The enhancement effect: Evidence for adaptation of inhibition using a binaural centering task

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The enhancement effect is consistently shown when simultaneously masked stimuli are preceded by the masker alone, with a reduction in the amount of masking relative to when that precursor is absent. One explanation for this effect proposed by Viemeister and Bacon [(1982). *J. Acoust. Soc. Am.* **71**, 1502–1507] is the adaptation of inhibition, which predicts that an enhanced component (the “target”) will be effectively more intense within the auditory system than one that has not been enhanced. Forward masking studies have indicated this effect of increased gain; however, other explanations of the enhancement effect have also been suggested. In order to provide an alternative measure of the amount of effective gain for an enhanced target, a subjective binaural centering task was used in which listeners matched the intensities of enhanced and unenhanced 2-kHz tones presented to opposite ears to produce a centered stimulus. The results showed that the enhancement effect produces an effective 4–5 dB increase in the level of the enhanced target. The enhancement effect was also measured using other enhancement paradigms which yielded similar results over a range of levels for the target, supporting an account based on adaptation of inhibition.

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I. INTRODUCTION

When one frequency component is deleted from a harmonic complex and then reinserted, it perceptually “pops out.” This pop-out effect is accompanied by lower detection thresholds for the component that is deleted and reinserted. In the psychoacoustical literature, this phenomenon is known as the “enhancement effect.” Viemeister (1980) showed this type of auditory enhancement by measuring detection thresholds for one component in a harmonic complex as well as for a narrowband portion of broadband noise. The general temporal structure of Viemeister’s stimuli for this “signal enhancement” task is shown in the upper panel of Fig. 1 (although, to represent harmonic complexes, the frequency axes would be linear). For this paradigm, the tone to be detected is referred to as the signal; the tones that are played simultaneously with the signal comprise the masker; and the tones that are at the same frequencies as the simultaneous masker, but that precede the masker, comprise the precursor (referred to as the “adaptor” by Viemeister). Viemeister found that the threshold for the signal was significantly lower when it was introduced with a delay relative to the onset of the masker components (i.e., when a precursor was present). Similarly, Summerfield *et al.* (1987) measured improved identification thresholds for synthetic vowels composed of enhanced components relative to unenhanced components, suggesting that enhancement can help listeners understand speech in the presence of noise.

There are several possible explanations for the enhancement effect. Since the precursor and the masker have the same spectral characteristics, they could be grouped together

as a single perceptual object, resulting in segregation of the signal and making it easier to detect (Carlyon, 1989). Alternatively, the “adaptation of masking” account proposes that the effectiveness of the masker is reduced by simple adaptation of its frequency components after exposure to the precursor (Viemeister, 1980). Those components therefore are effectively no longer at full intensity within the auditory system when the signal is later turned on, decreasing their ability to mask the signal.

Another possible explanation for the enhancement effect depends upon the adaptation of inhibition (or adaptation of

FIG. 1. Spectral representations as a function of time, of the signal- and masker-enhancement paradigms. The frequency axes are logarithmic to represent inharmonic complexes. The number of components shown in the precursor/masker complexes has been reduced for clarity, and the timing is as labeled.

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suppression). Suppression occurs when the neural response at the signal frequency is reduced due to inhibition by energy at flanking simultaneous masker frequencies (Houtgast, 1972; Abbas and Sachs, 1976). If this effect is subject to adaptation, the masker's suppression of the signal will be reduced by the adaptation of the inhibitory responses due to the presence of the precursor. Therefore, when the signal is presented, it is not suppressed as much as when the precursor is absent and the response to the signal is at a higher effective level (Viemeister and Bacon, 1982).

Viemeister and Bacon (1982) showed evidence of this increased gain using a "masker-enhancement" task, in which a "target" component within a forward masker is enhanced (lower panel of Fig. 1). A brief signal that appeared in isolation was forward masked by an equal-amplitude harmonic complex with a target component at the signal frequency. When the masker was preceded by a precursor consisting of all components in the masker except the target frequency, forward-masked detection thresholds for the signal were higher by several decibels relative to when the precursor was not present. The results could not be explained by any additional forward masking from the precursor itself, so Viemeister and Bacon (1982) concluded that the effective level of the target component was raised by the precursor, most likely due to adaptation of the inhibition produced by the flanking components. Using this experimental design with both normal and hearing-impaired listeners, Thibodeau (1991) found that hearing-impaired listeners showed neither suppression nor enhancement effects, providing support for the idea that suppression plays a role in enhancement. However, within-subject comparisons of the magnitude of the enhancement effect (using notched-noise stimuli instead of tonal complexes) to two-tone suppression paradigms (Wright *et al.*, 1993; Wright, 1996) has yielded ambiguous results, including some subjects showing enhancement, yet "negative" two-tone suppression (i.e., additional masking from the suppressor).

Viemeister and Bacon (1982) speculated as to whether the enhancement effect originates at a peripheral or central level of auditory processing. Exploring the enhancement effect physiologically, Palmer *et al.* (1995) used a signal enhancement paradigm in guinea pigs and recorded responses from auditory-nerve fibers, but they found no evidence of increased gain and concluded that enhancement is due to a central process. There is some evidence of the adaptation of inhibition in the cochlear nucleus of anesthetized guinea pigs (Scutt *et al.*, 1997; Scutt and Palmer, 1998); however, more recent physiological experimentation has focused on the inferior colliculus. Nelson and Young (2010), using inharmonic stimuli with time courses similar to that depicted in Fig. 1, found evidence of adapting inhibitory responses in the inferior colliculus of unanesthetized marmoset monkeys. The form of adaptation they observed could potentially account for the enhancement effect.

Direct psychophysical comparisons of signal- and masker-enhancement tasks using notched-noise stimuli (Wright *et al.*, 1993) have shown substantial variability between listeners and paradigms. Such observations have led to the suggestion that different underlying mechanisms may

account for the findings from different paradigms. However, a possible reason for increased variability with the signal enhancement method relative to masker enhancement could be the persistence of enhancement. Viemeister (1980), using harmonic complexes, showed the enhancement effect to persist out to several seconds, and Carlyon (1989) showed the effect was still present with noise stimuli when the onset of the masker-plus-signal segment was delayed 300 ms relative to the offset of the precursor. If the first interval of a two-interval, forced-choice signal enhancement task is a non-signal interval, the signal in the second interval may be slightly enhanced, even if no "precursor" is included. In this case, the initial "masker alone" interval may act as a precursor for the second interval and may serve to adapt the inhibition produced by the simultaneous masker. This sequential effect for simultaneous masking has been found empirically by Cao *et al.* (2009) with a yes/no method, but its effect on the thresholds of a two-interval, forced-choice procedure is unclear. There is also the possibility of the effect building up over consecutive trials as the masker alone is presented repeatedly in the non-signal intervals of each trial. This idea may even account for some of the "backward" enhancement seen by Kidd and Wright (1994), in which enhancement occurred when the masker-plus-signal segment was followed (rather than preceded) by presentation of the masker alone (a backward fringe). Under such circumstances, rather than the backward fringe affecting detection of the preceding signal, it may affect detection of the signal in the following interval or trial.

Another possible cause of the variability between signal- and masker-enhancement results seen by Wright *et al.* (1993), and an alternate explanation for masker-enhancement results in general, could be the confusion caused by similarity between the masker and the signal. Previous studies (e.g., Neff, 1986) have shown evidence of this masker/signal "confusion" in various forward masking tasks, and this effect can confound certain forward masking methods of measuring suppression (Moore and Glasberg, 1982). In a masker-enhancement task, when the target component is enhanced, it is more likely to be perceptually segregated from the rest of the masker complex. This may result in the signal being confused with the (now segregated) target component of the masker. That alone may cause a difference between the forward-masked thresholds, especially if that difference is only a matter of a few decibels. However, this seems unlikely when a substantial temporal delay is added between the masker and signal as used in Viemeister and Bacon (1982).

The present study attempts to determine whether or not an effective increase in the gain of the enhanced target can be observed in a novel auditory enhancement paradigm that is not confounded by either the masker/signal confusion of masker enhancement or the sequential effects of signal enhancement tasks. Given that there is no evidence of across-ear enhancement whereby a precursor produces enhancement in the contralateral ear (Viemeister, 1980; Summerfield *et al.*, 1987; Carlyon, 1989), the present study is able to utilize a binaural centering task in which a masked target to be centered is preceded by a precursor in one ear but not in the other. Therefore, an enhanced target can be

presented to one ear while an unenhanced target of the same physical level is simultaneously presented to the other ear. If enhancement is due to an effective increase in gain, this enhanced target should show an apparent lateral shift due to unequal effective (qualitative) intensity within the auditory system, producing an apparent nonzero interaural level difference (ILD).

Another advantage of this centering technique is that it can be used to explore enhancement effects at suprathreshold target levels. It is unclear how far above threshold enhancement can be seen, however. Most previous research on enhancement has been conducted with enhanced targets that were at or near threshold. If enhancement depends upon the adaptation of inhibition, clearly enhancement can only occur when suppression occurs. Sidwell (1987) found that a tonal forward masker flanked by noise exhibited decreasing suppression as the level of noise decreased, but, even at noise levels as low as 6-dB sound pressure level (SPL), a 50-dB-SPL pure tone still showed some evidence of suppression. This raises the prospect that enhancement may be seen for suprathreshold (well-detectable) levels of the target.

The segregation (“pop-out”) of the enhanced target component within the complex is the attribute that defines the enhancement effect, and previous research has shown the significance of this segregation by enhancing a target to improve performance in a task such as pitch matching to the target (Hartmann and Goupell, 2006; Serman *et al.*, 2008). The present study, however, will use target components that are substantially more intense than the surrounding complex and will most likely result in targets that are already perceptually distinct from the surrounding complex, even when not enhanced. If the enhancement effect occurs when the target is salient within the masker regardless of whether the precursor is included, explanations of the effect based on perceptual grouping no longer seem tenable.

The present study compares the enhancement effect across objective and subjective methodologies, uses targets that are well above detection threshold, and uses a subjective binaural centering task to reveal differences in the perceived level of the enhanced target. Of particular interest is whether the enhancement effect depends upon the level of the target component relative to the surrounding complex. If there is an increase in gain for the enhanced target due to adaptation of inhibition, an empirical question is whether the gain increase is similar across the various tasks and ranges of target levels.

II. METHOD

Three different experimental paradigms were used to measure the enhancement effect; however, the core methodology was consistent across tasks. The signal enhancement conditions are described first in full, followed by the masker-enhancement conditions noting only the deviations from the signal enhancement’s methodology. Finally, the subjective binaural centering task is described.

A. Subjects and apparatus

Five subjects participated in the experiments (two males and three females, 20–46 years old). Two were authors,

while the others were undergraduate students from the University of Minnesota who were paid to participate. All listeners had normal hearing based on pure-tone thresholds of 15-dB hearing level (HL) or better at octave frequencies from 250 to 8000 Hz. The subjects’ performance on the experimental tasks was asymptotic before data collection began.

The stimuli were generated digitally with MATLAB (The MathWorks, Natick, MA) on a personal computer (PC) equipped with a 24-bit sound card (GINA 3G, Echo Digital Audio, Santa Barbara, CA). Stimuli were presented over stereo headphones (MDR-V6, Sony Corporation, Tokyo, Japan) to listeners who were seated in a sound-attenuating chamber (Industrial Acoustics Company, Bronx, NY).

B. Signal enhancement

1. Stimuli

The signal was a 2-kHz pure tone, while the masker and precursor stimuli were inharmonic complexes consisting of pure tones from 250 to 8000 Hz with 0.1-octave spacing, similar to Nelson and Young (2010). The masker/precursor complex had five components removed symmetrically around a center frequency of 2 kHz leaving a 0.6-octave notch, roughly 838 Hz wide. The inharmonic complex used in the present study is illustrated in the upper panel of Fig. 1. With the exception of the signal, all components were presented at 40-dB SPL, and the phase of each component was randomized on each trial but consistent across the intervals of each trial.

The enhanced condition consisted of a 250-ms masker-plus-signal segment preceded by a 500-ms precursor. Each segment was gated separately with 10-ms raised-cosine, on-and-off ramps, therefore reducing the duration that each segment was presented at full intensity by 20 ms. The stimuli were temporally contiguous such that there was no silence between precursor and masker other than that due to gating; thus the gap between the full intensity of each segment was 20 ms. The unenhanced condition merely lacked the precursor segment.

2. Procedure

A two-interval, forced-choice task was used with one signal-present interval and one non-signal interval presented during each trial, with the two intervals separated by 750 ms of silence. The interval of each trial that contained the signal was determined randomly with equal *a priori* probability. A two-down, one-up tracking procedure was used to estimate the 70.7% correct point of the listener’s underlying psychometric function (Levitt, 1971). A block consisted of 12 reversals with the mean of the final eight defined as threshold. For the first four reversals a step size of 2 dB was used, which was then reduced to 1 dB for the final eight reversals. The initial signal level was set at least four steps above the expected threshold for clear detection at the start of each block of trials. All stimuli were presented to the listener’s left ear.

Each block was initiated by the listener. Each trial began with a “ready” light that flashed for 250 ms, followed by a 250-ms pause. Interval lights illuminated while stimuli were

presented, and the listener entered responses on a keyboard. The light marking the correct interval was then illuminated for feedback. Listeners typically ran in 2-h sessions, and the order of conditions run was chosen pseudo-randomly by the experimenters. A condition was complete after a total of four blocks, and the four threshold estimates from those blocks were averaged to yield the final threshold estimate for that condition.

C. Masker enhancement

The masker-enhancement timeline is illustrated in the lower panel of Fig. 1. There were only two differences from the signal enhancement methodology described above. First, the signal was a 30-ms pure tone (including 5-ms, on-and-off ramps) presented immediately after the masker segment, making it a forward, rather than simultaneous, masking task. Second, a 2-kHz target component was added to the masker and set to either 50- or 70-dB SPL (in separate conditions). This is in contrast to the equal-amplitude complexes used by Viemeister and Bacon (1982) and Thibodeau (1991). The 50-dB-SPL level was chosen to be at least 20 dB above the unenhanced, simultaneously masked detection threshold for the 2-kHz component based on preliminary findings.

As a supplemental condition to estimate the amount of suppression produced by the flanking inharmonic complex on the 70-dB-SPL target component, detection thresholds for the signal measured with a forward masker consisting of only a 70-dB-SPL, 2-kHz tone were compared to thresholds measured with the 2-kHz component plus the 40-dB-SPL inharmonic complex as the masker (i.e., the “unenanced” condition). Thresholds in these reference conditions were also measured with the level of the 2-kHz component set to 30-dB SPL to estimate the amount of suppression on a less intense target comparable to signal enhancement detection levels.

D. Binaural centering task

1. Stimuli

The general stimuli in the binaural centering task corresponded to those used in the signal enhancement task and are depicted in Fig. 2. For the enhanced condition, the stimuli presented to the left ear were similar to the signal enhancement stimuli shown in the upper panel of Fig. 1, while the right ear was presented with the unenhanced version without the precursor. In both ears, a 250-ms “center cue” (a diotic 2-kHz pure tone) followed the masker/target after a 250-ms delay. The precursor was present in the enhanced conditions (lower panel of Fig. 2), but not in the unenhanced conditions (upper panel of Fig. 2). The right ear never contained a precursor, while the masker and cue presented to the right ear were composed of the same frequency components as the left ear, including relative phases. The target was presented at a fixed level of either 50- or 70-dB SPL in one ear while the target level in the other ear was adjusted adaptively to estimate thresholds. The cue level was always the same as the fixed-target level and was added to the task to provide a centered reference for comparison.

BINAURAL CENTERING TASK

UNENHANCED

ENHANCED

FIG. 2. Spectral representations on logarithmic frequency as a function of time for both the unenhanced and enhanced conditions in the binaural centering task. The target (emphasized center component) in one ear is fixed in level, while the contralateral target is adjusted adaptively.

It may have also helped the listener segregate the target from the masker by cueing the listener to the target frequency.

2. Procedure

A cued, single-interval, two-alternative forced-choice task was used that consisted of left-to-center versus right-to-center discrimination, i.e., the direction that the 2-kHz tone appeared to move between the target and the cue segments. If the target was effectively more intense in the left ear, the resulting percept was consistent with a sound source to the left of the listener’s midline while the diotic cue was consistent with a source at midline. If the target was effectively less intense in the left ear, the target appeared to be to the right of midline and then moved to the center. The listener reported the apparent direction of movement of the 2-kHz tone across the target and cue segments (by pressing the appropriate response key), and, being a subjective task, no feedback was given.

For an entire block of trials, the target level was fixed in one ear while variable in the other, with the left-ear target variable in some conditions and the right-ear target variable in others. The level of the target in the variable-stimulus ear was adjusted adaptively based on the listener’s responses. In each block of trials, two independent interleaved adaptive tracks were presented, with an equal probability of a trial from either track being presented on a given trial (Jesteadt, 1980). The initial level of the variable target was set 15–20 dB from the fixed-target level, with the level of the variable target higher than the fixed level in one track and lower than the fixed level in the other track. For the upper track, a two-down, one-up tracking procedure was used such that when the listener made two consecutive responses consistent with the target being lateralized toward the variable ear, the level in the variable ear decreased, making the target appear to be closer to the midline in the next trial for that track. When the listener made

one response consistent with the target being lateralized away from the variable ear, the level in the variable ear increased. As a result, the upper track measured the threshold for the level in the variable ear that produced a percept just perceptibly closer to the variable ear than the cue. For the lower track, a two-up, one-down procedure was used such that when the listener made two consecutive responses consistent with the target being lateralized away from the variable ear, the target level increased. After one response consistent with the target being lateralized toward the variable ear, the level decreased. In this way, the lower track measured the threshold level in the variable ear that produced a percept just perceptibly further from the variable ear than the cue.

A block of trials ended when 12 reversals occurred in both tracks. In most cases, more than 12 reversals were obtained in one track before the other track also reached that cutoff, but only the last eight reversals of each track were used to calculate thresholds. The thresholds of the upper and lower tracks then effectively “framed” the ILD for the target that would match the apparent lateral position of the centered cue. Averaging those two ILDs yields an estimate of the target ILD that would produce a centered percept (Jesteadt, 1980). For a given fixed-target level, the conditions (enhanced/unenhanced and right/left-ear-target variable) were run in pseudorandom order and all conditions were run interleaved, so any effect of imperfect headphone placement or lack of proper comparison to the center cue, would be equalized across all conditions. All additional procedural details (e.g., step sizes) were the same as in the signal enhancement conditions described earlier.

III. RESULTS AND DISCUSSION

For the objective threshold measurements, listeners varied in their detection thresholds, but the general amount of enhancement (the difference between the unenhanced and enhanced thresholds) was relatively consistent across subjects and also with previous research using other types of stimuli (e.g., Viemeister and Bacon, 1982; Wright *et al.*, 1993). Averaged across listeners, for signal enhancement, the precursor decreased thresholds by 4.2 dB (from 26.9- to 22.7-dB SPL); while for masker enhancement, the precursor raised thresholds by 5.6 (from 39.2- to 44.8-dB SPL) and 4.3 dB (from 55.5- to 59.8-dB SPL) for the 50- and 70-dB-SPL target conditions, respectively.

In order to estimate the effect of suppression on the 70-dB-SPL target component, as well as on a 30-dB-SPL target for comparison, detection thresholds for the signal measured with a 2 kHz forward masker were compared to thresholds for the signal measured with the 2-kHz component with the flanking inharmonic complex as forward masker. The addition of the inharmonic complex to the masker reduced thresholds from 60.9- to 55.5-dB SPL for the 70-dB-SPL, 2-kHz conditions and from 29.3- to 22.1-dB SPL for the 30-dB-SPL, 2-kHz conditions. By this measure, 5.4 dB [standard error (SE) = 0.4 dB] of suppression was observed for the 70-dB-SPL component by the surrounding 40-dB-SPL inharmonic complex, and when the 2-kHz component was 30-dB SPL, this measure of suppression was only 1.8 dB greater [7.2

dB (SE = 0.6 dB)]. Therefore, an effect of suppression would have been present in all of the enhancement conditions used here and could have been reduced by adaptation after the addition of the precursor.

The means of the upper and lower tracks in each of the binaural conditions were converted to the ILDs that effectively produced centered images. These ILDs are shown in Fig. 3. The “centered” ILDs for the unenhanced conditions (white bars) were at or near zero. However, for the enhancement conditions (gray bars), recalling that the left ear was always the enhanced ear, the level of the variable target was adjusted such that the level in the right ear typically was 4.5 dB higher than in the left ear, consistent with the enhanced target being effectively more intense. If the target had been presented at those levels without the precursor, the target would have appeared to be shifted to the right of midline.

A two-by-two repeated measures analysis of variance (ANOVA) was performed for each level of the fixed target (corresponding to the upper and lower panels of Fig. 3), with the factors of enhanced vs unenhanced and left-ear variable vs right-ear variable. The dependent variable was the ILD of the target that was matched to the diotic cue. For the 50-dB-SPL fixed-target conditions (Fig. 3, top panel), there was a significant difference between the unenhanced and enhanced conditions, $F(1, 4) = 53.31$, $p = 0.002$, but not between the left or right ear being variable, $F(1, 4) = 1.97$, $p = 0.23$, and there

FIG. 3. The mean results of five listeners from the centering task with a 50-dB-SPL fixed target are plotted in the upper panel, while the lower panel is for the 70-dB-SPL fixed target. Each bar is the subjectively centered ILD of the target component. The horizontal dashed line represents ILD = 0, and error bars represent 95% confidence intervals.

was not a significant interaction, $F(1,4) = 0.56$, $p = 0.50$. Similar results were seen for the 70-dB-SPL fixed-target conditions (Fig. 3, bottom panel): unenhanced vs enhanced, $F(1,4) = 53.20$, $p = 0.002$; left vs right-ear variable, $F(1,4) = 3.74$, $p = 0.13$; interaction, $F(1,4) = 0.08$, $p = 0.80$.

The absolute value of the difference between the upper or lower track and the mean of the two tracks provides an estimate of the just noticeable difference (JND) of the ILD for each subject. The average across all subjects between the centered level and the thresholds of each track was 4.5 dB (SE = 0.9) for the 50-dB-SPL, fixed-target conditions. The 70-dB-SPL target reduced this average JND [3.2 dB (SE = 0.6)], perhaps by making it easier to segregate the target from the masker. The task was reported by the listeners as being easier to perform with the higher level target, in general. Although there were individual differences with respect to the range of thresholds across the upper and lower tracks within a condition, the centered level (the mean of the upper and lower tracks) was similar across subjects as shown by the error bars in Fig. 3.

The top panel of Fig. 4 shows the amount of enhancement estimated in the various monaural and binaural conditions. The amount of enhancement was calculated and compared across the different methodologies by taking the difference between the unenhanced and enhanced thresholds in the detection tasks and the difference between the centered ILDs in the unenhanced and enhanced conditions of the binaural centering task. For the centering task, the amounts of enhancement of the left- and right-ear-variable

targets were averaged together. To compare enhancement across paradigms, a one-way repeated measures ANOVA was then computed across the results of the various conditions shown in top panel of Fig. 4. There was no significant difference between the amount of enhancement across the conditions, $F(4,16) = 0.86$, $p = 0.51$.

Comparison of this particular measure of enhancement may not be correct for the masker-enhancement conditions, however. In general, detection thresholds do not change linearly with masker level in forward masking tasks (Jesteadt *et al.*, 1982); therefore, the differences in enhanced and unenhanced thresholds may not reflect the change in effective masker level. In order to provide an alternative measure for the masker-enhancement results, the slope of the forward masking function was determined. By comparing the 20-dB increase in the target component used in the masker (from 50- to 70-dB SPL) to the difference in the unenhanced signal-detection thresholds (16.3 dB), an estimate of the slope of the masking function is obtained. This slope can also be calculated from the forward maskers used to measure psychophysical suppression in the current study (a 40-dB increase in the masker, with signal-detection differences of 31.6-dB SPL for the 2-kHz-alone masker and 33.4-dB SPL for the inharmonic-complex masker). The result is a target-level-difference to signal-threshold-difference ratio of 1.22. By multiplying the amount of masker enhancement (shown in the top panel of Fig. 4) by this value, the effective increase in the target component can be determined (shown in the bottom panel of Fig. 4). A two-by-two repeated measures ANOVA was performed with the factors of target level (50- vs 70-dB SPL) and methodology (masker enhancement vs centering task). The dependent variable was the effective increase in the target level. There were no significant differences or interactions present: target level, $F(1,4) = 1.08$, $p = 0.36$; methodology, $F(1,4) = 2.18$, $p = 0.21$; interaction, $F(1,4) = 4.55$, $p = 0.10$.

Using consistent parameters across paradigms, the enhancement effect was shown in different objective and subjective tasks. The results are consistent with the hypothesis that the effective gain increases when a target is enhanced, perhaps due to adaptation of inhibition. It may be difficult to compare the signal enhancement paradigm to the masker enhancement and centering task versions, though, due to the possibility of sequential effects from stimulus presentation reducing the magnitude of the observed effect. However, it is interesting that the amount of enhancement is similar across a large range of target levels. The precursor/masker complex was held constant across all methodologies; therefore the amount of inhibition due to the complex presumably was also constant. The adaptation of this inhibition appears to cause similar increases in the effective gain of the target component over the range of target levels used in the present study.

The amount of enhancement observed in the centering task is not confounded by the masker/signal confusion that may be present in the masker-enhancement task, as well as the measure of psychophysical suppression, yet the results of the different methods are not substantially different. Assuming that adaptation of inhibition is the underlying cause of the enhancement effect, the centering task can also be a

FIG. 4. Top panel: The average amount of enhancement across five listeners in the various monaural and binaural conditions and target component levels. Bottom panel: The effective increase in the level of the target component from the masker enhancement and centering tasks (refer to the text). Error bars represent 95% confidence intervals.

method for simply detecting the presence of suppression, by showing that this inhibition has decreased as a result of adaptation. In addition, unlike previous research using two-tone suppression paradigms (Wright *et al.*, 1993; Wright, 1996), the present study's finding that the magnitude of the enhancement effect is similar to the amount of psychophysical suppression provides further evidence for the adaptation of inhibition account of auditory enhancement.

IV. CONCLUSIONS

- (1) The enhancement effect was shown across signal enhancement, masker enhancement, and a subjective binaural centering task. In these different methodologies, similar amounts of enhancement were shown across levels ranging from near threshold to suprathreshold levels of the target.
- (2) Based on the results of the centering task, the most plausible explanation for the enhancement effect appears to involve a true increase in internal gain for the enhanced target component. The results are not consistent with the alternative explanations that have been posited: The explanation involving the perceptual grouping of the precursor and the masker predicts that the target would merely "stand out," and the explanation involving only the simple adaptation of the masker components' intensity would predict less masking, but neither would result in the target itself being effectively more intense. Therefore, adaptation of inhibition is the most likely underlying mechanism of the enhancement effect.

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