens are weakened through greater stimulus mismatch (Experiment 3d), the left-ear disadvantage is not a prominent feature of the results. This feature of the left-ear advantage also gains further support when the results of Experiments 1 and 2 are also taken into consideration. As previously suggested by Hadlington et al. (2004) the left-ear disadvantage clearly relies on two processes. The first is one is obligatory, and is the automatic seriation of irrelevant auditory information which contains changing-state information. The other process is the maintenance of serial cues within short-term memory, and requires conscious effort on the part of the participant. Without the presence of this similarity of processes, both the left-ear disadvantage and the irrelevant sound effect should be diminished.

6. Conclusions

It appears that the irrelevant sound effect may be a more specific interaction of the requirement for serial recall and the presence of changing-state information than was first envisaged. The presence of a left-ear disadvantage for the presentation of irrelevant sound points towards a specific role of the right hemisphere of the brain in the processing of auditory material (which contains distinct structural and prosodic patterns) that conflicts with a need to recall or retain information in serial order. Evidence from this series of experiments has shown that the left-ear advantage can be extended beyond those tasks that include an overt requirement for verbatim serial recall. The example of the mental arithmetic task shows that tasks that have an application to everyday life are susceptible to this phenomenon, as well as demonstrating that tasks requiring serial order retention without overt serial order recall are also affected by irrelevant sound.

The results from this present series of experiments also serve to demonstrate that the notion of hemispheric specialisation may not be as clear-cut as previously envisaged (e.g., Kimura, 1961a, 1961b, 1964). As clearly shown, the right hemisphere has some important mediation role in the obligatory processing of both unattended speech and non-speech.

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