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# Acceptance of Noise with Monaural and Binaural Amplification

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**Abstract**

The present study investigated the effects of monaural and binaural amplification on speech understanding in noise and acceptance of noise for 39 listeners with hearing impairment. Results demonstrated that speech understanding in noise improved with binaural amplification; however, acceptance of noise was not dependent on monaural or binaural amplification for most listeners. These results suggest that although two hearing aids maximize speech understanding ability in noise, most individuals' acceptance of noise, which is directly related to hearing aid use, may not be affected by the use of binaural amplification. It should be noted that monaural amplification resulted in greater acceptance of noise for some listeners, indicating that binaural amplification may negatively affect some individuals' willingness to wear hearing aids. It should also be noted that interaural differences in acceptance of noise might exist for some listeners; therefore, if only one hearing aid is fitted, monaural ANLs should be measured.

**Key Words:** Acceptable noise level, binaural advantage, monaural amplification, speech understanding in noise

**Abbreviations:** ANL = acceptable noise level; BNL = maximum acceptable background noise level; BTE = behind-the-ear; ITE = in-the-ear; MCL = most comfortable listening level; SPIN = Speech Perception in Noise; SRT = speech reception threshold

**Sumario**

El presente estudio investigó los efectos de la amplificación monoauricular y binauricular sobre la comprensión del lenguaje en ruido y la aceptación del ruido por parte de 39 sujetos con hipoacusia. Los resultados demostraron que la compresión del lenguaje en ruido mejoró con la amplificación binauricular; sin embargo, la aceptación del ruido no dependió de la amplificación monoauricular o binauricular en la mayor parte de los sujetos. Estos resultados sugieren que aunque dos auxiliares auditivos maximizan la capacidad de entender el lenguaje en medio de ruido, la aceptación del ruido en la mayoría de los individuos, que está directamente relacionada con el uso del auxiliar auditivo, podría no verse afectada por el uso de una amplificación binauricular. Debe destacarse que la amplificación monoauricular resultó en una mayor aceptación del ruido para algunos oyentes, sugiriendo que la amplificación binauricular puede afectar negativamente la disposición de algunos individuos de usar auxiliares auditivos. Debe también notarse que pueden existir diferencias interauriculares en la aceptación del ruido para algunos sujetos; por lo tanto, si sólo se va a adaptar un audífono, debe medirse la ANL monoauricularmente.

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**Palabras Clave:** Nivel aceptable de ruido, ventaja binauricular, amplificación monoauricular, comprensión del lenguaje en ruido

**Abreviaturas:** ANL = nivel aceptable de ruido; BNL = nivel máximo aceptable de ruido de fondo; BTE = retroauricular; ITE = intraauricular; MCL = nivel de audición más confortable; SPIN = Percepción del Lenguaje en Ruido; SRT = umbral de recepción del lenguaje

One of the most frequent complaints of hearing aid users is difficulty understanding speech in the presence of background noise (Franks and Beckman, 1985; Kochkin, 1993). Research has demonstrated that one way to improve speech understanding in noise is through the use of binaural amplification (Bryne, 1981). Binaural amplification increases an individual's ability to recognize important acoustic cues in the presence of background noise (Wesselkamp et al, 1997). In addition, binaural amplification reduces head shadow effects, reduces binaural squelch, and introduces binaural redundancy (Dillon, 2001). Improvements in speech understanding using binaural amplification have been shown through improved word-recognition scores and speech-recognition thresholds, measured both in quiet and in the presence of noise (Hawkins and Yacullo, 1984; Ricketts, 2000; Persson et al, 2001).

It is well documented that background noise affects speech understanding; therefore, a primary rehabilitation goal in hearing aid fittings is the improvement of speech understanding in noise. One might assume that the effects of noise on speech understanding could be reduced with the introduction of binaural amplification (Bryne, 1981); however, recent research has demonstrated that binaural amplification may degrade speech understanding in noise relative to monaural amplification for some listeners due to binaural interference (Walden and Walden, 2005). Furthermore, it might also be assumed that individuals with good speech perception in noise ability may have more success or wear their hearing aids more often than individuals with poor speech perception in noise ability. However, only weak correlations have been found between results of speech perception tests and subjective evaluation of communication difficulty (Rowland et al, 1985). In addition, Humes et al (1996) reported a weak relationship between speech perception in noise scores and measures of hearing aid benefit, satisfaction, or hours of use. Based on these studies, the need for an objective test to determine hearing aid outcome is needed.

In 1991, Nabelek et al hypothesized that the willingness to listen to speech in background noise may be more indicative of hearing aid use than speech perception scores obtained in background noise. This hypothesis led to the development of a procedure called "acceptable noise level" (ANL), which is a measure of willingness to accept background noise while listening to speech. To obtain an ANL, listeners first adjust the level of a story to their most comfortable listening level (MCL). Then, multitalker speech babble background noise is added, and listeners adjust the babble to the maximum level of the background noise they would be willing to accept or "put up with" without becoming tense or tired while following the words of the story (called "BNL"). The ANL is calculated by subtracting the BNL from the MCL. Nabelek et al (1991) measured ANLs for three groups of hearing aid users (N = 15/group): full-time hearing aid users, part-time hearing aid users, and nonusers of hearing aids. Full-time users wore their hearing aids whenever they needed them; part-time users wore their hearing aids only occasionally; nonusers had completely stopped wearing their hearing aids. The results demonstrated that mean ANLs for the full-time users were significantly lower than mean ANLs for part-time users and nonusers; however, there was no mean ANL difference between part-time users and nonusers. These results indicated that ANL is related to hearing aid use.

To investigate the predictive value of ANL as a function of hearing aid use, Nabelek et al (this issue) measured ANLs in a large group of hearing aid users (N = 191). The hearing aid users were divided into three groups based on hearing aid use: full-time users (N = 69), part-time users (N = 69), or nonusers (N = 59) of hearing aids. Like the Nabelek et al (1991) study, the results demonstrated that ANLs were related to hearing aid use. Specifically, full-time hearing aid users accepted more background noise than part-time users or nonusers, but part-time users and nonusers could not be differentiated. These results suggested that individuals who accept high levels of background noise (i.e., have low ANLs) are more likely to wear hearing aids on a regular basis (i.e., become full-time hearing aid users). Conversely, individuals who accept low levels of background noise (i.e., have high ANLs) are less likely to wear hearing aids regularly (i.e., become part-time users or nonusers of hearing aids). Results of this study also demonstrated that ANLs are unaffected by the use of amplification and are not related to speech perception in noise scores, indicating ANLs and speech perception tasks measure two different reactions to background noise. Specifically, ANLs may be used as a predictor of hearing aid use while speech understanding in noise may be used as a measure of hearing aid benefit. Furthermore, a prediction of hearing aid use was determined based on the listener's unaided ANL. Since part-time users and nonusers could not be differentiated by ANL, these two groups were combined and called the "unsuccessful" hearing aid users. They were then compared to the full-time users (called "successful" hearing aid users). Regression analysis determined that unaided ANLs could predict a listener's success with hearing aids (i.e., hearing aid use/acceptance) with 85% accuracy (Nabelek et al, this issue).

ANLs have been assessed monaurally through an earphone with the frequency response shaped to simulate an appropriate hearing aid fitting (Nabelek et al, 1991), monaurally using one of the participants' personal, analog hearing aids (Lytle, 1994), and binaurally using the participants' personal, analog, or digital hearing aids (Nabelek et al, this issue). The results from these investigations indicated that the mean ANLs for each presentation method were 7.40, 7.95, and 7.10 dB, respectively (Nabelek et al, 1991; Lytle, 1994; Nabelek et al, this issue). Comparisons among these studies have not been analyzed statistically; however, based on the small difference in mean values between the three studies, it could be hypothesized that ANLs are not affected by monaural versus binaural amplification. Monaural and binaural ANLs, however, have not been compared within the same participants. It is possible that binaural amplification may improve ANLs, which should lead to increased hearing aid use/acceptance. Conversely, it is also possible that binaural amplification may have no effect or may even degrade ANLs, thereby supporting the use of monaural amplification for some listeners. Therefore, the purpose of the present study was to determine the effects of monaural and binaural amplification on acceptance of noise in the same participant cohort.

## METHODS

### Participants

Thirty-nine adults (mean age = 69 years; range = 30–89 years) served as the participants for this study. The criteria for inclusion included binaural hearing instrument users who had worn hearing aids for at least three months (see Figure 1 for mean audiometric data).

Testing was completed using the participant's personal hearing aids in the omnidirectional mode. All hearing aids were fitted by staff audiologists at the University of Tennessee Speech and Hearing Clinic independent of the study. At the University of Tennessee Speech and Hearing Clinic, patients are fitted based on the prescriptive method deemed to be appropriate for each patient's communication needs. Probe

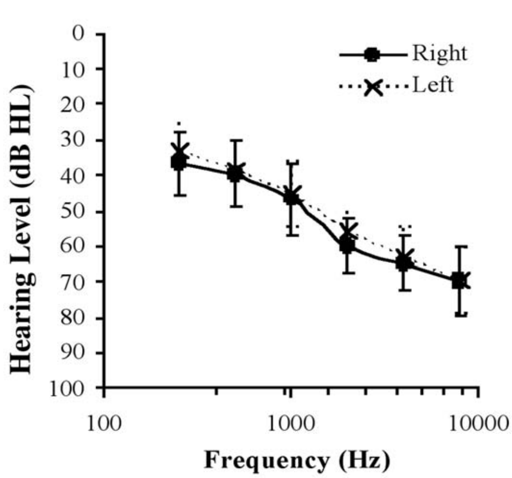


**Figure 1**. Mean pure-tone thresholds and standard deviations (all in dB) for all participants.

microphone, objective, and subjective evaluations are then conducted to verify the hearing aid fitting. The current study included 15 participants who used analog hearing aids and 24 who used digital hearing aids. Twenty-seven participants had in-the-ear (ITE) hearing aids, and 12 had behind-the-ear (BTE) hearing aids. The hearing aids were fitted to best meet the participants' amplification needs and were not adjusted for the purposes of this study.

### Procedures

For all procedures, the speech stimuli and background noise were delivered by a Dell (OptiPlex GX 400) personal computer compact disc player routed through a two-channel diagnostic audiometer (GSI-16) (ANSI [American National Standards Institute], S3.6-1996). The stimuli were then delivered through two ear-level loudspeakers located 1.5 m from the participant at 0 degrees and 180 degrees azimuth on the diagonal of an audiometric booth (IAC, model #404A; 2.7 m x 2.5 m). The audiometric booth met ANSI standards (ANSI, S3.1-1991) for acceptable ambient noise levels. The output levels of the speech stimuli and background noise were calibrated at the vertex of the listener and were checked periodically throughout the experiment. Prior to data collection, an experimental schedule was generated for each participant, listing a completely randomized assignment for each amplification condition (monaural right, monaural left, and binaural).

### Speech Understanding in Noise

The effects of both monaural and binaural amplification on speech understanding in noise are well established; therefore, speech understanding in noise data was collected for control purposes. Speech understanding in noise was assessed using a modified version of the Tillman and Olsen (1973) speech reception threshold (SRT) procedure (see Freyaldenhoven et al, 2005, for review). The primary stimulus consisted of a male recording of a list of spondee words (Basic Auditory Tests: CD #101 R2, Auditec of Saint Louis) and was delivered from a loudspeaker located at 0 degrees azimuth at the participant's MCL, which was established during the ANL procedure. The competing stimulus was multitalker speech babble (Revised Speech Perception in Noise; Bilger et al, 1984) and was delivered from a loudspeaker located at 180 degrees azimuth. The modification included the addition of multitalker speech babble, which was used as the competing stimuli for the ANL procedure (Note: the procedure was referred to as a "masked" SRT). This multitalker speech babble noise was added to ensure that the noise types were consistent between the masked SRT and ANL procedures. In addition, noise levels were varied and speech levels were fixed to ensure that speech levels were consistent between the masked SRT and ANL stimuli.

Two masked SRTs were measured for each amplification condition (monaural right, monaural left, and binaural), and the results were averaged to obtain a mean masked SRT for each participant. When testing monaurally, only one hearing aid was used, and the nontest ear was plugged with a Howard Leight (NRP 33 / SNR 34 CE) preshaped foam earplug.

### Acceptance of Noise

Acceptance of background noise was assessed for the monaural right, monaural left, and binaural amplification conditions. Acceptance of noise was evaluated using the ANL procedure described by Nabelek et al (this issue). A recording of male running speech (Arizona Travelogue, Cosmos Distributing Inc.) served as the speech stimuli and was delivered from a loudspeaker located at 0 degrees azimuth. Multitalker speech babble (Revised Speech Perception in Noise; Bilger et al, 1984) served as the competing stimulus and was delivered by a loudspeaker located at 180 degrees azimuth.

To obtain ANLs, each participant first adjusted the level of the story (Arizona Travelogue) to the most comfortable listening level (MCL). Multitalker babble was then added, and the participants adjusted the babble noise to the maximum level of the background noise they were willing to accept or "put up with" without becoming tense or tired while listening to and following the words of the story. This level was called the "background noise level" (BNL). The ANL was then calculated by subtracting the BNL from the MCL (see Nabelek et al, this issue, for ANL instructions). Two ANL trials were conducted for the each amplification condition (monaural right, monaural left, and binaural), and the results were averaged to obtain a mean ANL for each participant. When testing monaurally, only one hearing aid was used, and the nontest ear was plugged with a Howard Leight (NRP 33 / SNR 34 CE) preshaped foam earplug.

## RESULTS

### Speech Understanding in Noise

Monaural right, monaural left, and binaural masked SRTs were obtained for each participant. The masked SRTs were replicated for each amplification condition (monaural right, monaural left, and binaural), and a mean masked SRT was determined for each participant. Mean masked SRTs for each amplification condition were averaged across participants and are shown in Figure 2.

A one-way repeated measures analysis of variance (ANOVA) was performed to evaluate the effects of monaural and binaural amplification on masked SRT. The dependent variable was masked SRTs. The within-subject factor was amplification condition with three levels (monaural right, monaural left, and binaural). The analysis revealed a significant main effect for amplification condition ($F[2,76] = 17.04$; $p < 0.001$). Follow-up tests were conducted to evaluate mean pairwise differences using the Bonferroni test. Results revealed a significant mean difference between monaural right and binaural masked SRTs (mean difference = 3.10, $p < 0.001$) as well as monaural left and binaural masked SRTs (mean difference = 3.44, $p < 0.001$). No significant difference was seen between monaural right and monaural left masked SRTs (mean difference = 0.33, $p = 0.64$). These results suggested that speech understanding in noise improves when hearing aids are used binaurally.

### Acceptance of Background Noise

Monaural right, monaural left, and binaural ANLs were obtained for each participant. ANLs were replicated for each amplification condition (monaural right, monaural left, binaural), and a mean ANL was determined for each participant. Mean ANLs for each amplification condition were averaged across participants and are shown in Figure 3.

A one-way repeated measures ANOVA was performed to evaluate the effects of monaural and binaural amplification on ANL.

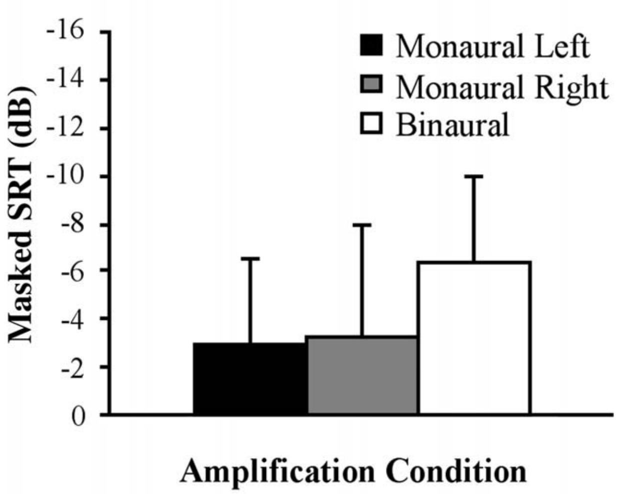


**Figure 2.** Mean masked SRTs and standard deviations (in dB) for each amplification condition (monaural left, monaural right, and binaural).

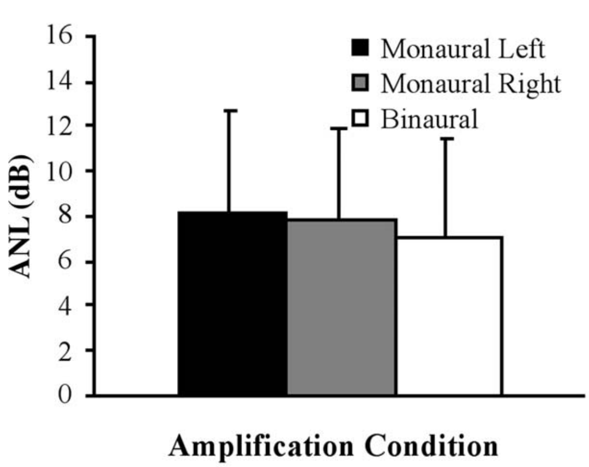


**Figure 3.** Mean ANLs and standard deviations (in dB) for each amplification condition (monaural left, monaural right, and binaural).

The dependent variable was ANL. The within-subject factor was amplification condition with three levels (monaural right, monaural left, and binaural). The analysis revealed no significant main effect for amplification condition ($F[2,76] = 2.98$; $p > 0.05$). These results suggested that acceptance of noise is not dependent on the use of monaural or binaural amplification.

## DISCUSSION

### Speech Understanding in Noise

Speech understanding in noise results revealed that masked SRTs were similar between ears when fit monaurally; however, on average, masked SRTs improved 3.2 dB when the spondee words were amplified binaurally. These results were expected based on previous studies demonstrating that binaural amplification improves speech understanding in noise. Table 1 shows benefit received from binaural speech understanding in noise for listeners with hearing impairment. Benefit was calculated by subtracting mean presentation level for monaural speech understanding in noise from mean presentation level for binaural speech understanding in noise for all studies. Speech understanding in noise results from the current study agree with previous findings, thereby suggesting that the current experimental design was appropriate for the identification of a possible effect between monaural and binaural amplification on acceptance of noise (i.e., ANL).

### Acceptance of Background Noise

The purpose of the present study was to determine if acceptance of background noise was affected by monaural or binaural amplification. Results demonstrated that acceptance of noise was not affected by binaural amplification, suggesting that an individual's acceptance of noise remains relatively constant when fitted with monaural or binaural amplification. These results are in agreement with previous ANL research obtained using various presentation methods (Nabelek et al, 1991; Lytle, 1994; Nabelek et al, this issue) (Table 2).

Research has demonstrated that ANLs are directly related to a listener's pattern of hearing aid use or the likelihood a listener will wear hearing aids (Nabelek et al, this issue). Specifically, individuals who accept high levels of background noise (i.e., have low ANLs) are likely to wear hearing aids on a regular basis. On the other hand, individuals who accept low levels of background noise (i.e., have high ANLs) are not likely to wear hearing aids regularly (Nabelek et al, this issue). Therefore, results of the present study suggest that an individual's willingness to wear hearing aids is not affected by the fitting of monaural versus binaural amplification for most listeners.

Although group data (N = 39) showed that ANLs were not significantly affected by monaural versus binaural amplification, individual data analysis revealed that monaural amplification resulted in greater acceptance of noise than binaural amplification for some listeners. For example, monaural ANLs were the same or higher than binaural ANLs for 26 listeners (i.e., listeners accepted the same or more noise in the binaural condition); however, monaural

**Table 1. Speech Understanding in Noise Benefit When Using Binaural Amplification**

| Investigators | Speech Stimuli | Speech Understanding in Noise Benefit (dB) |
|---|---|---|
| Hawkins and Yacullo (1984) (N = 11) | SRT in noise measured using the NU-6 Word List w/ speech babble as competing stimuli | 4.0 |
| Ricketts (2000) (N = 20) | Conventional presentation of HINT Sentences | 2.5 |
| Present Study (N = 39) | Masked SRT w/ speech babble as competing stimuli | 3.3 |

*Note:* Benefit = mean presentation level for binaural speech understanding minus mean presentation level for monaural speech understanding.

**Table 2. Acceptance of Background Noise Utilizing Different Presentation Methods for Listeners Who Wore Hearing Aids on a Full-Time Basis**

| Investigators | Presentation Method | Mean ANL (dB) | ANL Range (dB) |
|---|---|---|---|
| Nabelek et al (1991)<br>N = 15 | Monaurally through an earphone with a frequency response modified to each individual's hearing loss | 7.40 | 2–17 |
| Lytle (1994)<br>N = 20 | Monaurally utilizing one linear, analog hearing aid | 7.95 | 1–13 |
| Nabelek et al (this issue)<br>N = 69 | Binaurally utilizing two analog or digital hearing aids | 7.10 | 2–16 |
| Present Study<br>N = 39 | Monaurally utilizing one analog or digital hearing aid | 8.30 | 3–20 |
| | Binaurally utilizing two analog or digital hearing aids | 7.25 | 0–18 |

amplification resulted in greater acceptance of noise than binaural amplification for 13 listeners (i.e., listeners accepted less noise in the binaural condition) (Table 3). Since acceptance of noise is directly related to hearing aid use/acceptance (Nabelek et al, this issue), it is possible that individuals with better monaural than binaural ANLs may be more willing to use amplification if fitted monaurally than if fitted binaurally.

Individual data analysis also revealed that interaural ANL differences of 6 dB were present in four listeners. Three listeners exhibited a left ear deficit (i.e., ANL for the monaural left condition was 6 dB poorer than the monaural right condition) while a fourth listener exhibited a right ear deficit. It is, therefore, possible that hearing aid acceptance may be dependant on the ear being amplified in cases of monaural hearing aid use when large interaural ANL differences are present. Nonetheless, the results of the present study suggest that acceptance of noise should be measured both monaurally (i.e., monaural right and monaural left) and binaurally during hearing aid evaluations to maximize acceptance of noise.

## Implications for Future Research

The present study evaluated monaural and binaural acceptance of noise when utilizing hearing aids; however, future studies should evaluate monaural and binaural acceptance of noise in the unaided condition. Previous ANL research has demonstrated that ANLs are not affected by the introduction of hearing aids (Nabelek et al, this issue); therefore, it could be speculated that unaided monaural and binaural ANLs would be comparable to aided monaural and binaural ANLs. Should this be the case, potential monaural/binaural ANL effects as well as potential interaural ANL differences could be detected and addressed before hearings aids are fitted, thereby improving the potential for successful hearing aid use.

Results from the present study suggest that changing from monaural to binaural amplification did not affect acceptance of background noise when wearing omnidirectional hearing aids for the majority of the listeners. Conversely, Freyaldenhoven et al (2005) demonstrated binaural ANLs improved by 3 dB when changing from omnidirectional to directional mode. Therefore, it may be hypothesized that directionality may be more effective than binaural amplification when measuring acceptance of background noise. Furthermore, it is possible that one directional hearing aid may result in greater acceptance of noise than binaural, omnidirectional amplification. This hypothesis has not been evaluated and warrants further study.

**Table 3. Mean Difference between Binaural and Best Monaural ANL Calculated by Subtracting Listeners' Best Monaural ANL from Their Binaural ANL**

| Listeners | Mean Difference between Binaural and Best Monaural ANL (Binaural - Best Monaural) |
|---|---|
| N = 13 | 3.69 |
| N = 26 | -1.62 |

*Note:* A "positive" difference equals an increase in ANL (i.e., ANLs became poorer) from the best monaural to the binaural ANL.

## CONCLUSIONS

Results from the present study suggest that although two hearing aids maximize speech understanding in noise, most listeners' acceptance of noise (i.e., ANL) is not affected by the use of binaural amplification. Research has demonstrated that ANLs are directly related to listeners' willingness to use hearing aids (Nabelek et al, this issue); therefore, these results may suggest that a listener's willingness to wear hearing aids is not affected by the use of monaural versus binaural amplification. It should be noted, however, that monaural amplification resulted in greater acceptance of noise than binaural amplification for some listeners, indicating that binaural amplification may negatively affect some individuals' willingness to wear hearing aids. It should also be noted that ANLs for a given individual may be poorer for one ear than the other ear; therefore, if only one hearing aid can be purchased and hearing loss or speech discrimination is not an issue, ANLs should be measured monaurally to help clinicians determine which ear to fit with amplification. Lastly, binaural amplification significantly improved masked SRTs; however, ANL values were not significantly altered. These results provide further evidence that ANLs and speech perception scores reflect two different reactions to background noise. Therefore, the differential effects of masked SRT and ANL support the use of both measures during hearing aid evaluations.

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