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How to get a left-ear advantage: A technical review of assessing brain asymmetry with dichotic listening

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The dichotic-listening paradigm with verbal stimuli is a widely employed behavioral task for the assessment of hemispheric asymmetry for speech and language processing. Participants with assumed left-hemispheric dominance report the right-ear stimulus with higher probability than the left-ear stimulus. However, there is substantial between-subject and trial-to-trial variability observed in the paradigm, motivating scrutiny of the task set-up and theoretical models. Here, we give an in-depth discussion of specific features of stimulus material and experimental parameters, as well as the conditions of stimulus/response selection, which explain a significant proportion of intra- and inter-individual variability. Carefully considering these factors should be at the heart of any experimental planning when using the dichotic-listening paradigm to achieve an optimal testing situation for measuring laterality and avoid confounds in between-subject and between-group comparisons.

Key words: Dichotic listening, brain asymmetry, lateralization, validity.

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INTRODUCTION

In a special issue in honor of Kenneth Hugdahl one important experimental paradigm cannot be ignored: dichotic listening. At the time of writing, Kenneth has co-authored 126 articles using the consonant-vowel dichotic-listening paradigm, with the first dating back to 1982 (retrieved from Thomson Reuters' Web of Knowledge, May, 2017). During these 35 years of research he substantially extended and championed the paradigm, advancing our understanding of the lateralized hemispheric processing of speech sounds, how this lateralization interacts with higher-order cognitive functions such as attention and cognitive control, and how it is affected in various neurological and psychiatric conditions (for recent reviews see Hugdahl, 2011b; Hugdahl & Westerhausen, 2016).

A typical trial of a dichotic-listening experiment consists of simultaneous presentation of two different acoustic stimuli via headphones, whereby one of the stimuli is presented to the left and another one is presented to the right ear (Bryden, 1988b). In the simplest case, the participants are asked in each trial to identify and report the stimulus they hear. When the stimuli presented in this manner are speech sounds, such as syllables or words, participants typically identify and report more of the stimuli presented to the right than to the left ear. While the exact mechanism for this effect is still a matter of debate (see Hiscock & Kinsbourne, 2011; Pollmann, 2010), theoretical models agree on the fundamental principle that this right-ear advantage reflects the left-hemispheric dominance for speech and language processing (Hugdahl, 2011b; Tervaniemi & Hugdahl, 2003). Thus, the behavioral preference for the right-ear stimuli, the perceptual laterality, is thought to serve as an indicator of underlying processing asymmetry between the two cerebral hemispheres.

Interestingly, and in contrast to many phenomena in psychology which seem not to generalize beyond western societies (Henrich, Heine & Norenzayan, 2010), the right-ear advantage can be considered a truly global human perceptual phenomenon (Bless, Westerhausen, Torkildsen, Gudmundsen, Kompus & Hugdahl, 2015). After more than five decades of research (Hugdahl, 2011a) there is no finding in the literature of a natural sample showing a left-ear advantage as group mean in a verbal dichotic listening paradigm. The magnitude of the right-ear advantage may vary between groups, but it is common from childhood (e.g., Fennell, Satz & Morris, 1983; Hirnstein, Westerhausen, Korsnes & Hugdahl, 2013; Hugdahl, Carlsson & Eichele, 2001) and persists into older age (e.g., Gootjes, Van Strien & Bouma, 2004; Takio, Koivisto, Jokiranta *et al*., 2009; Westerhausen, Bless & Kompus, 2015). It can be found for both sexes (Hirnstein *et al*., 2013; Voyer, 2011; Voyer & Flight, 2001) and for right- and left-handers (Bryden, 1988a; Dos Santos Sequeira, Woerner, Walter *et al*., 2006; Foundas, Corey, Hurley & Heilman, 2006). The right-ear advantage for verbal material is present in language families as different as the Germanic languages English (e.g., Arciuli, Rankine & Monaghan, 2010), German (e.g., Westerhausen *et al*., 2006), and Norwegian (e.g., Kompus, Specht, Ersland *et al*., 2012); Finno-Ugric languages Finnish (Takio *et al*., 2009) and Estonian (Westerhausen *et al*., 2017); Romanic languages Italian (Brancucci, Della Penna, Babiloni *et al*., 2008), French (Bedoin, Ferragne & Marsico, 2010), and Spanish (Gadea, Marti-Bonmatí, Arana, Espert, Salvador & Casanova *et al*., 2009), as well as in Japanese (Tanaka, Kanzaki, Yoshibayashi, Kamiya & Sugishita, 1999), Turkish (Bayazıt, Öniz, Hahn, Güntürkün & Özgören, 2009), Mandarin Chinese, and Hindi (Bless *et al*., 2015). Thus, the right-ear advantage in verbal dichotic listening is remarkably robust at group level and replicated in virtually all natural samples.

However, this group-level homogeneity of the rightward perceptual laterality belies the considerable amount of response variation within group (between individuals) and within individuals (trial-by-trial fluctuation). In this technical review we examine the factors which contribute to the trial-to-trial variability and which can systematically bias task performance. The review may be considered a primer for experimenters considering the adoption of dichotic-listening procedure, but also as a precursor for developing theoretical approaches to hemispheric specialization of stimulus representation in auditory and speech perception.

INTER- AND INTRA-INDIVIDUAL DIFFERENCES IN THE DIRECTION OF THE PERCEPTUAL PREFERENCE

As outlined above, dichotic listening consistently reveals a right-ear advantage on group level. However, the direction of the perceptual preference can differ between individuals. In a typical group of right-handers about 20% of individuals exhibit a left-ear advantage when tested with a standard verbal dichotic-listening paradigm (Bryden, 1988b; and reanalysis of Carey & Johnstone, 2014, meta-analysis only including dichotic listening, personal communication, D. Carey, April 2017). For example, as presented in Fig.1a, the two large samples of right-handed participants 18.6 and 22.4%, respectively, showed a left-ear advantage in a consonant-vowel dichotic listening paradigm (Westerhausen *et al*., 2015). These *inter*-individual differences in the direction of the ear advantage are attributed to differences in the underlying hemispheric specialization (Hiscock & Kinsbourne, 2011; Tervaniemi & Hugdahl, 2003). As a right-ear advantage indicates left-hemispheric specialization, it is reversely assumed that a left-ear advantage indicates “atypical” right-hemispheric specialization for speech processing. However, as argued by Bryden (1988b), dichotic-listening studies show greater prevalence of left-ear advantage in population than the prevalence of “atypical” right-hemispheric specialization in population as suggested by assessment using more direct measures. For example, in the Wada (sodium amobarbital) test to assess hemispheric dominance, about 13% of the right-handed patients show atypical right-hemispheric dominance according to a recent meta-analysis (Carey & Johnstone, 2014). Comparable prevalence estimates can also be obtained using functional magnetic-resonance imaging (fMRI) on healthy individuals, indicating that between 5% (Badzakova-Trajkov, Häberling, Roberts & Corballis, 2010) and 12% (Mazoyer, Zago, Jobard *et al*., 2014) of the right-handed individuals show right-hemispheric dominance. Integrating results from fMRI and other methods (e.g., transcranial magnetic stimulation), Carey and Johnstone (2014) estimate that the population right-brain dominance is 10%. This leaves a gap of 5–15% between population-level estimates of atypical language lateralization achieved with dichotic listening and with the “direct” methods, suggesting that underlying hemispheric dominance is not the only source of variance in the direction of the ear advantage in the dichotic listening test.

The need to consider other sources of variance contributing to performance in the dichotic listening test is further underlined by the simple observation which is obvious to each experimenter: even individuals who show right-ear advantage when averaging across trials will nevertheless report a considerable proportion of left-ear stimuli during the experiment. As depicted in Fig. 1b, participants with a right-ear advantage (N = 2634) report the “subdominant” left-ear stimulus in 27.1% (±7.9) to 29.7% (±8.9) of the trials in a dichotic listening experiment (data from Westerhausen, Bless, Passow, Kompus & Hugdahl 2015). The models explaining the dichotic-listening laterality, reviewed in the next section, do not incorporate an explanation for why there would be *intra*-individual, trial-to-trial fluctuations. As it is doubtful that the hemispheric lateralization of speech processing would fluctuate from one moment to the next, theories of dichotic listening must deal with probability distributions which are modulated and biased by various factors of stimulus material and presentation.

CONCEPTUAL FRAMEWORK

From an information processing perspective, the processing of a single trial in a dichotic listening task may be seen as a two-stage process (Hiscock, Inch & Kinsbourne, 1999; Westerhausen, Passow & Kompus, 2013; Wood, Hiscock & Widrig, 2000): in an initial “bottom-up” stage a perceptual representation of the two competing stimuli is formed in auditory short-term or working memory, and in a subsequent stage cognitive-control processes modulate this representation for response selection in accordance with the task instruction.

The first-stage representation may be considered as a weighted mixture of both stimuli whereby the more salient stimulus will dominate perception and stimulus selection (Desimone & Duncan, 1995; Shinn-Cunningham, 2008). Determining which of the two stimuli is the more salient has, since the seminal papers by Doreen Kimura (1961a, 1961b), been linked to hemispheric asymmetry for speech and language processing (Hiscock & Kinsbourne, 2011; Tervaniemi & Hugdahl, 2003). As a participant with left-hemispheric specialization for speech processing will, across all trials of an experiment, more probably report the right-ear stimulus than the left-ear stimulus, it can also be assumed that within a prototypical single trial of the experiment the representation of the right-ear stimulus is stronger than the representation of the left-ear stimulus. Conversely, for individuals with “atypical” right-hemispheric specialization, the representation of the left-ear stimulus should be stronger (Van der Haegen, Westerhausen, Hugdahl & Brysbaert, 2013). The most prominent model for explaining the contralateral, (typically) right-ear advantage is the so-called structural model (Kimura, 1967). It suggests that the perceptual preference arises from the anatomical and functional properties of the ascending auditory pathways: (1) the projections from the cochlea to the contra-lateral hemisphere are anatomically stronger than the ipsilateral projections, and (2) the competition arising from the dichotic stimulation would produce a functional “occlusion” of the ipsilateral pathways by inhibitory influence from the stronger contralateral pathway. As a result, the right-ear stimulus selectively reaches the left hemisphere, while the left-ear stimulus

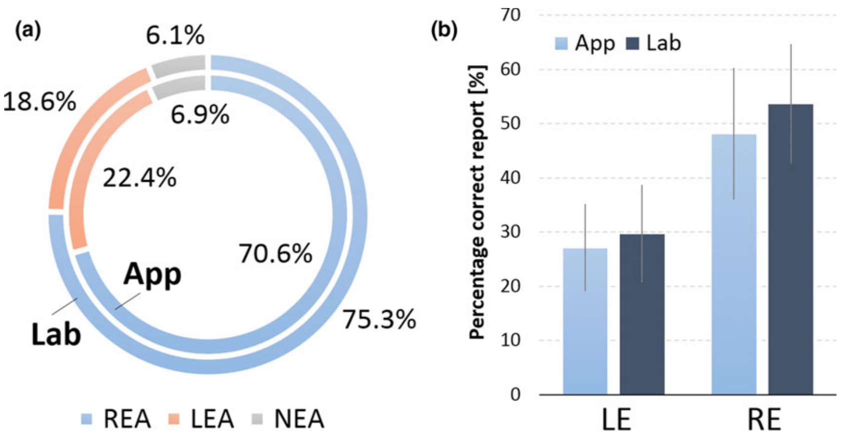

Fig. 1. Variability within the group-level right-ear advantage. (a) The proportion of individuals showing a right-ear advantage (REA), left-ear advantage (LEA), and no difference in the number of reported left- and right-ear stimuli (NEA) in a free-recall consonant-vowel dichotic-listening paradigm. The sample consists of N = 3,680 right-handed participants included in Westerhausen *et al.* (2015) study and the data was collected either in laboratory conditions (Lab, n = 757; see Hugdahl, 2003) or using the iDichotic iPhone (Bless *et al.*, 2013) application (App, n = 2923, see Bless *et al.*, 2015). (b) The average percentage of correct left- (LE) and right-ear (RE) reports in the same data set. Error bars indicate 95% confidence limits. [Colour figure can be viewed at wileyonlinelibrary.com]

reaches the right hemisphere. Given the left-hemispheric specialization for speech processing, only the right-ear stimulus has direct access to the relevant speech processing regions, resulting in the right-ear advantage. Several modifications and alternative models have been suggested, and the interested reader is referred to recent reviews (Hiscock & Kinsbourne, 2011; Pollmann, 2010) for a thorough discussion.

Thus, researchers or clinicians using dichotic listening to assess brain asymmetry follow the general assumption that the observed perceptual preference in a trial or across trials is a valid behavioral index of the underlying hemispheric dominance. Inherent to this idea is that left- or right-hemispheric specialization for speech processing provides preference for the ear contralateral to the dominant hemisphere which is a “built-in” property of the brain and which can be expected to be stable over time – certainly for the duration of a single dichotic-listening session – and, consequently, is constant across trials. Thus, any deviation from the contralateral preference, namely, trial-to-trial fluctuation and individual “misclassification” (i.e., showing a left-ear advantage, despite of being left-hemispheric dominant), cannot be readily explained by hemispheric specialization. Following the above outlined framework, two possible sources for such deviation can be distinguished (in addition to random noise). First, the features of stimulus material and experimental set-up could affect the formation of the initial stimulus representation in short-term memory. As we review below, the most substantial features are stimulus intensity, inter-aural lag, repetition effects and phonological features (voicing). Second, the cognitive control processes during the second processing stage may affect the response selection. In this review we will specifically consider the effect of the instruction to selectively attend to one ear.

Thus, the observed response (P) in a trial depends on a stimulus representation which can be seen as a function of three weighting sources: the “true” in-built laterality bias, the stimulus features, and attention. The probability of reporting the stimulus presented to ear *e* on a trial *n* is the result of a perceptual representation of the mixture of left-ear and right-ear stimuli. This can be formalized as follows:

$$R_{e,n} = L_e \times S_{e,n} \times A_{e,n}$$

where $R_{e,n}$ is the weighted representation of a stimulus presented to ear *e* on trial *n*, L_e is the “in-built” laterality bias which is constant across trials, $S_{e,n}$ represents stimulus properties in ear *e* on trial *n*, and consists of additive mixture of the following features (reviewed below): stimulus intensity, stimulus delay relative to other ear, stimulus repetition relative to trial *n*-1, and stimulus voicing. $A_{e,n}$ is attentional bias towards ear *e* on trial *n*. With the condition that the values of L and A are above zero (L>0, A>0), and S is equal to or larger than zero (S> = 0), the situation where no stimulus is presented in one ear can be incorporated into this formulation. This formulation incorporates the interaction between attention, in-built laterality bias and stimulus properties. Of the elements in this model, the terms S and A can be altered from trial to trial, and consequently contribute to the trial-to-trial variability, affecting the estimation of L_e. In an ideal situation where both S and A are equivalent to 1, only the “true” laterality would contribute to the mixed perceptual representation favoring one ear.

In the following section we provide an overview of empirical evidence demonstrating on how trial-inherent and trial-to-trial carry-over effects can act on a trial-by-trial basis to enhance, reduce, or reverse the “in-built” perceptual bias. For simplicity, left-hemispheric language specialization with a perceptual bias towards the right-ear stimulus is considered throughout the discussion. However, the general principles can be assumed to act in the same manner for participants with right-hemispheric language specialization.

FEATURES OF STIMULUS MATERIAL AND EXPERIMENTAL SET-UP

There are several ways of how the initial perceptual representation can be altered by changing one or several features relating to the stimulus administration. Three features which are relatively easy to control are inter-channel stimulus intensity differences, inter-channel onset asynchrony (time lag), and trial-to-trial stimulus repetition.

Inter-channel intensity differences

An intuitive way of shifting a participant's behavior towards demonstrating a left-ear advantage is presenting the left-ear stimulus louder than the right-ear stimulus. It has been frequently demonstrated that introducing intensity differences between the two auditory channels during stimulus administration affects the response preference in a systematic fashion (Berlin, Lowe-Bell, Cullen Jr, Thompson & Stafford, 1972; Bloch & Hellige, 1989; Hugdahl, Westerhausen, Alho, Medvedev & Hämäläinen, 2008; Ozgoren, Bayazit, Oniz & Hugdahl, 2012; Tallus, Hugdahl, Alho, Medvedev & Hämäläinen, 2007). When presenting the right-ear stimulus louder than the left, the magnitude of the right-ear advantage is increased, and the effect is proportional to the magnitude of the introduced inter-aural intensity difference. Likewise, presenting the left-ear stimulus louder than the right-ear stimulus will reduce the magnitude of the right-ear advantage, and result in a left-ear advantage given the left-ear intensity bias is sufficiently strong. More specifically, it has been demonstrated that increasing the intensity difference in favor of the left-ear stimulus by about 6 to 12 dB will result in approximately equal numbers of correct reports of left- and right-ear stimuli (Berlin *et al.*, 1972; Hugdahl *et al.*, 2008; Westerhausen, Moosmann, Alho *et al.*, 2010). A further increase of the intensity difference in favor of the left ear produces a significant left-ear advantage. A reliable test of hemispheric dominance using dichotic listening thus relies on an experimental set-up that guarantees that the sound level of the two stimuli is equal, that is, the sound volume balance of equipment (e.g., the headphones) and mean stimulus intensity needs to be considered. In addition to the stimulus presentation, which can be controlled by the experimenter, the peripheral auditory acuity difference between the left and right ear may also have a systematic effect on the magnitude and the direction of the ear advantage. Asymmetrical peripheral hearing loss will increase the likelihood that the stimulus presented to the "better" ear is reported (Speaks, Bauer & Carlstrom, 1983; Speaks, Blecha & Schilling, 1980). Thus, it is crucial that a dichotic-listening experiment must incorporate hearing tests. It is common practice to exclude participants with strong (usually above 10 dB) inter-aural acuity differences from experimental samples (Hugdahl *et al.*, 2009). On individual level it is conceivable that such peripheral differences can be compensated by adjusting the stimulus intensity in the disadvantaged ear so that it would be louder than the other ear. However, while it appears plausible that such compensation could be used, there is, to the best of the authors' knowledge, currently no systematic examination into this.

Inter-channel onset asynchrony

A second feature in stimulus presentation which has been implicated to produce a left-ear advantage, is the so-called "lag-effect" (Studdert-Kennedy, Shankweiler & Schulman, 1970). Stimulus-onset asynchrony (SOA) between the left- and the right-ear stimulus increases the likelihood of reporting the trailing of the two stimuli (Berlin, Lowe-Bell, Cullen Jr, Thompson & Loovis, 1973; Wood *et al.*, 2000). Accordingly, for SOAs larger than 20–30 msec with trailing left-ear stimulus a left-ear advantage has been reported, while for shorter SOAs the right-ear preference appears to withstand the lag-induced left-shift (Berlin *et al.*, 1973; Studdert-Kennedy *et al.*, 1970). However, the findings are less consistent than for the intensity effect reported above, as Wood et al (2000) find a reduction of magnitude, but do not replicate the reversal of the ear advantage. Also, Ozgoron *et al.* (2012) report the opposite effect, that is, a higher report likelihood of the leading rather than the lagging stimulus producing a left-ear advantage for a condition in which the right-ear stimulus is trailing by 35 msec. While the reasons for this inconsistency deserve further exploration, it is nevertheless important to carefully check the stimulus presentation for SOAs between the channels.

Trial-to-trial stimulus repetition

Intensity and lag-effect are within-trial effects, as they can be attributed to manipulations of relative alignment and relative saliency of the two stimuli of one trial. In addition to such within-trial effects, the likelihood of left-ear report is also susceptible to a between-trial effect where preceding stimuli influence the performance on a given trial. It has been shown that a negative priming effect exists for repeated stimuli in dichotic listening (Sætrevik & Hugdahl, 2007a, 2007b) whereby a stimulus which was presented on the immediately preceding trial (prime) is less likely to be reported on the current trial (probe). This effect appears independent of whether the right- or the left-ear syllable of the prime stimulus is repeated. As shown by Sætrevik and Hugdahl (2007a, 2007b), this effect substantially modulates the ear advantage similarly to the within-trial influences discussed above. The magnitude of the right-ear advantage is increased when the left-ear stimulus is repeated, whereas when the right-ear stimulus is repeated, the negative priming is sufficient to produce a left-ear advantage. While it appears difficult to completely avoid such "carry-over effects" from trial to trial, it is possible to control for them. Using a pseudorandomized order and carefully balancing for stimulus repetition will reduce possible negative priming biases compared to an ad hoc computer-controlled randomization of trials.

Phonological properties of the stimuli

A reliable and valid dichotic-listening paradigm requires that the two sounds constituting a stimulus pair are as similar as possible but not identical, to allow for distinguishable perceptual categories (Wexler, 1988). This is commonly achieved by using stimuli which only differ in the initial phoneme, such as rhyming words (e.g., *pin* and *bin*, see Fernandes, Smith, Logan, Crawley & McAndrews, 2006; Wexler & Halwes, 1983) or syllables (e.g., *pa* and *ba*; see Hugdahl & Andersson, 1986; Hugdahl *et al.*, 2009; Studdert-Kennedy *et al.*, 1970). Whenever stop-consonant vowel combinations are utilized, the stimuli will be characterized by differences in voicing of the initial syllable. Voicing is a phonological characteristic which refers to the vocal cord vibration during the articulatory process. For example, in Norwegian voiced syllables (such as /ba/, /da/, or /ga/) are characterized by a short time interval (ca. 25 ms) between the release of the consonant sound and the onset of the rhythmic vocal-cord vibrations of the vowel (the voice-onset time). Unvoiced (or voiceless) syllables (such as /pa/, /ta/, or /ka/), on the other hand, have a long voice-onset time (ca. 70 ms). The voicing of the initial phoneme represents an articulatory property of the stimulus that is directly linked to a categorical percept (e.g., *pa* vs. *ba*, or *pin* vs. *bin*). Importantly, systematic studies on the effect of stimulus voicing in dichotic listening have revealed that unvoiced syllables are preferably reported in dichotic listening, irrespective to which ear they are presented (e.g., Arciuli *et al*., 2010; Berlin *et al*., 1973; Gerber & Goldman, 1971; Rimol, Eichele & Hugdahl, 2006; Voyer & Techentin, 2009); for review see (Arciuli, 2011). For example, Rimol *et al*. (2006) found that dichotic stimulus pairs of voiced with voiced syllables (VV, e.g., /ba/-/da/) and of unvoiced with unvoiced syllables (UU, e.g., /pa/-/ta/) produce the classical right-ear advantage. Similarly, when presenting a voiced syllable to the left and an unvoiced to the right ear (VU), a right-ear advantage was found which was, however, substantially accentuated compared with the UU and VV conditions. Finally, when presenting an unvoiced syllable to the left and a voiced to the right ear (UV), a significant left-ear advantage was found. This is a demonstration of how the perceptual dominance of unvoiced stimuli overrides the right-ear advantage. In this, "voicing" contributes to the observed trial-to-trial variability. Thus, in order to reduce the intra-individual variance, it has been advocated to use VV and UU trials only, a strategy which has been frequently employed when studying fundamental properties of dichotic listening (e.g., Brancucci *et al*., 2008; Hugdahl *et al*., 2008; Westerhausen, Moosmann, *et al*., 2010). Furthermore, it has been suggested that the cognitive requirements of UV/VU trials and UU/VV trials differ (Westerhausen *et al*., 2013), that is, the two stimuli presented in VV/UU are more likely perceived as one "fused" stimulus (see also Cutting, 1976; Wexler & Halwes, 1983) and accordingly require less cognitive resources for stimulus selection than UV/VU trials. Accordingly, faster and more accurate responses, and reduced involvement of inferior frontal brain regions in VV/UU trials has been demonstrated (Westerhausen *et al*., 2013). However, there is no reason to believe that the stronger involvement of higher cognitive processes would affect the direction of the preference in a systematic manner during UV/VU trials. Thus, as long as equal number of VU and UV stimulus pairs is presented in an experiment, the voicing effect is likely "averaged out" on individual level, and on sample level. Nevertheless, it can be argued that UU/VV trials, by relying less on second stage cognitive processing, might represent a more direct measure of underlying "in-built" laterality bias.

While dominance of unvoiced stimuli in dichotic listening has been frequently and independently replicated in many laboratories (e.g., Berlin *et al*., 1973; Gerber & Goldman, 1971; Rimol *et al*., 2006; Voyer & Techentin, 2009), recent evidence indicates that the effect is, in contrast to the overall right-ear preference, not universal but rather depends on the linguistic importance of the contrasted voicing categories in the examined language. This is illustrated by a recent study by Westerhausen *et al*. (2017), comparing the voicing-effect in Norwegian and Estonian. While Norwegian, similarly to English, is characterized by a clear distinction between voiced (i.e., /b/, /d/, /g/) and unvoiced (i.e., /p/, /t/, /k/) initial plosive consonant phonemes (reflected e.g. in the minimal pair *pin* vs. *bin*), Estonian does not have a comparable distinction at word beginning. Instead, only unvoiced initial plosive consonant phonemes occur within the standard Estonian language repertoire (Asu & Teras, 2009). Accordingly, the effect of voicing on the magnitude of the right-ear advantage was substantially reduced in Estonian native speakers compared with Norwegian native speakers (Westerhausen *et al*., 2017). Importantly, Norwegian native speakers showed a significant left-ear advantage in the critical UV condition, while no comparable effect was found in the Estonian native speakers. The dependency of the voicing effect on language background emphasizes the relevance of learning experience for establishing the phenomenon, a notion which is further supported by developmental studies (Andersson, Llera, Rimol & Hugdahl, 2008; Arciuli *et al*., 2010; Westerhausen, Helland, Ofte & Hugdahl, 2010). For example, in a longitudinal study, testing a cohort of children at the age of 5, 6, 7, and 8 years, the voicing effect was found to increase in strength with age, approaching a response pattern comparable to the adult pattern at the age of 8 years (Westerhausen, Helland *et al*., 2010). That is, a significant left-ear advantage in the UV condition was observed only in oldest group. Coinciding with the start of formal literacy education in elementary school at about the age of 5 or 6 years, the observed development seems to be associated with the children's experience with recognizing and manipulating phonological units like phonemes, syllables, or words.

CONDITIONS OF STIMULUS/RESPONSE SELECTION

The stimulus features listed above interact with the stable laterality bias to create the first-order perceptual representation. Subsequently, cognitive control processes manipulate the representation in line with the task instructions to form the final perceptual representation of the mixture, which will form the basis for the report on this trial. Here we consider the effect of attentional biasing in transforming the working-memory representation which determines the report within a trial.

Dichotic listening is often administered with a free-report instruction (also referred to as non-forced or divided attention), that is, participants are asked to report the stimulus they have heard best after each trial. It was pointed out that a free-report approach would allow participants to deploy attention to the left or right ear in an idiosyncratic manner introducing trial-to-trial variation; or, alternatively, if this attentional modulation would be consistently employed, it would bias perception systematically (Bryden, 1969; Hugdahl & Andersson, 1986; Mondor & Bryden, 1991). Thus, paradigms using instructions to direct attention were introduced both to control for the effect of attention as well as to systematically study the selective attention effect (e.g., Asbjørnsen & Hugdahl, 1995; Bloch & Hellige, 1989; Bryden, Munhall & Allard, 1983; Dean & Hua, 1982; Foundas *et al*., 2006; Hiscock & Beckie, 1993; Hugdahl & Andersson, 1986; Kompus *et al*., 2012). The overall result pattern produced by instructing the participant to selectively report the stimuli from one ear is straightforward. Asked to selectively attend to and report stimuli presented to the right ear, the magnitude of the right-ear advantage is usually found to be enhanced compared to a free-recall condition. Similarly, when instructed to attend to the left ear, a left-ear advantage can be observed. Thus, healthy adult participants are able to overcome the bottom-up, right-ear preference by selectively attending to the left ear. Consequently, also trial-to-trial variability in attentional focus or stable attentional bias across the experiment needs to be considered when using the dichotic-listening paradigm to assess laterality.

One suggestion that was put forward is to only use the correctly reported syllables form directed-attention version of the dichotic-listening paradigm for determining laterality (see e.g., Bryden *et al*., 1983), and compare the correctly reported syllables from the attended ear between attend-left and attend-right conditions. While this "control attention" approach usually reveals a right-ear advantage, it assumes that attending to the left- and the right-ear stimulus requires comparable cognitive processes during perception and stimulus selection. The bias to the left ear by selectively attending to the left ear-stimulus is considered to be of comparable magnitude to the bias to the right when asked to attend to the right-ear stimulus. In other words, the effect of attention was thought to be independent and "additive" to the "true", in-built laterality effect and could thus be controlled by keeping the attention effect constant as suggested above. However, this basic assumption has been challenged (Hugdahl *et al*., 2009) as this view overlooks the fact that a dichotic-listening paradigm does not provide a neutral baseline situation, and consequently the top-down attention instruction will interact with the bottom-up bias. The perceptual preference for right-ear input creates two different experimental conditions that set different demands during second-stage stimulus or response selection. Selectively attending and reporting the right-ear stimulus requires reporting the input which is already preferred, while selectively attending and reporting the left-ear stimulus demands the processing of the weaker stimulus in presence of a stronger one (Hugdahl *et al*., 2009). The claim of differential processing demands in an "attend left" as compared with an "attend right" set-up, have been substantiated by a behavioral dissociation between the two experimental conditions. For example, patients with schizophrenia (Green, Hugdahl & Mitchell, 1994; Hugdahl, 2003), attention-deficit/hyperactivity disorder (Dramsdahl, Westerhausen, Haavik, Hugdahl & Plessen, 2011; Øie, Skogli, Andersen, Hovik & Hugdahl, 2014), as well as in patients with multiple sclerosis (Reinvang, Borchgrevink, M., Aaserud *et al*., 1994), Klinefelter syndrome (Kompus *et al*., 2011), and Alzheimer's disease (Gootjes, Bouma, Van Strien, Van Schijndel, Barkhof & Scheltens, 2006) show a selectively reduced ability to attend to and report the left-ear stimulus compared to a healthy control group, while at the same time the performance does not deviate in the "attend right" condition. A similar selective effect on the "attend left" performance was reported in healthy aging (e.g., Andersson *et al*., 2008; Takio *et al*., 2009; Thomsen, Specht, Rimol *et al*., 2004; Westerhausen, Bless, Passow, *et al*., 2015): while groups of young and old subjects do not differ in their performance in the "attend right" condition, older individuals are not able to successfully follow the instruction to selectively attend to the left-ear stimulus in the attend-left condition. The dissociation is further substantiated by imaging studies, demonstrating a differential pattern of frontal brain activation (Kompus *et al*., 2012) in the two conditions. The attend-left condition is accompanied by more pronounced activations in the left inferior frontal gyrus and caudate nucleus than the attend-right condition, while the right inferior frontal gyrus and caudate nucleus were activated to a comparable degree in both conditions. Thus, it appears that reporting the left-ear stimulus is more demanding than reporting the right-ear stimulus, and that the employed cognitive processes are not comparable between these two conditions.

In summary, voluntary preferences to selectively report one of the two stimuli, based on the instruction to attend to a specific ear, or triggered by arbitrary attentional strategies, have to be considered when planning a dichotic-listening experiment. The suggestion that laterality should be estimated based on the correct answers in the "attend right" and "attend left" condition is not defensible. The known differences in difficulty between the two conditions might especially affect individuals of lower cognitive capability (as demonstrated in the clinical studies reviewed above), who can be expected to show a reduced number of correct left-ear identifications, and conversely an inflated right-ear advantage. Free-report instruction conditions, with their lower cognitive demands, might be better suited to prevent such confounding of laterality estimates and cognitive abilities. Nevertheless, trial-to-trial variability or idiosyncratic strategies in reporting only stimuli from one side remain a challenge for the free-report set-up, and mitigation strategies have to be considered. As indicated when discussing the voicing effect, one promising approach is to only use stimulus combination which "fuse", that is, are perceived as one stimulus (e.g., UU/VV trials, or rhyming words). Here the participant often does not realize that two stimuli are presented, so that selection strategies are precluded (Westerhausen *et al*., 2013; Wexler & Halwes, 1983).

CONCLUSION

The dichotic-listening paradigm has been widely used to determine the hemispheric lateralization of speech perception in single subjects as well as groups. However, as we illustrate in the formalized model of dichotic listening trial presented in this review, only one portion of the representation-formation is in fact determined by the "in-built" lateralization, which this paradigm aims to measure. The two other factors (stimulus properties and attentional bias) make a substantial contribution for determining the outcome of a dichotic-listening trial and experiment. As we have summarized in this review, there is substantial evidence for the strong effect each of these factors can have on the measured laterality. The paradigm is sensitive to sources of variation stemming from stimulus choices (initial consonant pairs making up the dichotic stimuli), their composition (onset of the stimuli in the two channels), their order (priming effect), sound intensity in the two auditory channels (details relating to the auditory presentation equipment, such as headphones or computer soundcard), and instructions given to the participants. Ignoring these sources of variance may lead the experimental results to demonstrate apparently reduced right-ear advantage or even left-ear advantage in the subjects. These aspects are particularly important when implementing the dichotic-listening paradigm with speech sounds in a new language, where the particular features of the phonetic structure of the language may introduce biases which need to be rigorously assessed by having full control over other experimental variables. Similarly, these factors need to be considered with care when performing comparison between groups who may differ with regard to the effects of any of these variables.

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REFERENCES

Andersson, M., Llera, J. E., Rimol, L. M. & Hugdahl, K. (2008). Using dichotic listening to study bottom-up and top-down processing in children and adults. *Child Neuropsychology*, *14*, 470–479.

Arciuli, J. (2011). Manipulation of voice onset time during dichotic listening. *Brain and Cognition*, *76*, 233–238.

Arciuli, J., Rankine, T. & Monaghan, P. (2010). Auditory discrimination of voice-onset time and its relationship with reading ability. *Laterality: Asymmetries of Body Brain and Cognition*, *15*, 343–360.

Asbjørnsen, A. E. & Hugdahl, K. (1995). Attentional effects in dichotic listening. *Brain and Language*, *49*, 189–201.

Asu, E. L. & Teras, P. (2009). Estonian. *Journal of the International Phonetic Association*, *39*, 367–372.

Badzakova-Trajkov, G., Häberling, I. S., Roberts, R. P. & Corballis, M. C. (2010). Cerebral asymmetries: Complementary and independent processes. *PloS one*, *5*, e9682.

Bayazıt, O., Öniz, A., Hahn, C., Güntürkün, O. & Özgören, M. (2009). Dichotic listening revisited: Trial-by-trial ERP analyses reveal intra- and interhemispheric differences. *Neuropsychologia*, *47*, 536–545.

Bedoin, N., Ferragne, E. & Marsico, E. (2010). Hemispheric asymmetries depend on the phonetic feature: A dichotic study of place of articulation and voicing in French stops. *Brain and Language*, *115*, 133–140.

Berlin, C. I., Lowe-Bell, S. S., Cullen Jr, J. K., Thompson, C. L. & Loovis, C. F. (1973). Dichotic speech perception: An interpretation of right-ear advantage and temporal offset effects. *The Journal of the Acoustical Society of America*, *53*, 699–709.

Berlin, C. I., Lowe-Bell, S. S., Cullen Jr, J. K., Thompson, C. L. & Stafford, M. R. (1972). Is speech "special"? Perhaps the temporal lobectomy patient can tell us. *The Journal of the Acoustical Society of America*, *52*, 702–705.

Bless, J. J., Westerhausen, R., Arciuli, J., Kompus, K., Gudmundsen, M. & Hugdahl, K. (2013). "Right on all occasions?" – On the feasibility of laterality research using a smartphone dichotic listening application. *Frontiers in Psychology*, *4*, 42.

Bless, J. J., Westerhausen, R., Torkildsen, J. V., Gudmundsen, M., Kompus, K. & Hugdahl, K. (2015). Laterality across languages: Results from a global dichotic listening study using a smartphone application. *Laterality*, *20*, 434–452.

Bloch, M. I. & Hellige, J. B. (1989). Stimulus intensity, attentional instructions, and the ear advantage during dichotic listening. *Brain and Cognition*, *9*, 136–148.

Brancucci, A., Della Penna, S., Babiloni, C., Vecchio, F., Capotosto, P., Rossi, D. *et al*. (2008). Neuromagnetic functional coupling during dichotic listening of speech sounds. *Human Brain Mapping*, *29*, 253–264.

Bryden, M. P. (1969). Binaural competition and division of attention as determinants of the laterality effect in dichotic listening. *Canadian Journal of Psychology*, *23*, 101–113.

Bryden, M. P. (1988a). Correlates of the dichotic right-ear effect. *Cortex*, *24*, 313–319.

Bryden, M. P. (1988b). An overview of the dichotic listening procedure and its relation to cerebral organization. In K. Hugdahl (Ed.), *Handbook of Dichotic Listening: Theory, methods, and research* (pp. 1–43). Chichester: Wiley & Sons.

Bryden, M. P., Munhall, K. & Allard, F. (1983). Attentional biases and the right-ear effect in dichotic listening. *Brain and Language*, *18*, 236–248.

Carey, D. P. & Johnstone, L. T. (2014). Quantifying cerebral asymmetries for language in dextrals and adextrals with random-effects meta analysis. *Frontiers in Psychology*, *5*, 1128.

Cutting, J. E. (1976). Auditory and linguistic processes in speech perception: Inferences from six fusions in dichotic listening. *Psychological Review*, *83*, 114–140.

Dean, R. S. & Hua, M. S. (1982). Laterality effects in cued auditory asymmetries. *Neuropsychologia*, *20*, 685–690.

Desimone, R. & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience*, *18*, 193–222.

Dos Santos Sequeira, S., Woerner, W., Walter, C., Kreuder, F., Lueken, U., Westerhausen, R. *et al*. (2006). Handedness, dichotic-listening ear advantage, and gender effects on planum temporale asymmetry – a volumetric investigation using structural magnetic resonance imaging. *Neuropsychologia*, *44*, 622–636.

Dramsdahl, M., Westerhausen, R., Haavik, J., Hugdahl, K. & Plessen, K. J. (2011). Cognitive control in adults with attention-deficit/hyperactivity disorder. *Psychiatry Research*, *188*, 406–410.

Fennell, E. B., Satz, P. & Morris, R. (1983). The development of handedness and dichotic ear listening asymmetries in relation to school achievement: A longitudinal study. *Journal of Experimental Child Psychology*, *35*, 248–262.

Fernandes, M., Smith, M., Logan, W., Crawley, A. & McAndrews, M. (2006). Comparing language lateralization determined by dichotic listening and fMRI activation in frontal and temporal lobes in children with epilepsy. *Brain and Language*, *96*, 106–114.

Foundas, A. L., Corey, D. M., Hurley, M. M. & Heilman, K. M. (2006). Verbal dichotic listening in right and left-handed adults: laterality effects of directed attention. *Cortex*, *42*, 79–86.

Gadea, M., Marti-Bonmatí, L., Arana, E., Espert, R., Salvador, A. & Casanova, B. (2009). Corpus callosum function in verbal dichotic listening: inferences from a longitudinal follow-up of relapsing–remitting multiple sclerosis patients. *Brain and Language*, *110*, 101–105.

Gerber, S. E. & Goldman, P. (1971). Ear preference for dichotically presented verbal stimuli as a function of report strategies. *The Journal of the Acoustical Society of America*, *49*, 1163–1168.

Gootjes, L., Bouma, A., Van Strien, J. W., Van Schijndel, R., Barkhof, F. & Scheltens, P. (2006). Corpus callosum size correlates with asymmetric performance on a dichotic listening task in healthy aging but not in Alzheimer's disease. *Neuropsychologia*, *44*, 208–217.

Gootjes, L., Van Strien, J. W. & Bouma, A. (2004). Age effects in identifying and localising dichotic stimuli: a corpus callosum deficit? *Journal of Clinical and Experimental Neuropsychology*, *26*, 826–837.

Green, M. F., Hugdahl, K. & Mitchell, S. (1994). Dichotic listening during auditory hallucinations in patients with schizophrenia. *American Journal of Psychiatry*, *151*, 357–362.

Henrich, J., Heine, S. & Norenzayan, A. (2010). The weirdest people in the world? *Behavioral and Brain Sciences*, *33*, 61–83.

Hirnstein, M., Westerhausen, R., Korsnes, M. S. & Hugdahl, K. (2013). Sex differences in language asymmetry are age–dependent and small: A large-scale, consonant-vowel dichotic listening study with behavioral and fMRI data. *Cortex*, *49*, 1910–1921.

Hiscock, M. & Beckie, J. L. (1993). Overcoming the right-ear advantage: A study of focused attention in children. *Journal of Clinical and Experimental Neuropsychology*, *15*, 754–772.

Hiscock, M., Inch, R. & Kinsbourne, M. (1999). Allocation of attention in dichotic listening: differential effects on the detection and localization of signals. *Neuropsychology*, *13*, 404–414.

Hiscock, M. & Kinsbourne, M. (2011). Attention and the right-ear advantage: what is the connection? *Brain and Cognition*, *76*, 263–275.

Hugdahl, K. (2003). Dichotic listening in the study of auditory laterality. In K. Hugdahl & R. J. Davidson (Eds.), *The asymmetrical brain* (pp. 441–475). Cambridge, MA: MIT Press.

Hugdahl, K. (2011a). Fifty years of dichotic listening research – Still going and going and.... *Brain and Cognition*, *76*, 211–213.

Hugdahl, K. (2011b). Hemispheric asymmetry: contributions from brain imaging. *Wiley Interdisciplinary Reviews: Cognitive Science*, *2*, 461–478.

Hugdahl, K. & Andersson, L. (1986). The “forced–attention paradigm” in dichotic listening to CV–syllables: A comparison between adults and children. *Cortex*, *22*, 417–432.

Hugdahl, K., Carlsson, G. & Eichele, T. (2001). Age effects in dichotic listening to consonant-vowel syllables: Interactions with attention. *Developmental Neuropsychology*, *20*, 445–457.

Hugdahl, K. & Westerhausen, R. (2016). Speech processing asymmetry revealed by dichotic listening and functional brain imaging. *Neuropsychologia*, *93*, 466–481.

Hugdahl, K., Westerhausen, R., Alho, K., Medvedev, S. & Hämäläinen, H. (2008). The effect of stimulus intensity on the right ear advantage in dichotic listening. *Neuroscience Letters*, *431*, 90–94.

Hugdahl, K., Westerhausen, R., Alho, K., Medvedev, S., Laine, M. & Hämäläinen, H. (2009). Attention and cognitive control: Unfolding the dichotic listening story. *Scandinavian Journal of Psychology*, *50*, 11–22.

Kimura, D. (1961a). Some effects of temporal-lobe damage on auditory perception. *Canadian Journal of Psychology/Revue canadienne de psychologie*, *15*, 156–165.

Kimura, D. (1961b). Cerebral dominance and the perception of verbal stimuli. *Canadian Journal of Psychology/Revue Canadienne de Psychologie*, *15*, 166–171.

Kimura, D. (1967). Functional asymmetry of the brain in dichotic listening. *Cortex*, 163–178.

Kompus, K., Specht, K., Ersland, L., Juvodden, H. T., van Wageningen, H., Hugdahl, K. & Westerhausen, R. (2012). A forced-attention dichotic listening fMRI study on 113 subjects. *Brain and Language*, *121*, 240–247.

Kompus, K., Westerhausen, R., Nilsson, L. G., Hugdahl, K., Jongstra, S., Berglund, A. *et al*. (2011). Deficits in inhibitory executive functions in Klinefelter (47, XXY) syndrome. *Psychiatry Research*, *189*, 135–140.

Mazoyer, B., Zago, L., Jobard, G., Crivello, F., Joliot, M., Perchey, G. *et al*. (2014). Gaussian mixture modeling of hemispheric lateralization for language in a large sample of healthy individuals balanced for handedness. *PloS one*, *9*, e101165.

Mondor, T. A. & Bryden, M. P. (1991). The influence of attention on the dichotic REA. *Neuropsychologia*, *29*, 1179–1190.

Øie, M., Skogli, E. W., Andersen, P. N., Hovik, K. T. & Hugdahl, K. (2014). Differences in cognitive control in children and adolescents with combined and inattentive subtypes of ADHD. *Child Neuropsychology*, *20*, 38–48.

Ozgoren, M., Bayazit, O., Oniz, A. & Hugdahl, K. (2012). Amplitude and phase-shift effects on dichotic listening performance. *International Journal of Audiology*, *51*, 591–596.

Pollmann, S. (2010). A unified structural-attentional framework for dichotic listening. In K. Hugdahl & R. Westerhausen (Eds.), *The two halves of the brain: Information processing in the cerebral hemispheres* (pp. 441–468). Cambridge, MA: MIT Press.

Reinvang, I., Borchgrevink, H. M., Aaserud, O., Lie, V., Malt, U. F., Nakstad, P. *et al*. (1994). Neuropsychological findings in a non–clinical sample of workers exposed to solvents. Journal of Neurology, Neurosurgery, and Psychiatry, *57*, 614–616.

Rimol, L. M., Eichele, T. & Hugdahl, K. (2006). The effect of voice-onset-time on dichotic listening with consonant-vowel syllables. *Neuropsychologia*, *44*, 191–196.

Sætrevik, B. & Hugdahl, K. (2007a). Endogenous and exogenous control of attention in dichotic listening. *Neuropsychology*, *21*, 285–290.

Sætrevik, B. & Hugdahl, K. (2007b). Priming inhibits the right ear advantage in dichotic listening: Implications for auditory laterality. *Neuropsychologia*, *45*, 282–287.

Shinn-Cunningham, B. G. (2008). Object–based auditory and visual attention. *Trends in Cognitive Sciences*, *12*, 182–186.

Speaks, C., Bauer, K. & Carlstrom, J. (1983). Peripheral Hearing LossImplications for Clinical Dichotic Listening Tests. *Journal of Speech and Hearing Disorders*, *48*, 135–139.

Speaks, C., Blecha, M. & Schilling, M. (1980). Contributions of monotic intelligibility to dichotic performance. *Ear and hearing*, *1*, 259–266.

Studdert-Kennedy, M., Shankweiler, D. & Schulman, S. (1970). Opposed effects of a delayed channel on perception of dichotically and monotically presented CV syllables. *The Journal of the Acoustical Society of America*, *48*, 599–602.

Takio, F., Koivisto, M., Jokiranta, L., Rashid, F., Kallio, J., Tuominen, T. *et al*. (2009). The effect of age on attentional modulation in Dichotic listening. *Developmental Neuropsychology*, *34*, 225–239.

Tallus, J., Hugdahl, K., Alho, K., Medvedev, S. & Hämäläinen, H. (2007). Interaural intensity difference and ear advantage in listening to dichotic consonant–vowel syllable pairs. *Brain Research*, *1185*, 195–200.

Tanaka, S., Kanzaki, R., Yoshibayashi, M., Kamiya, T. & Sugishita, M. (1999). Dichotic listening in patients with situs inversus: brain asymmetry and situs asymmetry. *Neuropsychologia*, *37*, 869–874.

Tervaniemi, M. & Hugdahl, K. (2003). Lateralization of auditory-cortex functions. *Brain Research Reviews*, *43*, 231–246.

Thomsen, T., Specht, K., Rimol, L. M., Hammar, A., Nyttingnes, J., Ersland, L. & Hugdahl, K. (2004). Brain localization of attentional control in different age groups by combining functional and structural MRI. *Neuroimage*, *22*, 912–919.

Van der Haegen, L., Westerhausen, R., Hugdahl, K. & Brysbaert, M. (2013). Speech dominance is a better predictor of functional brain asymmetry than handedness: A combined fMRI word generation and behavioral dichotic listening study. *Neuropsychologia*, *51*, 91–97.

Voyer, D. (2011). Sex differences in dichotic listening. *Brain and Cognition*, *76* 245–255.

Voyer, D. & Flight, J. (2001). Gender differences in laterality on a dichotic task: The influence of report strategies. *Cortex*, *37*, 345–362.

Voyer, D. & Techentin, C. (2009). Dichotic listening with consonant-vowel pairs: The role of place of articulation and stimulus dominance. *Journal of Phonetics*, *37*, 162–172.

Westerhausen, R., Bless, J. J. & Kompus, K. (2015). Behavioral laterality and aging: The free-recall dichotic-listening right-ear advantage increases with age. *Developmental Neuropsychology*, *40*, 313–327.

Westerhausen, R., Bless, J. J., Passow, S., Kompus, K. & Hugdahl, K. (2015). Cognitive control of speech perception across the lifespan: A large-scale cross-sectional dichotic listening study. *Developmental psychology*, *51*, 806–815.

Westerhausen, R., Helland, T., Ofte, S. & Hugdahl, K. (2010). A longitudinal study of the effect of voicing on the dichotic listening ear advantage in boys and girls at age 5 to 8. *Developmental Neuropsychology*, *35*, 752–761.

Westerhausen, R., Moosmann, M., Alho, K., Belsby, S. O., Hämäläinen, H., Medvedev, S. *et al*. (2010). Identification of attention and cognitive control networks in a parametric auditory fMRI study. *Neuropsychologia*, *48*, 2075–2081.

Westerhausen, R., Passow, S. & Kompus, K. (2013). Reactive cognitive-control processes in free-report consonant-vowel dichotic listening. *Brain and Cognition*, *83*, 288–296.

Westerhausen, R., Põldver, N., Naar, R., Radziun, D., Kaarep, M. S. & Kreegipuu, K. *et al*. (2017). Effect of voicing on perceptual auditory laterality in Estonian and Norwegian native speakers. *Applied Psycholinguistics*, https://doi.org/10.1017/S0142716417000170.

Westerhausen, R., Woerner, W., Kreuder, F., Schweiger, E., Hugdahl, K. & Wittling, W. (2006). The role of the corpus callosum in dichotic listening: a combined morphological and diffusion tensor imaging study. *Neuropsychology*, *20*, 272–279.

Wexler, B. E. (1988). Dichotic presentation as a method for single hemisphere stimulation studies. In K. Hugdahl (Ed.), *Handbook of dichotic listening: Theory, methods, and research* (pp. 85–115). Chichester: Wiley & Sons.

Wexler, B. E. & Halwes, T. (1983). Increasing the power of dichotic methods: The fused rhymed words test. *Neuropsychologia*, *21*, 59–66.

Wood, S., Hiscock, M. & Widrig, M. (2000). Selective attention fails to alter the dichotic listening lag effect: Evidence that the lag effect is preattentional. *Brain and Language*, *71*, 373–390.

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