When exposed to sounds, would perceived loudness not be affected by social context?

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Introduction.

Becoming annoyed by environmental noise is not only determined by the acoustical characteristics of exposure (e.g., average sound pressure levels), but by non acoustical factors as well, such as by the predictability of the sound event. Although there clearly is a social aspect to several of these factors (e.g., predictability usually requires the direct or indirect provision of information by someone), this social aspect of noise annoyance has not received much social scientific attention [cf. 1,2,3]. Maris, Stallen, Vermunt and Steensma [4,5] have demonstrated experimentally that a negative relationship between the producer and the receiver of environmental sounds can *cause* the receiver to be more annoyed by the sound. Similarly, a positive relationship between the producer and the receiver can *cause* the receiver to be less annoyed by the sound. The key finding was that being exposed to aircraft noise in an unfair way generally increases aircraft noise annoyance. By contrast, fair ways were shown to lead to further decreases in noise annoyance at relatively higher levels of exposure. These findings raise the question how much earlier the social context of noise exposure may already be influencing the auditory processing of environmental noise. An arguably earlier response to sound exposure is its perceived loudness. This immediate judgment of how loud a particular sound is qualifies for our study for a number of reasons.[1]

At first sight, perceived loudness is less subject to contextual influences of social nature as it is more directly related to sensation than the more comprehensive and conscious response of noise annoyance. Extensive psychophysical research in laboratory settings has demonstrated that the perceived (or, as it is sometimes called, apparent) loudness of pure tones is consistently and quite strongly related to sound intensity. The perceived loudness of more complex sounds, such as nearly all environmental sounds, also appears well to be generally predictable upon the basis of the relatively highest sound pressure levels present in the signal (e.g., the L_{10} : the level exceeded 10% of the time). However, there is considerable between-subject variation in this loudness response, equal if not more than the variation in mean annoyance scores at various sound pressure levels [6]. This raises questions about the ecological validity of loudness estimates based on laboratory observations. As we will show, the variability of loudness judgments has not received much interest from psychologists, and neither public nor political need is likely to alter this situation. When the general public is asked for salient distinctions between various sounds in ecological settings, loudness is not among the solicited semantic categories. Guastavino [7] asked citizens to name every possible category into which they could classify two or more of sixteen urban environmental sounds. None of the large number of categories listed reflected distinctions being made in terms of 'loudness'. Furthermore, the psychophysicists´ approach has a strong political standing. E.g., in most legal standards on tolerable levels of environmental noise exposure, the (average) sound pressure level is the most significant measure upon which regulatory action need (or need not) be taken. This simplification of quantifiable auditory experiences to SPL only has strong moral and social implications indeed: by identifying SPLs as the essential determinants, one need not any more address the noise regulation itself as a potentially significant moderator of the intensity-loudness relationships.

Especially during the last two decades, the advent of modern techniques have enabled psychologist to more directly observe the earliest sensory and neurobiological processes, and thereby to study the origins of perceptual variability. For example, the way an individual's prior mental state influences the selection of auditory information for further processing can now be indexed by the time course of brain processes that respond to sound. Long-latency brain responses that can begin as early as 60 ms after stimulus onset [8; for a review, see 9] have been shown to vary with endogenous influences. That is, their amplitudes are not exclusively determined by the processing of the exogenous stimulation. Woldorff, Hansen, & Hillyard [10] even offer evidence of influences of endogenous selective auditory attention upon middle-latency brain responses (20-50 ms post stimulus onset). With the prior induction of a negative affective state, it has been possible to manipulate even the early-latency brain responses, which occur within the first 10 ms of the presentation of sound [11].[2]

Social factors typically carry strong affective information, such as self esteem derived from group membership or confidence based on timely information provision. In nearly all psychological journals, recent research is reported that in some way demonstrates the decisive role of affect in the selection of behavioral responses. This role of affect either concerns the affective value of the stimuli or the affective state of the individual. Therefore, given the variability of loudness judgments, on the one hand, and, on the other hand, the significance of affect as moderator of attentional processes, it would be a worthwhile project to investigate how environmental sounds in their contexts are attended to, particularly if they carry negative connotations [cf. 13]. As worthwhile is to determine how this influence of context could moderate perceived loudness. It is the purpose of this paper to describe the general scientific background for such a project. We will do so specifically in Section 2 by presenting the major ways in which moderators of the intensity-loudness relationship have been studied. In Section 1 we will first offer some more general remarks on contextuality and its relevance to interpretations of the intensity-loudness relationship.

1. Loudness in context.

Contextuality is a major subject in a variety of disciplines, ranging from philosophy (of science) and linguistics to social and cultural theory. With regard to contextuality, these disciplines are generally interested in understanding how the *meaning* of a particular behavior Y is dependent upon the context of that behavior. For example, let Y be the speech act 'luid' (Dutch). Does it convey the same information as 'loud' (English) or 'laut' (German)? If the various adjectives have specific and context-bound connotations, then their use will automatically generate a particular set of expectations. For example, the Dutch 'luidheid' (literal translation: loudness) has a technical

[1] Thus, our primary interest is not the study of the (social) determination of thresholds, or JNDs.

[2] There is even evidence of a top-down influence of attention right down to the outer hair cells. See [12].

analytical connotation; in ordinary communication the word ‘hard’ would be the common term. Therefore, if one wants to establish (or observe effects of) communicative interaction, then the use of the term ‘luid’ *per se* will create cognitive conflict and, perhaps, lead to inappropriate behavioral responses. It goes without saying that behavior that is considered context from one point of view may be considered Y-behavior from another point of view at the same time. In the context of this paper contextuality refers to the moderation of the relationship X →Y by Z with Z being the contextual factor.[3] Specifically, with X being the intensity of the auditory stimulus and Y the perceived loudness, the interest is in social and affective variables Z that may determine the strength and/or nature of the relationship X →Y .

Perceived loudness is typically measured directly by numbers, as by methods of magnitude estimation or production; indirect scaling techniques by cross-modal judgments have generally revealed the same relationship between stimulus magnitude and response intensity, both in the case of loudness as well as regarding other modalities, like brightness, smell, taste, force of handgrip or electric shock. If applied to average ratings these relationships are quite well described by Stanley Stevens’ power law.[4] According to Stevens, the exponent *c* of the power function is determined by basic biophysical properties of the sense organs (“transducers”); contextual effects should be treated largely as biases in responding (e.g., leading respondent to change the labels that they apply to their perceptual events), but not as evidence of adaptations in the perceptual apparatus itself. However, the assumed uni-dimensional nature of the `transduction´ had been questioned nearly as early as Stevens’ groundbreaking work itself [see, e.g., 14]. In a more philosophical manner, it has been contested that a sensory experience, whilst changing in intensity with changes in the magnitude of the applied stimulus, remains a rather constant quality. This polarity in points of view has already been discussed in one of the first reviews of the various psychophysical scaling approaches [15]: “That [the subjects] judgment is based on more than the sensory input arising from a particular stimulus can hardly be doubted; that it interacts with the range of stimuli employed, the type of judgments called for, the past tasks to which [the subject] has been exposed, and other variables as well surely must be the case.”(p.244). Yet, this only means that the difficult task still is “to discover, or perhaps construct, relationships between independent variables and behavior that are invariant over reasonably wide ranges of experimental conditions.” (p.245). Since, this work has been conducted, a.o., by Luce [16]. On the basis of his experiments he concluded that "by introducing contexts such as background noise in loudness judgments, the shape of the magnitude estimation functions certainly deviates sharply from a power function" (p.73). Indeed, recent studies have shown that, for only about half of the respondents the power form may be a good approximation [17].

Besides the various studies of the appropriateness of Stevens’ scaling assumption two other lines of studies are relevant to this paper. Lawrence Marks c.s. have conducted a series of studies on the differential effects of stimulus context in sensory processing of predominantly simple sound stimuli (e.g., 18,19,20; see Section 2). Furthermore, an interesting line of interdisciplinary studies of the loudness of complex sounds has been initiated over the last years by Hugo Fastl c.s. By applying special digital techniques to individual sound events, they were able to spread the acoustic energy of the original sound signal in a way that made the event unrecognizable while retaining its loudness-time function. We will discuss the various studies on the intensity-loudness relationship under one of two headings, depending upon whether the moderators were primarily of physical (2.1.) or of psychological nature (2.2.).

2. Context in loudness.

Contextual effects in the perception of sensory stimuli takes many forms. One helpful distinction could be made between physical and psychological contextuality, even though there are many situations where this distinction will be difficult to apply unequivocally.[5] Physical contextuality refers to the various arrangements of physical stimuli, whether all of the same or of different modality, as they may determine sensory processing and perception. Psychological contextuality is at stake when the emphasis is on the simultaneous presence of stimuli of non-physical nature. Research interest in both types of contextuality has arisen about equally early [e.g., 21,22] but it has become much more voluminous for the physical category. Psychological studies of contextuality have been conducted more on visual than auditory processing. It follows that, when searching in the latter domain for studies on the particular subject of loudness judgments - as is the subject of this paper - there may not appear many.[6] Not a single study was found when the search was further restricted to studies on the moderating role of (social) affect in loudness judgment. Below, we will discuss the studies we have come across when conducting the less restrictive search.

2.1. Physical contextuality.

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[3] This relation is to be distinguished from the mediation relationship, i.e., when X is determined by Z, as in Z → X → Y. Here, Z is the straightforward determinant of X, and it would be but confusing to call Z the *context* and not the *cause* of X. In psycho-acoustics the term modulation is also used often, but indiscriminately-so in cases of mediation and moderation.

[4] The general form of the law is $\psi(I)=k.I^c$ where I is the magnitude of the physical stimulus, $\psi(I)$ is the psychophysical function relating to the subjective magnitude of the sensation evoked by the stimulus, c is an exponent that depends on the type of stimulation and k is a proportionality constant that depends on the type of stimulation and the units used. It replaced Fechner’s logarithmic law which had been, for almost 100 years, the only noteworthy hypothesis relating magnitude of sensation to stimulus intensity.

[5] From a modern cognitive science point of view, the distinction would rather be made between exogenous and endogenous causation.

[6] This restriction to loudness needs emphasis. It is theoretically distinct from other assessments of sounds, such as disturbance or annoyance. With the general interpretation of noise as unwanted sound there is no clear conceptual interpretation of ‘noisiness’[e.g., 23]; its standing is somewhere in between loud and annoying.

Physical contextuality appears in virtually every sensory modality tested [20]. Context can exist within one or between dimensions. An example of one-dimensional contextuality is, in the auditory domain, when a target sound is presented within a range of similar sounds with, on average, high SPL *versus* sounds with SPLs shifted, on average, to lower values. In such ´single shift´ situations differential effects are ascribed typically to response-based processes. Contextuality can also be bi-dimensional, or representing "dual shifts". For example, sounds can take on one of two frequencies, e.g., 500 and 2500 Hz, but with complementary mean intensities, such that the intensities at 500Hz are low (e.g., ranging from 35-70 dB) when those at 2500Hz are high (e.g., 55-90 dB), and *vice versa*. Under these conditions, shifting from one contextual set to another causes a shift in the relative loudness of stimuli at 500 and 2500 Hz, even when these sounds are of the same physical intensity [19]. This shift is in accordance with adaptation level theory [24] which postulates that, when volunteers are given subsets of qualitatively different stimuli such as sound frequencies in separate critical bands, loudness is judged at each frequency relative to its own or band-specific adaptation level. In general, stimuli processed through the channel that received the strongest contextual stimuli are perceived as relatively weaker than stimuli processed through other channels. Whereas the induction of this kind of differential context effects (DCE) seems to require the presentation of relatively high stimulus intensities, the functional characteristics of DCEs suggest that they arise automatically and reflect sensory changes induced at an early stage in perceptual processing. DCEs are relatively long lasting, a few brief stimuli being capable of effecting changes that last more than a minute [20]. Patsouras, Filippou and Fastl [25] repeatedly presented two sound events of a high speed train passages (9s with max. loudness 50 sone; 11s with 58 sone) randomly with six other train passages to a group of 9 subjects together with slides of the trains. The color of the high speed train was alternatively showed precisely as running at the time (grey with small red stripe) or (photo-shopped) completely green, yellow or red color; an additional 'sound only/no slide' presentation served as control condition. Whereas some subjects showed a strong influence whilst others showed nearly no impact, there also was the overall tendency for both the red-colored train and the original appearance to result in a higher estimated loudness, whereas the green-colored train seemed to reduce its perceived loudness. Böhm, Patsouras and Fastl [26] investigated whether the loudness of each of four train passings (duration 16s; respective sound intensities not reported) was judged differently when compared to judgments when volunteers were also exposed to visual information about the sound source: photo (static representation) or video (dynamic representation). Whereas the static information did not lead to significantly different loudness judgments, the presentation of video information led to average reductions in loudness of 5%. At the highest of the four sampled train passing intensities, a reduction of 10% was observed.

2.2. Psychological contextuality.

To the best of our knowledge, Aylor and Marks [18] were the first to draw attention to the subjective determinants of the perception of loudness. In a well controlled field experiment they found that sounds (white noises of 3 s duration; various sound pressure levels in range 40 to 100 dB) from behind each of two barriers to sound (a tile wall, a hedge) both of which completely shielded the sound sources from view were perceived as equally loud although they had clearly different transmission losses (-17dB and -0.5dB, respectively). Except for the highest SPL levels, sounds from behind a slat fence (also -0.5 dB) or passing through no barrier at all (thus, transmitted with partial and full visibility of the source, respectively) were judged as less loud than the same sounds if heard from behind the hedge. The investigators were puzzled about the explanation: "When a sound source is occluded visually, one expects its loudness to be diminished. Sounds coming from behind barriers appear surprisingly loud, and hence are overestimated relative to sounds coming from open spaces."(p.400). A more consistent explanation could be that both tile wall and hedge alert the mind (and make salient the need for protection) while they do not allow any view on the origin of the (negatively appraised) sound. In the case of the slat fence this psychological stress is less. Using environmental sounds of similar duration (seconds rather than minutes or more) Hellbrück, Fastl and Keller [27] tried to manipulate the degree of sound recognition. They cut a 20 minute traffic noise scene (gated railway-road traffic crossing; Laeq = 76.3 dB) into 80 pieces of 15 seconds each. Each 15 s sound event was presented both in its original (S_{orig}) and "distorted" unrecognizable form (S_{rearr}).[7] On a fine graded verbal loudness scale, one group of randomly assigned subjects rated the perceived loudness of the 80 S_{orig}. Another group rated the 80 S_{rearr}. Except for S_{orig} of relatively high intensity, S_{orig} was generally perceived as louder than S_{rearr}. Fastl, Menzel and Krause [28] had one group of subjects compare each of 36 environmental sounds (duration: 3 s; 18 S_{orig}, 18 S_{rearr}) to a modulus environmental sound. Here, S_{orig} was judged significantly louder than S_{rearr} only 3 times, whereas a not significant difference -albeit in the same direction- was reported for 10 cases; S_{orig} and S_{rearr} were perceived equally loud once.[8] Whether the effect is due to "sharpened attention" in cases when sources cannot (easily) be recognized, as Hellbrück et al. suggest, or due to related forms of arousal, is unclear. The above results warrant further study as they obviously suggest the hypothesis that the successful identification of a sound tends to positively moderate the intensity-loudness relationship.

Maris et al. [4,5] had participants exposed to environmental sounds (aircraft noise; 50 and 70 dB(A) Laeq) for 15 minutes when performing a difficult mental task. While exposing the participants to the noise, the experimenter behaved in a procedurally fair or neutral [4] or unfair and neutral [5] way (a 2x2 Analysis of Variance (ANOVA) design, random assignment of subjects). They found that noise annoyance when treated (un)fairly was significantly different from the neutral treatment. Loudness judgments were collected on a 9 point graphical scale, which was part of a larger questionnaire to be filled in after 15 minutes. In both studies the ANOVAs of the loudness judgments

[7] Essentially, the sounds S_{orig} are analyzed by FTT and, after spectral broadening, re-synthesized by IFTT to produce S_{rearr}.

[8] In 4 out of the 18 events S_{rearr} tended to be judged as louder than S_{orig}; these judgments all seem to have occurred at the relatively highest Laeq levels of their study.

indicated no main effect of procedure on loudness and no interaction effect of procedure and sound intensity.

3. Concluding remarks.

The various studies presented above show that, over a wide range of sound intensities, the perceived loudness of the stimulus is not determined by its physical characteristics only. Except perhaps for intensities in the highest regions, there is additional determination by other sensory and/or cognitive information. Moderation of the intensity-loudness relationship occurs apparently with at least small to modest effects, and it seems to occur at every level of attentional functioning: alerting (that is, when tonically maintaining the alert state and phasically responding to a warning signal); orienting (when selecting endogenous and exogenous information upon multiple sensory inputs) and executive control (when performing more complex operations of monitoring and comparison making, and of resolving conflicts between behavioural intentions) [cf. 29]. This threefold functional distinction is a helpful tool in the assessment of various reported loudness moderating influences.[9]

For example, some DCE findings indicating channel specific response readiness may be interpreted as resulting from differential *alertness*. A similar adaptation process could underlie the increased loudness response to sounds, which occurs when those sounds are generated by an expressly red- rather than a neutrally-colored source [25]. The observation by Guastavino, Katz, Polack, Levitin and Dubois [30] that stereophonic presentation of various outdoor city sounds, when compared to ambisonic presentation (judged as more true-to-nature than stereophonic sound) solicits less evaluative responses to the background noises present in the sounds, may also fit such differential channel sensitivity. It would be interesting to investigate how loudness responses to environmental sounds could relate to basic alertness mechanisms at the brain stem level [31,11]. Other studies show *orienting* effects. One of the earliest investigations of loudness moderation demonstrated how exogenous stimulation (visual flash 10μs) in synchrony with an auditory stimulus (300ms) leads to increased loudness [21]. Differential endogenous orienting seems to be at work when responding to environmental sounds that are recognizable *vs* unrecognizable [27,28], which may mean that relevant memory categories are and are not readily available, respectively. Also interesting in this respect is the finding that the personal significance of sounds, e.g. ringtones [32] appears to be encoded and decoded automatically by the brain. As studies of bi-dimensional contextuality show, it may be difficult to not attend to information from readily available categories, as exist in cases of synesthetic correspondence or other strong congruency [33]. Then, the loudness of the stimulus that should not be attended to may be overestimated relative to its physical level of intensity. Finally, the results of the early field experiment by Aylor and Marks [18] are reminiscent of attentional effects at the level of *executive control*. Their subjects had ample time to consider the different characteristics of the various stimulus conditions, and they were even instructed to be sensitive to them.[10]

Average loudness estimates are related to sound intensities but with considerable scatter. Thus, substantial individual differences exist, and they may be partly due to different individual assessments of the (social) context of the sounds. Modern and non invasive brain research techniques (e.g., ERP, fMRI, MEG) in particular allow finer tuned assessments of such individual differences. They have not yet been applied in the study of moderation of the loudness-intensity relationship. As results from the studies reviewed in this paper suggest that, at various levels of attention, endogenous factors play a significant role in the selection of auditory information for further processing, application of these techniques is likely to considerably increase our understanding of the (social) determinants of the perceived loudness of environmental sounds.

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[9] Although other major distinctions in cognitive organisation are also meaningful, these three types of mechanisms have been indexed by activities in different parts of the brain. Evidence suggests that hormones are differentially active, with dopaminergic components related to aspects of executive attention and noradrenergic and cholinergic components related to alerting and orienting, respectively.[30]

[10] Participants were seated in a swivel chair surrounded by the barriers and sounds placed at 4.4 and 5.6 meters, respectively, and instructed that the purpose of the experiment was “in particular to learn about the loudness of sounds that come from different barriers” (p.398).

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