Journal of Environmental Psychology 30 (2010) 112–118

Contents lists available at ScienceDirect

Journal of Environmental Psychology

journal homepage: www.elsevier.com/locate/jep

Effects of aircraft noise and speech on prose memory: What role for working memory capacity?

Patrik Sörqvist*

Laboratory of Applied Psychology, Centre for Built Environment, University of Gävle, SE-801 76 Gävle, Sweden

ARTICLE INFO

Article history:
Available online 11 November 2009

Keywords:
Aircraft noise
Individual differences
Irrelevant speech
Prose memory
Working memory capacity

ABSTRACT

Previous research indicates that aircraft noise and meaningful background speech are particularly detrimental to school adolescents' ability to remember what they read, but until now the effects from aircraft noise and speech have never been compared directly in an experiment. Furthermore, individual differences in susceptibility to these effects are not well understood. The present investigation addressed these two issues. Adolescents attending upper secondary school were recruited as participants and the data collection was made in their ordinary classrooms. The results from two experiments revealed that speech is more detrimental to prose memory than is aircraft noise, and individual differences in working memory capacity contributes more to individual differences in susceptibility to the effects of aircraft noise on prose memory than to the effects of speech. Some applied implications of those findings to noise abatement interventions are suggested.

1. Introduction

Learning by reading is the linchpin of regular school education. People's ability to learn from texts determines their academic success and will have a strong influence on their lives. Hence, it is most unfortunate but still well established that noisy school environments provide serious barriers for adolescents' ability to remember what they read (for reviews, see Beaman, 2005a; Shield & Dockrell, 2003). Two noteworthy observations can be made from this line of research. The first observation concerns differences in effect magnitude between noises and the second observation concerns individual differences in susceptibility to these effects, both of which are addressed in the present investigation.

Research that aims to compare different environmental noises is mainly applied in nature. Specifically, the results from such investigations have implications for the formulation of acoustic standards and they inform decision makers how to best allocate limited noise abatement resources. In a series of classroom experiments, Hygge (2003) demonstrated that the effect from aircraft noise on prose memory exceed the effect from road traffic noise, train noise, and speech from a foreign language. Hygge did not include a condition with speech meaningful to the participants. However, meaningful irrelevant speech has also repeatedly been shown to have larger effects on prose memory in comparison with several non-speech sounds (Boman, 2004; Hygge, Boman, & Enmarker, 2003; Oswald, Tremblay, & Jones, 2000). Because of this, aircraft noise and irrelevant speech stands out as two particularly detrimental types of noises. However, thus far their effects have never been compared experimentally.

Based on some major theories of auditory distraction, one would expect prose memory to be more disrupted by speech than by aircraft noise. One of those theories is the interference-by-process account by Jones and colleagues (e.g., Macken, Tremblay, Alford, & Jones, 1999; Marsh, Hughes, & Jones, 2008). According to this theory, disruption is a function of the similarity of the processes required by the primary task (in this case reading) and the processes required by listening to the sound. Speech should therefore be particularly detrimental to prose memory because the automatic processing of the semantic content in speech sounds will compete with the deliberate processing of the semantic content in the prose material. Since listening to non-speech sounds, such as aircraft noise, does not require processing of meaning, prose memory should not be as disrupted by aircraft noise. A second theory intended to explain effects of speech on cognitive processes is the phonological loop account proposed by Baddeley and colleagues (e.g., Salamé & Baddeley, 1982). This theory also suggests that speech should be more detrimental to prose memory than aircraft noise, although the explanation is different from the one made by the interference-by-process account. According to Baddeley's theory, phonological information from the speech sound is automatically encoded into a phonological store where it meets phonological information encoded from the text while reading. The

* Tel.: +46 26 64 85 42.
E-mail address: patrik.sorqvist@hig.se

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doi:10.1016/j.jenvp.2009.11.004

disruption caused by the sound is a function of the phonological similarity between the sound and the materials within the phonological store. Since aircraft noise does not contain phonological information, aircraft noise should not produce disruption according to this theory. A third theory proposed to explain effects of noise on cognitive performance is the one by Cowan (1995). This theory assumes that noise depletes attentional resources which otherwise could have been used to entertain the primary task. Unexpected or surprising sound events are assumed to draw attention away from the task and disrupt performance. A speech sound should hence be more detrimental to prose memory when it contains unexpected sound events, but in principle it should be possible for an aircraft noise to be more disruptive than speech.

In addition to comparing the effects of aircraft noise and speech, the present investigation aims to study individual differences in susceptibility to those effects. Differences in susceptibility to auditory distraction have received much attention during the last decade (e.g., Beaman, 2005b; Bell & Buchner, 2007; Ellermeier & Zimmer, 1997; Elliott, Barrilleaux, & Cowan, 2006; Elliott & Cowan, 2005; Macken, Phelps, & Jones, 2009), but besides speech, only a few of those studies have concerned noise typical in the "everyday" environment (e.g., transportation noise such as aircraft noise). The few exceptions include a study by Boman, Enmarker, and Hygge (2005) which concerned the effects of road traffic noise amongst people of different ages, and a study by Dockrell and Shield (2006) which concerned the effects of children's babble on pupils with special educational needs.

It has since long been argued that the processing of acoustic change is a fundamental basis of auditory distraction (e.g., Cowan, 1995; Jones & Macken, 1993) and recently Macken et al. (2009) showed that people who are good at processing acoustic change are more distracted by sound than others, at least when distraction is measured by a reduction in serial recall of sequences of digits. However, during the last five years of so, several investigators have stressed the importance of working memory capacity (WMC) in explaining differences in susceptibility to auditory distraction. WMC is commonly measured by the operation span (OSPAN) task introduced by Turner and Engle (1989). This task requires participants to remember a sequence of words and simultaneously calculate mathematical operations. People's performance on OSPAN is related to several cognitive abilities and constructs including general intelligence (Unsworth & Engle, 2005). This suggests that an OSPAN score reflects a very general cognitive capacity. In particular, according to the WMC theory by Engle and colleagues (e.g., Kane, Bleckley, Conway, & Engle, 2001) participants' performance on OSPAN reflects their ability to focus attention of the task at hand in the presence of irrelevant materials. Based on this theory one would expect WMC to predict the ability to solve cognitive tasks in the presence of auditory distraction. Inline with this assumption, it has been shown that individuals with low WMC are more distracted by background speech while reading (Sörqvist, Halin, & Hygge, 2009; Sörqvist, Ljungberg, & Ljung, submitted for publication), more susceptible to intrusions from speech words into the recall of memory items (Beaman, 2004), more susceptible to distraction from hearing one's own name spoken in the background (Conway, Cowan, & Bunting, 2001), and more distracted by changing-state tones while performing a serial recall task (Elliott et al., 2006) than are individuals with high WMC. In light of these observations, it could be argued that noise abatement resources should first of all be allocated to people with poor WMC. However, the relationship between WMC and susceptibility to distraction from transportation noise and other naturally existing noise sources have never been investigated. Without such investigations it is uncertain if WMC also plays a role in more ecologically valid situations. The objectives of the present investigation were twofold. First, it aimed to compare the effects of aircraft noise and speech on school adolescents' prose memory. Second, it aimed to explore the relationship between WMC and susceptibility to those effects.

1.1. Experiment 1–2

An ecologically valid but still well controlled approach was desired in the present investigation. To this end, two experiments were conducted in ordinary upper secondary school classrooms and the adolescents attending these schools were tested together with their classmates in groups of about 20 individuals. The relationship between WMC and susceptibility to the effects of aircraft noise and speech on prose memory was examined in Experiments 1a and 1b respectively. Experiment 2 compared the effects of speech and aircraft noise directly. The data collection for Experiments 1a and 1b was made at the same time with participants from the same classes, but reported separately on readability. This was considered a methodologically better approach than to recruit different classes for different experiments because between-study comparisons would otherwise be strongly influenced by between participants variability.

2. Experiment 1a

The purpose of Experiment 1a was to test the hypothesis that there is a relationship between adolescents' WMC and their susceptibility to effects of aircraft noise on prose memory.

2.1. Method

2.1.1. Participants

Twenty-five adolescents were recruited from three upper secondary school classes in Sweden. Two reported having problems with reading (e.g., dyslexia) and were removed prior to the analyses. The remaining 23 individuals (14 females and 9 males) were approximately 17 years old and reported normal hearing ability, normal reading skills and Swedish as their native tongue. "Normal hearing ability" was established by asking the participants whether or not they have attenuated hearing. This procedure appeared to be sufficient for the present purposes because all pupils in Sweden take part in an audiogram screening from which they will know whether or not they have hearing loss. All participants received a cinema ticket as compensation.

2.1.2. Aircraft noise

Sounds from different airborne aircrafts were recorded outside using a stereophonic microphone. The sounds were put together with computer software so as to create 10 sound sequences of aircrafts passing by the listener (i.e., it sounded as if aircrafts was flying by, one by one, without overlap). Each sequence was 1 min long and contained 3–4 passing aircrafts (see Fig. 1). The sounds were filtered with computer software as if it had passed through a brick wall. The brick wall was simulated using an octave band equalizer (1024 bin FIR filters), adjusting the decibel levels of specific octave bands (<31 Hz: +6 dB; 63 Hz: +6 dB; 125 Hz: 0 dB; 250 Hz: −6 dB; 500 Hz: −6 dB; 1 kHz: −12 dB; 2 kHz: −17 dB; 7 kHz: −22 dB; 8 kHz: −27 dB; >16 kHz: −36 dB). The purpose of this manipulation was to make the sound perceived as indoors.

2.1.3. Tasks

2.1.3.1. Operation span. A computerized version of the OSPAN task was used to assess the participants' WMC. In this task, mathematical operations such as "IS $(4+2)\times 3 = 18$?" were presented on a computer screen. The participants' task was to respond "yes" or