THE PERSISTENCE OF LOUDNESS IN SPEECH FREQUENCIES INFLUENCE OF ECOLOGICAL CONTEXT.

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Abstract

The initial loudness of a tone persists unless it is near threshold or at high frequencies. Three studies are discussed showing that ICP Loudness Adaptation appeared at all frequencies tested (at 60 dB), while simple adaptation loudness appeared only at 8000 Hz. Correlation of ICP adaptation with TEOAE effects and ecological context is discussed.

The initial loudness of an ongoing level tone tends to persist (with some exceptions). Why should this be so? It has been long known that steady stimulation of auditory neurons produces declining neural activity (for example, Derbyshire & Davis, 1935). The term loudness adaptation has frequently been used to refer to a decline in the loudness of a level intensity stimulus, in a manner that may parallel the declining neural activity. When the loudness fails to decline, it may be said that loudness "failed to adapt".

Is there a measure of loudness adaptation related to the presumed decline in peripheral auditory activity? The question is complicated since Doucet & Relkin (1997) and Relkin & Doucet (1997) have shown that the association between neural activity and loudness loses strength as intensity increases. Investigating the question, Hood (1950) presented a level tone in one ear and asked listeners to match the loudness by adjusting the intensity of a contralateral intermittent comparison tone. The average decline in loudness was matched by about a 22 dB decline in contralateral intensity and supported a viable model of loudness coding (Small, 1963; Weiler & Hood, 1977). Weiler & Hood (1977) based their test of the model on auditory "units" rather than direct neural activity. There is evidence of some interaural "induced" adaptation (Bocca & Pestalozza, 1959; Botte, Canevet, & Scharf, 1982; Scharf, 1983; Ward, 1973; Weiler, Gold, Sandman, & Warm, 1992).

Monaural techniques promise freedom from putative binaural effects. As described below, there has been controversy about the differences in loudness adaptation found with Simple Adaptation (SA) procedures as opposed to that found with the Ipsilateral Comparison Paradigm (ICP).

<u>The minimal approach, called the Simple Adaptation (SA</u>) procedure by Scharf, (1983) asks listeners to give loudness judgments for a level monaural tone without any use of comparison techniques. The tone decay observed at frequencies around 1000 Hz in normal listeners may be limited to intensities within about 30 dB SL. In more recent studies, Miskiewicz, Scharf, Hellman, and Meiselman (1993), and Hellman, Miskiewicz and Scharf (1997) extended the frequency range to 16,000 Hz. These authors indicate evidence of increasing Simple Adaptation above about 4000 Hz. Weiler, Sandman, and Dou (1997) noted this appearance of Simple Adaptation at higher intensities and frequencies could also be described as using stimuli outside the speech range, and urged further study.

The Ipsilateral Comparison Paradigm (ICP) was the term used by Dange et al. (1993) to refer to the reference-based procedure used by Weiler, Sandman, and Pederson (1981). Weiler et al. assumed that a sensory comparison stimulus was necessary for cognitive re-evaluation of the level on-going baseline stimulus, and that when the sensory referent was provided the listener would perceive a decline in loudness stemming from the declining neural activity. They presented a continuous 1000 Hz tone monaurally for 7 minutes with a sensory referent in the form of a five sec. 20 dB increment stimulus superimposed over the continuous tone every 30 seconds. Participants were instructed to provide Loudness Magnitude Estimates (LMEs) when signaled. Dange, et al. (1993), like Weiler, et al. (2000), found loudness adaptation for a wide variety of intensities at 1000 Hz. Tannen et al. (1996) reported similarly strong ICP adaptation from 250 to 4000 Hz at about 60 dBA.

Loudness Adaptation and the Speech Range

Based on the conjectures of Weiler, Sandman, and Dou (1997), a series of 3 studies have been completed comparing SA and ICP adaptation inside and outside the primary speech frequencies. The speech range is typically cited as extending from approximately 500 to 4000 Hz, although some speech information is found above and below these values. For the studies considered here, 8000 Hz is considered clearly outside the primary speech range. The following research questions were considered: 1) Is ICP loudness adaptation found inside and outside the speech range? 2) Is SA adaptation at 60 dB found only outside the speech range?

Study #1, served as the pilot study and used a mixed design. The 40 listeners were randomly assigned to one of four equal groups to be tested with both SA and ICP methods at the frequencies of 1000, 4000, 6000, or 8000 Hz, at 60 dB HL. Magnitude Estimates of Loudness at the start and end of the procedure were used to calculate the proportional change, (after Scharf, 1983). The ICP method revealed significant loudness adaptation (decline) for all four frequencies. The SA showed significant loudness adaptation (.37 or 37% decline) only at 8000 Hz, and was comparable to the ICP value (.38 or 38%). Weiler, Maguire, Dou & Warm, (Fechner Day, 1999) concluded this data, obtained by Maguire supported the expectations of Weiler, Sandman, and Dou (1997).

Study #2, was a completely within group design which focused on 4000, 6000 and 8000 Hz. The purpose was to determine whether the conclusions of Study #1 could be repeated. All 20 listeners were tested by Boudouris with SA and ICP at 60 dB HL for all three frequencies. As in study 1, the ICP method yielded significant adaptation at all frequencies while the SA method revealed significant adaptation only at 8000 Hz-outside the primary speech range. However, unlike study 1, the significant SA adaptation at 8000 Hz was lower than the ICP value

Study #3, the Current Comprehensive Study

Like Study #2, Study #3 is a completely within group design. The purpose of the present study was to extend the frequency range examined by including 250, 500, 1000, and 8000 Hz; and also to determine if the SA and the ICP show identical adaptation at 8000 Hz, (Study 1) or if the SA value is less than the ICP (Study 2).

The Listeners were 20 voluntary subjects, F=17, M=3, ranging in age from 18 to 55 yrs. (mean age 22-23 yrs) with normal hearing. As in Studies 1 & 2, all had normal hearing at 20 dB HL at 250, 500, 1000, 2000, 4000 and 8000 Hz (ANSI, 1996).

The Instrumentation was the same as in Studies 1 & 2. The ICP and SA methods were performed on a calibrated GSI-16 audiometer, in an IAC sound booth.

The Procedures were the same as in the previous studies-- each participant completed a brief training period and all tones were presented at 60 dB HL. The ICP presented a continuous monaural tone for 5 min., with a 10 dB HL increment (the referent), added to the 60 dB HL continuous tone every 30 sec. for 10 sec. During the ICP procedure, listeners were cued to assign magnitude estimates of loudness to each presentation of the baseline intensity and the intermittent referent stimulus. The SA procedure consisted of a continuous monaural tone presented for 5 min. with regular magnitude estimates of loudness solicited on the same schedule used for the ICP. Thus for both procedures, a total of 19 judgments were solicited. The participants were instructed to assign a loudness of "100" to the first baseline stimulus and subsequently to increase or decrease the number, depending on whether they perceived the tone to increase or decrease in loudness. If they perceived no change in the tone, they were instructed to use the same number given in the previous judgment. The 8 conditions formed by the combination of SA and ICP procedures at 250, 500, 1000 and 8000 Hz were presented in random order to each of the listeners.

Results for Study #3

Student t-tests revealed that the ICP adaptation was significant at all frequencies. The SA adaptation once again was significant at only 8000 Hz- outside the primary range of speech frequencies. Like Study #2, the SA at 8000 Hz was significantly less than the ICP adaptation. The present study # 3 is compared with Study 2 in Table 1.

Table 1: Mean Proportions of Loudness Adaptation for Studies 2 & 3.

	250 Hz	500 Hz	1000 Hz	4000 Hz	6000 Hz	8000 Hz
Study 2						
ICP	**x**	**x**	**x**	**.32***	**.37***	**.44***
SA	**x**	**x**	**x**	**.07**	**.04**	**.15***
Study 3						
ICP	**.29***	**.23***	**.29***	**x**	**x**	**.54***
SA	**.02**	**-.01**	**.01**	**x**	**x**	**.18**

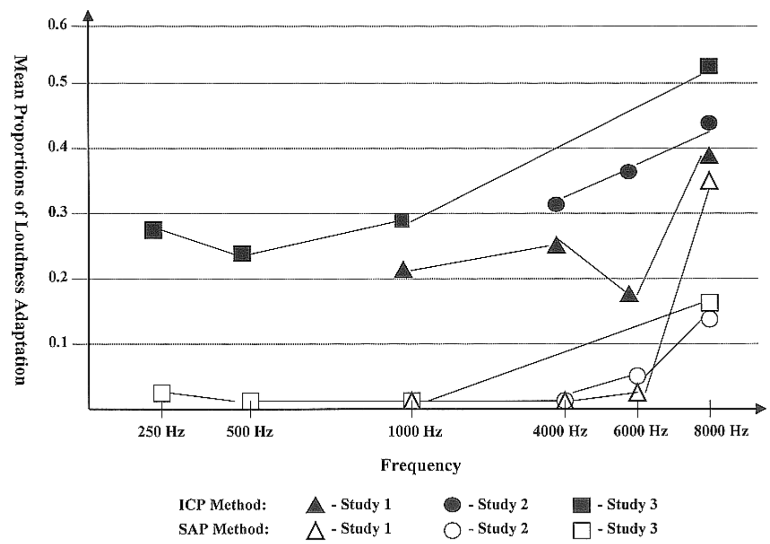
*** p<.05, df=19 The adaptation is significantly greater than .00.**

For the present study the Pearson correlation showed a significant relationship between ICP and SA adaptation at 8000 Hz only (r=.46, df=18, p<.05). This is similar to Study 2 at 8000 Hz (r=.62, df=18, p<.05).

Discussion of 3 studies

In all 3 studies the ICP procedure revealed statistically significant loudness adaptation (decline) at all frequencies tested; and in all 3 studies the SA procedure showed significant loudness adaptation only at 8000 Hz, outside the speech range. (See Figure 1). Both studies 2 and 3 found SA adaptation at 8000 Hz to be no more than half the ICP loudness adaptation, whereas the pilot Study 1 found nearly identical adaptation at 8000 Hz. Anomalies of variance and covariance at 6000 Hz in Studies 1 and 2 were tentatively related to the transition from inside to outside the speech range. Significant correlations between ICP and SA adaptation were found only at 8000 Hz. The presence of SA adaptation at 8000 Hz was consistent with the findings of Miskiewicz et al (1993) and Hellman et al (1997).

Fig 1: Auditory Adaptation for 3 Studies



Induced Adaptation and Recalibration

Nieder et al. (ASA, 2001) have reported "Recalibration", or a decline in loudness during short term 2AFC studies. Scharf (ISP, 2001) has considered the possibility that this may be the same phenomenon shown by ICP loudness adaptation in the present study. We have not yet found support for this hypothesis in on-going exploratory studies. Weiler and Cobb (1982) had studied ICP adaptation at various referent durations but found no adaptation for a 500 ms increment (Nieder's longest). Dange et al. (1993), Tannen (1996) and Weiler et al. (2000) found no support for the hypothesis that a sort of central "contrast" effect was responsible for ICP loudness adaptation. "Induced" monaural loudness adaptation appears to be that same "contrast" hypothesis rejected by Dange et al. and others. Dange et al. (1993) and Weiler et al. (2001) found strong effects for decremental referents which were apparently not considered by Nieder et al. or Scharf.

Monaural adaptation--Peripheral or Central?

Weiler, Sandman and Pederson (1981) argued their monaural method (now called the ICP) was more closely tied to peripheral auditory events than the previous binaural techniques Following Collet et al. (1992), Dou, et al. (1999) found significant correlations between suppression of transient evoked otoacoustic emissions (TEOAEs) with classic tone decay, and furthermore with ICP and SA adaptation at 4000 Hz. Classic tone decay and ICP adaptation correlated with each other. This is evidence for a peripheral origin for ICP loudness adaptation, albeit not as simple as Weiler et al. (1981) had hoped for.

Ecological Context, and Helson's AL.

There is an ecological validity to the absence of simple loudness adaptation (SA) at the primary speech frequencies and above 30 dB SL. If one were to be distracted by a simple loudness decline as the auditory neurons showed fatigue, then an additional burden would be placed on the speech recognition system. A level "platform" is desirable for the detection of the rapid and subtle changes that comprise the speech signals. Whatever the mechanism for the absence of simple loudness adaptation, its absence in the speech frequencies has a practical ecological value. Helson (1964) wrote "all psychophysical scaling methods are fundamentally bipolar rating scales with the neutral or zero category provided by the organism whether or not it is incorporated into the scale." The voice frequencies may well be a contextual anchor for the human organism. Peripheral adaptation may be perceived as loudness adaptation within speech frequencies when the ICP provides the referent stimulus. When a steady, redundant, middle intensity tone is presented within the speech range, the SA is at zero, and may serve as the zero point against which changing stimuli are perceived.

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