# Negative Masking and the Units Problem in Audition

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**Daniel Shepherd**
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# ABSTRACT

For humans with adequately operating auditory systems the arrival of acoustic waves to the ear and the subsequent displacement of the tympanic membrane gives rise to the sensations and perceptions commonly known as hearing. One aspect of hearing is loudness, to which the field of psychophysics attempts to ascribe a physical correlate intrinsic to the incoming acoustic wave. For over 50 years psychophysicists have attempted to explicitly define the just-noticeable difference (JND) for loudness: the smallest amount, in physical units, that a stimulus needs to be increased to produce a perceptual difference. A review of the literature suggests that the problem in defining the JND is twofold. Firstly there is the measurement problem, with specific weighting on two competing measures of the JND: the level difference ($\Delta L$) vs. the Weber fraction ($\Delta X/X$). Deciding between the two measures has proved difficult: within the natural operating range of the auditory system the two measures are directly proportional to one another. Secondly there is the units problem, concerned with the physical unit in which the measure should be expressed. The units problem exists because it has yet to be determined which property of the acoustic stimulus accounts for the perception of loudness. There are several candidates: acoustic pressure ($p$); acoustic intensity ($I$); acoustic power ($P$), and acoustic energy ($E$). The necessity of determining which, if any, is the proper measure of the stimulus is forced by the phenomenon of negative masking, which is manifest when the stimulus is expressed in terms of pressure. Selecting among the various quantities is complicated by the fact that the four measures are linearly related and constitute a direct transformation of one another. In the laboratory context existing techniques can produce stimuli that severely challenge the auditory system and break down the proportionality exhibited by the various candidate JNDs. These techniques however require greater scrutiny and development. Buus and Florentine (1991) have proposed that the JND measure (i.e., $\Delta p/p$, $\Delta I/I$, $\Delta L$) that realizes a linear relationship with the detectability index, $d'$, is the correct measure. The proportionality of the measures makes such comparison complicated, and threshold values need to be inflated by manipulating stimulus parameters in order to exceed the range of proportionality. This is accomplished using short duration (10-ms) sinusoids and low level masking noise. The experimental program commenced with a series of negative masking experiments to ensure the phenomenon is still relevant to short duration stimuli. Laming's (1986) sensory analytical model, which assumes the auditory system responds to pressure, provided an acceptable fit to these data. Experiments on the pedestal effect, a related phenomenon, generated fixed-increment functions that could be compared to the masking functions generated from the negative masking data. A consistent relationship between the two was found when the stimuli were expressed in units of pressure. Attention then turned to improving the studies undertaken by Buus and Florentine (1991) to determine what the proper measure of the JND should be. A series of experiments, differentiated by stimulus conditions, suggest a JND measure expressed in pressure units had the most linear relationship with *d'*. The results argue for pressure as the correct measure of the stimulus, and $\Delta p/p$ to be the most qualified representative of the JND.

**KEYWORDS:** psychophysics, sinusoid, pressure, intensity, difference threshold, short-duration stimuli, negative masking, pedestal effect, psychometric function, masking function, fixed-increment function, *d'*

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Oscar Wilde

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