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Hemispheric asymmetries in auditory distraction

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ABSTRACT

Serial-verbal short-term memory is impaired by irrelevant sound, particularly when the sound changes acoustically (the changing-state effect). In contrast, short-term recall of semantic information is impaired only by the semanticity of irrelevant speech, particularly when it is semantically related to the target memory items (the between-sequence semantic similarity effect). Previous research indicates that the changing-state effect is larger when the sound is presented to the left ear in comparison to the right ear, the *left ear disadvantage*. In this paper, we report a novel finding whereby the between-sequence semantic similarity effect is larger when the irrelevant speech is presented to the right ear in comparison to the left ear, but this *right ear disadvantage* is found only when meaning is the basis of recall (Experiments 1 and 3), not when order is the basis of recall (Experiment 2). Our results complement previous research on hemispheric asymmetry effects in cross-modal auditory distraction by demonstrating a role for the left hemisphere in semantic auditory distraction.

1. Introduction

Evolution has shaped the brain's hemispheres into two functionally specialised processing systems (Kinsbourne, 1970). One source of evidence for hemispheric specialisation comes from the demonstration of a number of deficits (and syndromes) associated with the language functions of brain-damaged patients (Searleman, 1977). Another source of evidence for hemispheric specialisation comes from the finding that the auditory system has stronger contralateral than ipsilateral pathways that results in sound such as speech being processed predominantly by the opposite hemisphere to its presentation source. For example, input to the right ear has privileged access to the left hemisphere which plays a dominant role in the processing of linguistic information, and input to the left ear has privileged access to the right hemisphere which plays a more subservient role in linguistic processing and a more dominant role in non-linguistic processing (such as the processing of changes in complex auditory patterns; Shankweiler, 1966; Tzourio, Crivello, Mellet, Nkanga-Ngila, & Mazoyer, 1998). This is thought to result in the *right ear advantage* found in studies of linguistic sound processing and the *left ear advantage* found in studies of non-linguistic sound processing (Hugdahl et al., 2009; Poeppel et al., 2004; Tervaniemi & Hugdahl, 2003). These ear advantages have been demonstrated for to-be-attended sound. In the present article, we explore hemispheric asymmetry in the processing of to-be-ignored sound in a visual–verbal task setting (i.e., cross-modal auditory distraction).

1.1. The changing-state effect and right hemisphere processing

Short-term verbal memory for the correct serial order of a set of sequentially presented visual items (visual–verbal serial recall) is markedly impaired by the mere presence of background sound that participants are explicitly instructed to ignore. Two key signatures of this *irrelevant sound effect* are that the to-be-ignored sound must change acoustically from one sound element to the next (Jones & Macken, 1993) and that the focal task must require serial rehearsal (seriation) of the to-be-recalled (TBR) items (Beaman & Jones, 1997; Hughes, Vachon, & Jones, 2007). If the participants are required to recall the items in serial order, changing-state sound sequences (e.g., "a b a b a b a") are invariably more disruptive than steady-state sound sequences (e.g., "a a a a a a a"). This is called the *changing-state effect*. While the acoustic properties of the sound are endowed with disruptive power in the visual–verbal serial recall setting, the meaning of the sound is relatively impotent (Buchner, Irmen, & Erdfelder, 1996; Jones & Macken, 1993; Tremblay, Nicholls, Alford, & Jones, 2000; but see Buchner, Rothermund, Wentura, & Mehl, 2004). These observations are in line with the view that the changing-state effect is a function of the similarity between two sets of order processes: The deliberate processing of the order of the TBR items and the involuntary processing of the order between successive and perceptually discrete sound events (for a review, see Macken, Tremblay, Alford, & Jones, 1999).

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Evidence of a hemispheric bias in cross-modal auditory distraction in the context of serial recall comes from recent studies by Hadlington and colleagues (Hadlington, Bridges, & Darby, 2004; Hadlington, Bridges, & Beaman, 2006). They found that the changing-state effect is larger when the sound is presented to the left ear only, compared with when the sound is presented either to the right ear only or to both ears. This finding was coined the *left ear disadvantage* and was only manifest when the task required serial recall (Hadlington et al., 2006). Since more efficient obligatory processing of change in a sound stream results in greater disruption of serial recall (Macken, Phelps, & Jones, 2009), the left ear disadvantage suggests that the right hemisphere plays a prominent role in processing acoustic features of irrelevant sound streams (see also Grimshaw, Kwasny, Covell, & Johnson, 2003; Poeppel et al., 2004; Zatorre, Evans, & Meyer, 1994). In other words, the right hemisphere's specialisation in processing the order between successive sound events turns into a disadvantage when sound is to-be-ignored and the task-goal requires order processing.

1.2. The between-sequence semantic similarity effect and left hemisphere processing

In contrast to the effects of sound on serial order processes (e.g., visual–verbal serial recall), the mere meaning of sound (i.e., when speech is used) can indeed contribute to disruption of tasks that require or encourage semantic processing for efficient performance (Marsh, Hughes, & Jones, 2008, 2009; Oswald, Tremblay, & Jones, 2000; Sörqvist, 2010a). In particular, Marsh et al. (2008, 2009) have shown that when meaning is the basis of retrieval, rather than serial order, the semanticity of irrelevant speech is more disruptive than its acoustic properties. For example, to-be-ignored words produce more disruption than non-words or reversed-words when the focal task requires semantic processing (for a review, see Marsh & Jones, in press). Marsh et al. have employed an experimental paradigm in which each experimental trial involves visually-presented TBR exemplars that are members of the same semantic category (e.g., Fruit). During some trials, the participants are also presented with to-be-ignored spoken words that are either taken from the same semantic category as the TBR items (e.g., other Fruit) or from a different semantic category (e.g., Tools). Three findings from this research are of particular interest here: First, recall is poorer in the semantically related condition, the *between-sequence semantic similarity effect*. Second, this effect arises only when participants are instructed to recall the TBR words in any order (free recall): The effect is not found when participants attempt to recall words according to their order of presentation (serial recall). Third, the participants tend to recall the semantically related irrelevant words by mistake, even though they are instructed to ignore items presented in the auditory modality. *Semantic auditory distraction* thus embodies (a) an effect of mere meaningfulness (words produce more disruption than non-words), (b) a between-sequence semantic similarity effect (words related to the TBR items produce more disruption than unrelated words), and (c) promotion of intrusions from non-target items by speech semantically related to TBR items. The findings seem to be accommodated most easily within an *interference-by-process* approach to auditory distraction, similar to that applied to the changing-state effect (Marsh et al., 2008, 2009). The interference-by-process view explains semantic auditory distraction in terms of (a) deliberate inhibition of non-target competitors activated by speech which spreads to target items and thus impairs recall and (b) breakdown of source-monitoring (i.e., a failure to keep track of the source of target and non-target items).

Beaman, Bridges, and Scott (2007) concluded in a recent review that auditory distraction and the right ear advantage in dichotic listening are based on different mechanisms. If the two phenomena were mediated by the same mechanism, the right ear advantage observed in dichotic listening—due to stronger contralateral than ipsilateral connections and dominant linguistic processing in the left hemisphere—should be accompanied with a right ear disadvantage in auditory distraction (i.e., greater magnitude of disruption from irrelevant sound when presented to the right ear). In contrast, Hadlington et al.'s (2004, 2006) studies compellingly show that the changing-state effect is larger when the sound is presented to the left ear. However, the right ear advantage in dichotic listening may suggest a *right ear disadvantage* in semantic auditory distraction particularly because both concern linguistic processing. Moreover, semantic auditory distraction can be modified by attentional control processes (Beaman, 2004; Beaman et al., 2007; Sörqvist, Halin, & Hygge, 2010; Sörqvist, Ljungberg, & Ljung, 2010) similar to the right ear advantage in dichotic listening (Hugdahl et al., 2009), but the changing-state effect cannot (Beaman, 2004; Beaman et al., 2007; Elliott & Cowan, 2005; Sörqvist, 2010b; see Sörqvist, in press for a review). These similarities lean towards the possibility that the left hemisphere's advantage in linguistic processing turns into a disadvantage when semantic information conveyed by sound has to be deliberately ignored. A relatively large body of neuroscientific evidence lends credence to this hypothesis, demonstrating dominant semantic processing of speech sound in the left hemisphere (e.g., Beaman et al., 2007; Scott, Rosen, Beaman, Davis, & Wise, 2009; Zahn et al., 2000) and interhemispheric inhibition of speech presented to the left ear (Bloom & Hynd, 2005; Clark, Lufkin, & Zaidel, 1993; Westerhausen & Hugdahl, 2008). Hence, with left ear input, the speech sound's capacity to interfere with the semantic processes in the left hemisphere should be attenuated. On the other hand, with right ear input, the semantic analysis of the speech is more readily conducted and should thus increase disruption. We therefore expected to find a greater between-sequence semantic similarity effect when speech is presented to the right compared to the left ear.

2. Experiment 1

Experiment 1 required recall of visually-presented words that were all members of the same semantic category. Sequences of to-be-ignored spoken words were either presented to the left or to the right ear and were either semantically related or unrelated to the TBR items. We expected to find a larger between-sequence semantic similarity effect when the sound was presented to the right ear. The typical procedure utilized to study by-ear effects is to present sounds to both ears simultaneously. It should be noted however that sound in the current study was never presented binaurally because the limited number of available semantic categories prohibited this option. Any evidence for a right ear disadvantage might therefore be fundamentally unrelated to the right ear advantage typically observed in dichotic listening studies. However, some evidence indicates that a right ear advantage is also found when sound is presented monaurally (Bradshaw & Nettleton, 1988). In Experiment 1 we also examined whether the right ear disadvantage is found when the sound is presented synchronously with the TBR items as well as when the sound is presented during a retention interval between presentation and recall of the target items.

2.1. Method

2.1.1. Participants

A total of 84 right-handed undergraduate students from the University of Gävle took part in the experiment in exchange for a cinema ticket. All reported normal or corrected-to-normal vision, had normal hearing (screened) and Swedish as their native language.