

Modulation frequency as a cue for auditory speed perception

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Supplementary information

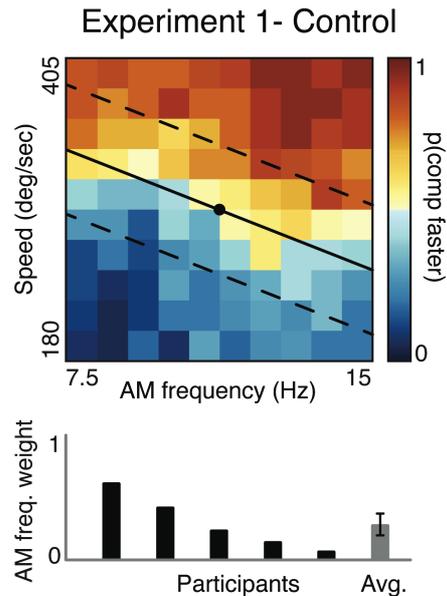


Figure S1. Results of the control experiment (see Figure 1). Participants were presented with the same stimuli and task of Experiment 1 and were explicitly instructed to actively ignore the information provided by the AM-frequency. The upper panel shows the results from all participants aggregated. The x-axis represents AM-frequency, while the y-axis represents speed. The color of each cell represents the probability of responding “comparison faster”, with warmer colors representing higher probabilities. The dot at the center shows the standard stimulus. The solid line represents the line of subjective equality (LSE, i.e. the combination of speed and AM-frequency at which the standard and comparison stimuli appear equally fast), while the dashed lines represent 25% and 75% probabilities of responding “comparison faster”. The lower panel shows the scaled weight of the AM-frequency for each participant (black bars), and the average (grey bar). Values higher than zero indicate that the participant relies on the information provided by the AM-frequency to solve the task. The bar represents the standard error of the mean.

Supplementary data analyses

For each combination of speed and AM-frequency, we calculated the proportion of “comparison faster” responses. Given that we assessed perceived speed as a function of two independent variables (speed and AM-frequency), psychophysical data can be represented as psychometric surfaces (instead of psychometric curves, which are better suited to represent perception as a function of a single independent variable, see [S1] and [S2] for a similar approach). Therefore, the probability of responding “comparison faster” as a function of speed (Y-axis) and AM-frequency (X-axis) is plotted in Figure 1 of the main text and in Figure S1 with warmer colors representing higher probabilities. Such a surface can be read vertically (i.e., column-wise) and horizontally (i.e., row-wise). The X-axis

represents the 10 AM-frequencies used in the experiments, while the Y-axis represents each of the 10 speed values. Thus, reading each column vertically allows appreciating the effect of speed for each single AM-frequency value. Likewise, reading each row horizontally allows seeing the effect of the different AM-frequencies for each speed.

Data were analyzed by fitting the probability of responding “comparison faster” with a generalized linear mixed model (GLMM [S3-S4]). Traditional approaches in psychophysics generally apply two-level analyses: first, the parameters of the psychometric functions (i.e., the point-or in our case the line-of subjective equality and the just noticeable difference) are estimated for each participant and condition, and then a second (inferential) analysis (e.g., ANOVAs, t-tests, etc.) is performed on such estimated parameters [S4]. Compared to two level analyses, the main advantage of the GLMM is that the variance is divided into a fixed and a random component. The fixed component tests the effect of the independent variables manipulated in the study (in our case the AM-frequency and the speed), while the random effect accounts for the heterogeneity among different participants. Thus, the GLMM allows for a joint analysis of clustered categorical data at both the population and individual levels, while dramatically reducing the number of fitted parameters. Moreover, such a model allows for an easy assessment of the goodness of fit, and thus the selection of the best statistical model (for instance, via the Akaike Information Criterion [S5], see main text).

To further explore the inter-subject variability (i.e., to investigate the strength of the influence of AM-frequency on speed perception in each participant), we run a second analysis at the individual level, beside group-level analyses. For each participant we fitted the same generalized linear model used for the group analysis, but applied at the individual level (i.e., for each participant we fitted the probability of responding “comparison faster”, with speed and AM-frequency as fixed effects, and by applying a probit link function). Clearly, this implies dropping the random effects, given that such analysis is performed at the single participant level. For each participant, the linear coefficients of AM-frequency and speed ($\beta_{AM\ freq}$ and β_{Speed} , respectively) were used to calculate the weight given by each participant to the AM-frequency ($\omega_{AM\ freq}$), by dividing the linear coefficient of the AM-frequency by the sum of the two linear coefficients (i.e., $\omega_{AM\ freq} = \beta_{AM\ freq} / (\beta_{AM\ freq} + \beta_{Speed})$). In other words, the AM-frequency coefficient is normalized based on the sum of the AM-frequency and speed coefficients, with values higher than 0 indicating that the participant relies—at least in part—on the AM-frequency cue to estimate the speed of moving sounds.

Supplementary references

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- S5. Akaike H. 1973. Information theory and an extension of maximum likelihood principle. In: Petrov BN and Csáki FF (Eds.), *Proceedings of the 2nd International Symposium on Information Theory, Budapest, Hungary*: Akadémiai Kiadó. p267–281.