# Sensibilité directionnelle de la sonie pour des bruits et des sons familiers

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# INTERINDIVIDUAL DIFFERENCES IN DIRECTIONAL LOUDNESS SENSITIVITY

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In memory of Jean-Claude Risset

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## 1. INTRODUCTION

* Binaural loudness in free field depends on the azimuthal and vertical positions of the sound source relative to the listener *(Sivonen and Ellermeier, 2006 ; Sivonen, 2007 ; Vannier, 2015)*.
* **Directional Loudness Sensitivity (DLS)** is the difference in level between a frontal (reference) and a non-frontal (test) position of the sound source at the point of subjective equality (PSE) in loudness.
* While the level of the sound source at the theoretical center of the head is constant in DLS measurements, the level at the entrance of the ear canals depends on source position, as a result of the direction-dependent signal filtering by the Head Relative Transfert Functions (HRTFs).
* Previous studies reported **large interindividual differences in DLS**, which were not completely explained by individual differences in HRTFs nor by differences in loudness functions (*Vannier, 2015*).
* It has been proposed that **loudness constancy** could possibly explain why some listeners show little or no DLS *(Sivonen and Ellermeier; 2006)*.

## 2.OBJECTIVES

* **Assess interindividual differences in DLS** within a large listeners sample and for various source positions.
* **Test broadband noise** in free field vs narrow-band used in the literature (except in *Sivonen, 2007*, using binaural synthesis).
* **Test the loudness constancy hypothesis**.

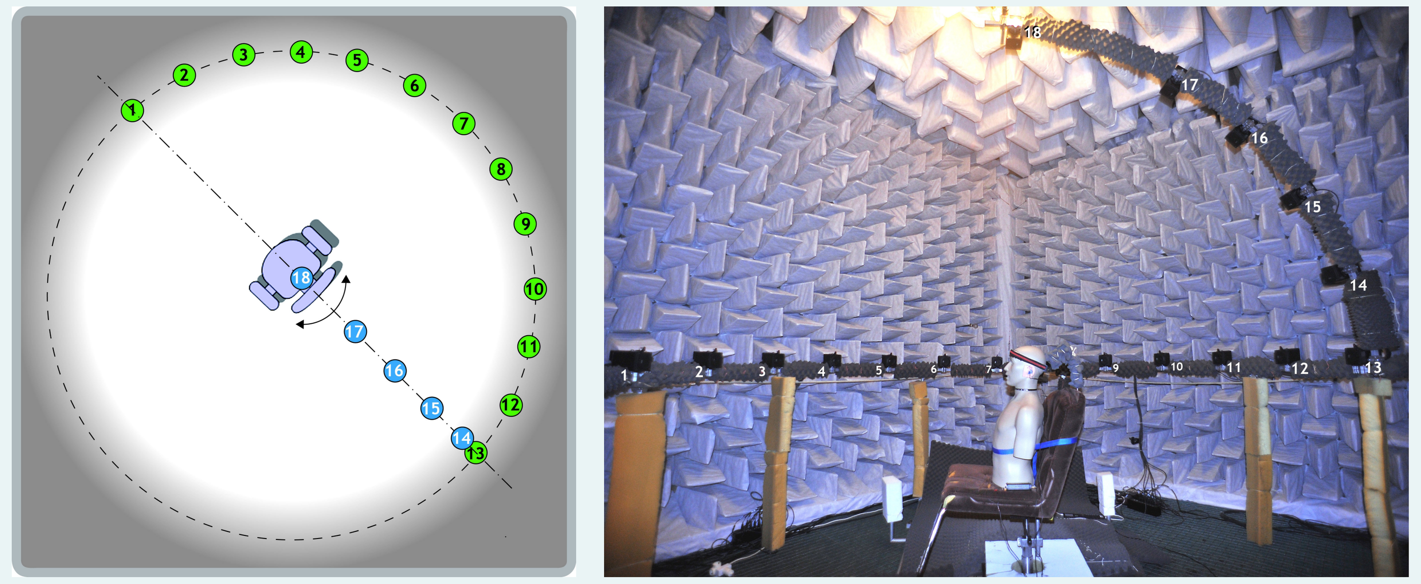


Figure 1. Schematic view and picture of the experimental set-up.

## 3. APPARATUS

* Free field listening (anechoic room), 13 horizontal (spaced 15° apart) and 5 vertical loudspeakers (15, 30, 45, 60 and 90°) at 2m each from the center of the head (Fig. 1).
* Listener seated on rotating chair face to 1 of the 13 horizontal loudspeakers.
* Head supported by a headrest and maintained by a headband with the entrance of listener's ear canals aligned with the center of horizontal loudspeakers.
* => 66 possible Test positions of the source in the right upper part of the listener's space.

## 4. METHOD

* **2AFC interleaved procedure:** Pair of sounds, 1 from the frontal REFERENCE position with a fixed level of 65 dB SPL, 1 from one of 66 possible TEST positions with variable level. Task: which one was louder?
* Two starting levels of the test sound: 8 dB above or below the reference level.
* Adapting rules: 2down-1up (for starting level = 8 dB above) or 1down-2up (for starting level = 8 dB below).
* Level increment/decrement : 4 dB until the $4^{th}$ reversal and 1 dB until the $10^{th}$ reversal.
* Interleaved procedure: 1 bloc = 8-10 runs = 4-5 TEST positions * 2 starting levels.
* **"Partial DLS"** (for 1 run) = **[Reference - Test] level** averaged across the last 6 reversals.
* **DLS at the PSE** (for 1 TEST position) = Partial DLS **averaged across 2 starting levels x 2 repetitions.**

## 5.EXPERIMENT 1: WHITE NOISE

* **Stimulus**: White Noise (160-17 000 Hz) with duration of 1 sec.
* **Listeners:** 25 naive young adults with normal hearing, equally distributed in gender and musical experience (8 in *Sivonen and Ellermeier, 2006;* 17 in *Vannier, 2015*).
* **At-ear levels:** Measured with blocked ear canals for all loudpeaker positions in 23 of the 25 listeners.

### Results

* **DLS mainly < 0:** Test sounds mostly perceived less loud than frontal Reference (Fig. 2 and 3).
* Interindividual **differences** in **DLS sign and magnitude** are large and increase with azimuth (Fig. 2).
* Effect of azimuth on DLS decreases as elevation increases (Fig. 3).

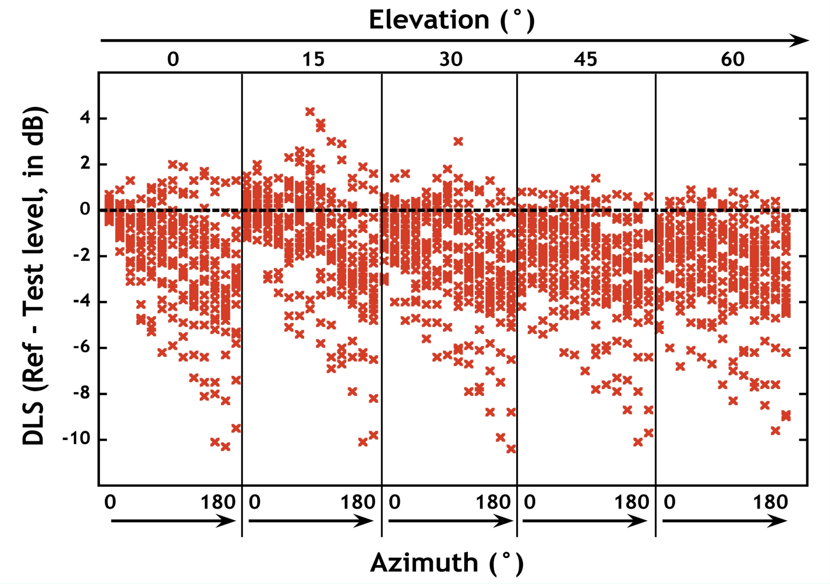



Figure 2. Distributions of the 25 individual values of DLS obtained by elevation (5) and azimuth (13 from 0 to 180°). Each symbol represents the individual mean of 4 partial DLS estimates (2 starting levels * 2 repetitions).

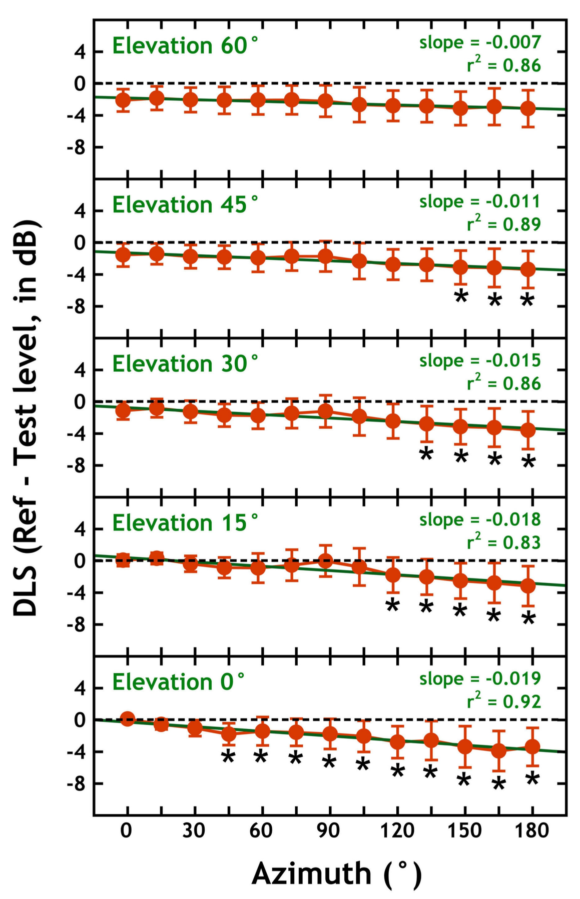
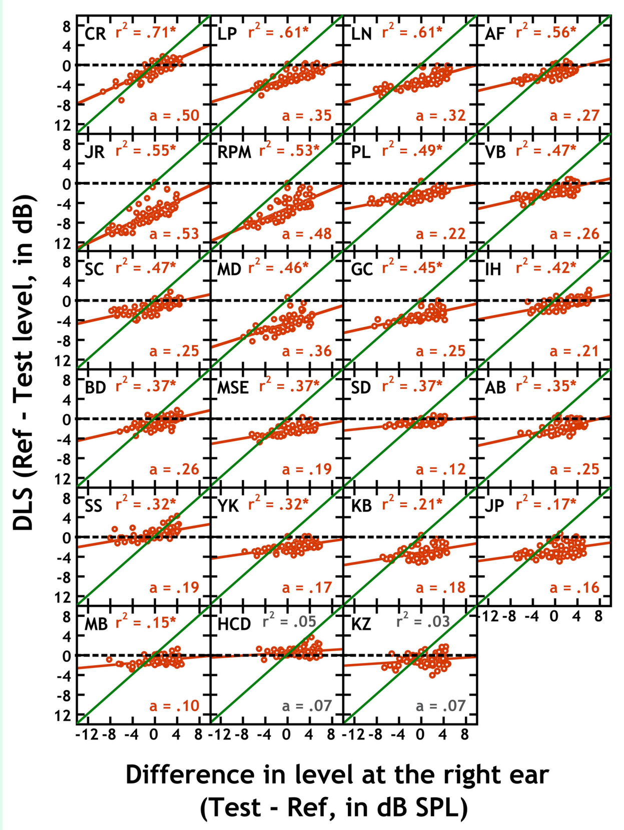



Figure 3. DLS averaged across the 25 listeners as a function of azimuth for each elevation (from bottom to top). Bars represent +/- 1 standard deviation. The data were fitted with linear regressions whose slope and $r^2$ are reported in upper right corners. Stars show the DLS that significantly differ from that obtained for the 0°-azimuth at the same elevation according to post-hoc Scheffé tests.

* **Difference** (Test - Reference) **in level at the right ear** significantly **correlated with DLS**, and relationship fitted with robust linear regression, for 21/23 listeners when all test positions are included (Fig. 4).
* **Slope** of linear fit always **< 1:** DLS varies less than the level difference at the right ear (Fig. 4).
* Large individual **differences** in **slope** (range = 0.07 to 0.50) and in **part of the variance in DLS accounted for by difference in at-ear level (r2**; range = 3 to 71%), see values in Fig. 4.
* Linear relationships are often robust for low elevations but weaken as elevation increases (Table 1).

Figure 4. Individual DLS against difference in level at the right ear. Each panel is for a different listener. Each symbol is for a different position (N = 66). The data were fitted with linear regressions whose r2 and slope are reported (in red for significant correlations, in grey otherwise). The green diagonal represents perfect relationship (slope = 1). The at ear measurement were done on 23 listerners.




| Listener | $r^2$ of the relationship between DLS and Difference in level at the right ear for each elevation | | | | |
|---|---|---|---|---|---|
| | 0° * | 15° | 30° | 45° | 60° |
| CR | 0.90 | 0.80 | 0.76 | 0.59 | 0.48 |
| LN | 0.88 | 0.70 | 0.66 | 0.41 | 0.42 |
| HCD | 0.81 | 0.28 | 0.64 | 0.11 | 0.26 |
| SC | 0.81 | 0.63 | 0.56 | 0.36 | 0.02 |
| GC | 0.80 | 0.52 | 0.39 | 0.28 | 0.40 |
| JR | 0.72 | 0.59 | 0.59 | 0.48 | 0.25 |
| LP | 0.70 | 0.66 | 0.69 | 0.60 | 0.18 |
| MD | 0.69 | 0.49 | 0.65 | 0.58 | 0.33 |
| VB | 0.64 | 0.49 | 0.41 | 0.61 | 0.41 |
| RPM | 0.62 | 0.48 | 0.57 | 0.59 | 0.52 |
| SS | 0.57 | 0.12 | 0.13 | 0.73 | 0.44 |
| AF | 0.56 | 0.63 | 0.72 | 0.54 | 0.37 |
| PL | 0.49 | 0.53 | 0.46 | 0.40 | 0.45 |
| MSE | 0.49 | 0.39 | 0.36 | 0.41 | 0.20 |
| SD | 0.47 | 0.49 | 0.33 | 0.19 | 0.04 |
| YK | 0.42 | 0.45 | 0.36 | 0.52 | 0.37 |
| AB | 0.39 | 0.54 | 0.46 | 0.49 | 0.35 |
| BD | 0.35 | 0.81 | 0.56 | 0.17 | 0.09 |
| KB | 0.33 | 0.33 | 0.11 | 0.16 | 0.10 |
| KZ | 0.25 | 0.19 | 0.12 | 0.00 | 0.37 |
| JP | 0.22 | 0.36 | 0.28 | 0.08 | 0.01 |
| IH | 0.16 | 0.07 | 0.00 | 0.00 | 0.17 |
| MB | 0.08 | 0.29 | 0.10 | 0.22 | 0.26 |

** azimuth 0° excluded*

Table 1. Individual r2 of the relationship between DLS and difference in level at the right ear for each elevation. Red values show significant relationships.

## Discussion

* DLS magnitude larger for white noise than for 1/3-oct-band or pink noise (*Sivonen and Ellermeier, 2006; Vannier, 2015; Sivonen, 2007*).
* Individual DLS are only partially accounted for by differences in at-ear level, in agreement with previous studies. The degree of contribution of these level differences strongly varies between listeners.
* Hypothesis: Are listeners with smaller DLS more sensitive to loudness constancy?
* *Florentine and Epstein (2012)*: Binaural loudness constancy is stronger with familiar sounds.
* Hypothesis for Experiment 2: Is the DLS reduced if familiar sounds are used?

## 6.EXPERIMENT 2: "NATURAL" SOUNDS AND FILTERED WHITE NOISE

* **Stimuli**: Organ (1.6 sec), Applause (1sec) + Filtered white noise (1 sec), see spectrum in Fig. 5.
* **Listeners:** 9 with large DLS in Experiment 1 for 7 Test positions selected from Experiment 1 (Table 2).

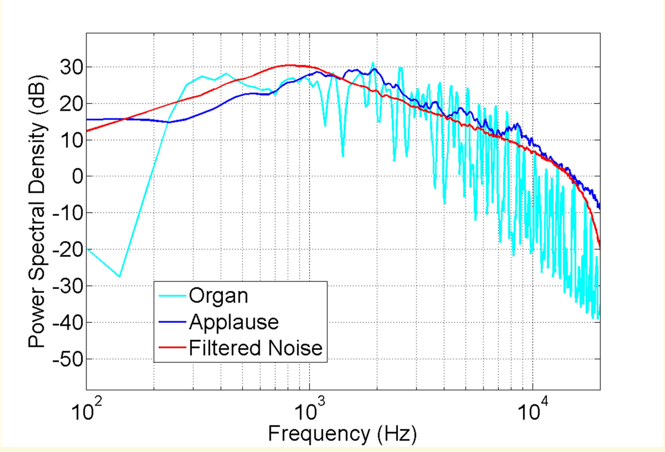



Figure 5. Power Spectral density of the three signals used in Experiment 2 (organ, applause, filtered noise).

Indivual DLS obtained in Experiment 1

| Listener | by Test position (azimuth, elevation): 45, 0 | 45, 30 | 45, 60 | 90, 0 | 120, 0 | 150, 0 | 180, 0 | averaged across positions |
|---|---|---|---|---|---|---|---|---|
| JR | -4.8 | -4.7 | -6.1 | -5.9 | -7.3 | -10.1 | -9.5 | -6.9 |
| MD | -4.7 | -3.4 | -4.1 | -4.2 | -6.3 | -7.5 | -7.4 | -5.4 |
| RPM | -4.1 | -3.9 | -4.9 | -4.7 | -3.8 | -8.0 | -7.4 | -5.3 |
| GC | -3.1 | -4.0 | -3.8 | -2.2 | -3.4 | -4.8 | -5.3 | -3.8 |
| KB | -3.1 | -3.2 | -2.9 | -3.4 | -5.0 | -4.7 | -4.1 | -3.8 |
| LN | -2.5 | -1.6 | -4.1 | -2.3 | -4.2 | -5.2 | -5.8 | -3.6 |
| PL | -1.3 | -2.6 | -3.1 | -3.2 | -3.5 | -3.1 | -3.1 | -2.8 |
| YK | -2.2 | -1.9 | -1.3 | -2.3 | -3.7 | -3.6 | -3.0 | -2.6 |
| AB | -1.4 | -0.4 | -0.7 | -1.5 | -3.6 | -3.4 | -2.9 | -2.0 |

Table 2. Test positions (in blue) and listeners (in red) investigated in Experiment 2 along with the DLS obtained in Experiment 1 with the white noise (in black).

### Results and Discussion

* DLS smaller for familiar sounds (organ and applause) than for white noise (Fig. 6).
* DLS for filtered noise (spectral envelop similar to applause, see Fig. 5) smaller than for white noise but identical to familiar sounds (Fig. 6).
* => Differences in DLS between familiar sounds and white noise likely result from differences in spectral envelop.
* => Energy in the high-frequency spectrum of the stimulus is important in DLS judgments.
* => Experiment 2 provided no explanation about the interindividual differences in DLS observed in Experiment 1 and in past studies.

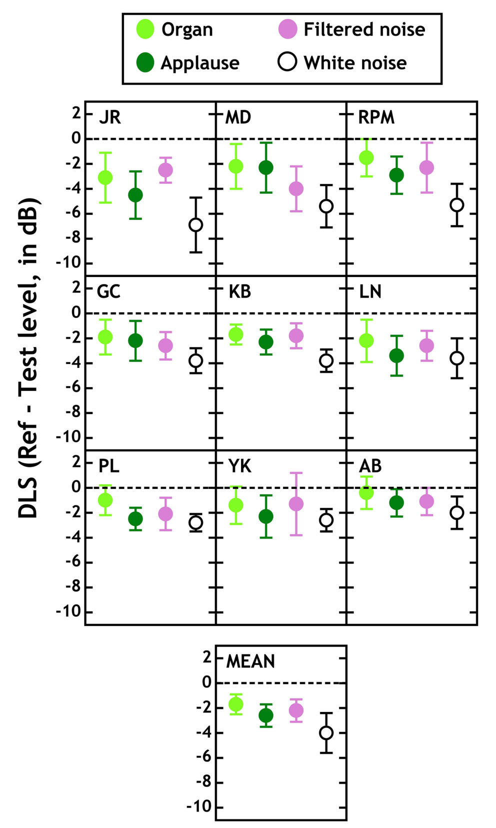



Figure 6. Individual and mean DLS obtained in Experiment 2 with each different stimulus (Organ, Applause and Filtered noise = dark green, light green and pink circles, respectively) along with those obtained in Experiment 1 with the white noise (white circles).

## 6.CONCLUSION AND PERSPECTIVES

* Large DLS is observed for broadband noise and is only partially accounted for by at-ear levels.
* Individual computation of **binaural gain** and of **at-ear level in the high-frequency part of the signal** are in process so as to further identify factors that may have contributed to our perceptual result.
* Further research is needed to evaluate the possible contribution of loudness constancy to DLS judgments.

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Vannier (2015). Sonie de champs acoustiques stationnaires en situation d'écoute dichotique. PhD Thesis, Institut National des Sciences Appliquées, Lyon, France.
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