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ORIGINAL ARTICLE

Digits in noise testing in a multilingual sample of Asian adults

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ABSTRACT

Objective: Appropriate speech-in noise assessment is challenging in multilingual populations. This study aimed to assess whether first preferred language affected performance on an English Digits-in-noise (DIN) test in the local Asian multilingual population, controlling for hearing threshold, age, sex, English fluency and educational status. A secondary aim was to determine the association between DIN test scores and hearing thresholds.

Design: English digit-triplets in noise testing and pure-tone audiometry were conducted. Multiple regression analysis was performed with DIN scores and hearing thresholds as dependent variables. Correlation analysis was performed between DIN-SRT and hearing thresholds.

Study sample: 165 subjects from the Singapore Longitudinal Ageing Study, a population-based longitudinal study of community-dwellers over 55 years of age.

Results: Mean DIN speech reception threshold (DIN-SRT) was −5.7 dB SNR (SD 3.6; range 6.7 to −11.2). Better ear pure tone average and English fluency were significantly associated with DIN-SRT.

Conclusions: DIN performance was independent of first preferred language in a multilingual ageing Singaporean population after adjusting for age, gender and education. Those with poorer English fluency had a significantly lower DIN-SRT score. The DIN test has the potential to provide a quick, uniform method of testing speech in noise in this multilingual.

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Introduction

Speech-in-noise testing is considered the most representative measure available of our ability to hear in day-to-day life and of the functional deficit experienced by people with sensorineural hearing loss (Moore et al. 2014). It can aid in the identification and selection of hearing rehabilitation strategies (Smits, Goverts, and Festen 2013; Downes and Turton 2018). Several speech-in-noise tests have been developed for these purposes (Nilsson, Soli, and Sullivan 1994; Bench, Kowal, and Bamford 1979; Boothroyd, Hanin, and Hanth 1985), the most commonly used one in English-speaking communities being the Hearing In Noise Test (HINT) (Nilsson, Soli, and Sullivan 1994).

However, understanding speech-in-noise depends on several factors other than hearing ability, such as cognitive factors, age, linguistic ability and experience with hearing devices (Torkildsen et al. 2019). The linguistic complexity of sentence tests involves significant cognitive demand and requires a certain level of language proficiency as compared to that of digits (Smits, Goverts, and Festen 2013; Koole et al. 2016). The applicability of sentence tests is therefore limited since the performance of listeners with more severe hearing impairment, limited linguistic skills in the test language and children, for example, may be severely impacted (Smits, Goverts, and Festen 2013).

The problem is compounded in a multilingual society. Studies involving non-native listeners have demonstrated the contribution of linguistic skills, including language proficiency and auditory processing, to the recognition of sentences in noise (Marinova-Todd, Siu, and Jenstad 2011). The language of test items has been shown to significantly affect test accuracy in speech audiometry (words in babble noise) for non-native English speakers, and hearing loss increases the confounding effect of language on their performance in English speech-in-noise testing (Marinova-Todd, Siu, and Jenstad 2011).

The Dutch Digits-in-Noise (DIN) test was first developed in 2013 (Smits, Goverts, and Festen 2013) based on the telephone version developed in 2004 (Smits, Kapteyn, and Houtgast 2004). It requires listeners to repeat three spoken digits presented through headphones, while a continuous masking noise is presented to the same ear. A computer program was developed to play the speech and noise files, adjust the signal-to-noise ratio (SNR) and record and judge the response. The SNR is adjusted for each successive digit-triplet presentation by presenting a higher or lower noise intensity depending on whether the response of the previous digit-triplet was correct or not. A

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speech reception threshold is then determined. The results show high reliability and high correlation with sentence speech reception threshold (SRT), whilst having a low standard error of measurement (Kaandorp et al. 2015).

DIN testing has been successfully used in listeners with hearing loss up to severe hearing impairment, cochlear implant users, children and non-native listeners (Kaandorp et al. 2016; Kaandorp et al. 2015). As such, it has been proposed as one method of measuring speech recognition ability in noise that is suitable for a wide range of listeners. The use of digits renders the test predominantly one of the auditory periphery by minimising the top down input required to process very simple words in a closed set paradigm (Smits, Goverts, and Festen 2013). While understanding digits may not be fully representative of a patient's ability to hear in real-life situations, digits are some of the first words learned in a non-native language. They are therefore more universally applicable than sentence tests in a multilingual population (Potgieter et al. 2018).

The DIN has been utilised as a hearing screening tool for large populations and in populations where distance from and/or lack of access to audiological facilities may otherwise preclude them from having a hearing test (Jansen et al. 2013; Denys et al. 2018). A telephone version was originally used as a remote screening tool in the Netherlands (Smits, Merkus, and Houtgast 2006) and has subsequently been utilised in England, Australia, Germany, Poland, Switzerland, France and the United States (Folmer et al. 2017; Smits, Goverts, and Festen 2013; Smits et al. 2016). In Asia, a Korean version of the DIN has been developed for smartphone-based hearing screening (Han et al. 2020). Recently, the use of the DIN test has become more diverse, including the World Health Organization smartphone application hear WHO, which currently supports English, Mandarin and Spanish versions (Swanepoel et al. 2019). Modification of DIN testing protocols has enabled more accurate and earlier identification of high frequency hearing loss (Vlaming et al. 2014; Vercammen et al. 2018; Zadeh et al. 2021). The use of antiphasic stimulus testing may potentially allow categorisation of conductive hearing loss as well (De Sousa et al. 2020). In terms of hearing assistive device selection and fitting, DIN has been shown to be highly correlated with (Zhang et al. 2019) and more feasible (Kaandorp et al. 2015) than standard speech-in-noise tests in assessment of candidacy for and progress following cochlear implantation. It has also been employed successfully in personalised remote care (Cullington et al. 2018) and has recently been implemented in the "Remote Check" function on Cochlear's Nucleus Smart App (Cochlear Limited, Sydney, Australia) for cochlear implant users to perform remote integrity checks. Auditory training with a digits-in-noise task has been shown to improve cochlear implant users' speech recognition, including HINT sentence-in-noise SRT (Oba, Fu, and Galvin 2011). This highlights its potential not only as a monitoring but also a training tool.

Singapore is a small (5.7 million people) (Statistics Singapore 2015), multiethnic, multilingual country. Based on a nation-wide census, 74.4% of the population are ethnically Chinese, 13.4% Malay and 9.0% Indian (Statistics Singapore 2015). Amongst the ethnic Chinese over 55 years of age alone, 24% prefer to speak English, 39% Mandarin and 37% Chinese dialects (Statistics Singapore 2015), of which there are more than 20 (Lee 2017). Most speak two or more languages well. Locally validated speech audiometry tools do not exist in most of the languages spoken, and tests developed in other countries (eg Mandarin tests developed in China) have limited validity due to the locally contextualised use of language. A speech-in-noise test which is universally applicable and administrable would improve accessibility.

The aim of this study therefore is to assess whether first preferred language affected performance on an English DIN test in the local Asian multilingual population, controlling for hearing threshold, age, sex, English fluency and educational status. A secondary aim is to determine the association between DIN test scores and hearing thresholds. We hypothesise that English DIN testing is a universal method for assessment of speech-in-noise recognition amongst our multilingual population, even amongst participants with no or little knowledge of English and a range of hearing losses.

Materials and methods

Participants

The Singapore Longitudinal Ageing Study (SLAS) is a population-based longitudinal study of ageing and health transition of community-dwelling older Singaporeans aged 55 years and above (ClinicalTrials.gov Identifier: NCT03405675). To date, about 6000 older adults from two waves of recruitment (SLAS-1 beginning in 2004 and SLAS-2 in 2009) have been followed up at three to five yearly intervals for cognitive, mood and physical function measurements. Hearing loss was previously determined by the whispered voice test; no audiological data were collected. The analytic cohort for this study comprises SLAS participants who lived in the area close to the general hospital where the study was to be conducted. They were telephoned by research nurses and invited to participate in audiometric and cognitive testing.

Participants were recruited only if they had no known diagnosis of dementia and were able to communicate in English or Mandarin. Those who agreed to participate gave written informed consent.

A cohort of 185 participants was recruited for the study. Face-to-face structured interviews were conducted by trained research assistants at the study centre. Demographic information including first and second spoken language preference and education level was recorded. The demographics are described in Table 1.

Table 1. Participant demographics.

	All (n = 165)	
Age (mean, median, SD, min, max, IRQ) (years)	72, 71, 6, 60, 85, 10	
Sex (n,%)		
Male	52 (31.5)	
Female	113 (68.5)	
Language (n,%)	First	Second
English	30 (18.2)	14 (8.5)
Mandarin	86 (52.1)	45 (27.3)
Hokkien	20 (12.1)	48 (29.1)
Cantonese	17 (10.3)	22 (13.3)
Teochew	7 (4.2)	13 (7.9)
Hakka	4 (2.4)	8 (4.8)
Other	1 (0.6)	15 (9.1)
English fluency (n,%)		
Good	30 (18.2)	
Fair	14 (8.5)	
Poor	121 (73.3)	
Education level (n,%)		
No education	20 (12.2)	
Primary	61 (37.0)	
Secondary	70 (42.4)	
Diploma/university/post-grad	14 (8.5)	

A variable was developed to capture English fluency. English fluency was categorised as High if English was their primary language, Medium if English was their secondary language and Low if English was not their primary or secondary language (see Table 1).

Hearing assessment

The hearing assessment was carried out by English and Mandarin speaking trained research assistants in a quiet room. Communication took place in English or Mandarin, according to each participant's choice, regardless of their preferred first or second language.

Otoscopic examination was carried out and any occluding wax removed prior to the hearing assessments.

Automated pure tone audiometry was performed using a fully automated audiometer (KUDUWave^{TM}, eMoyo, Johannesburg, South Africa). This audiometer utilises insert earphones for air conduction audiometry covered by circumaural earcups providing attenuation similar to a single-walled sound booth (Swanepoel et al. 2015). The audiometer was calibrated according to ISO389-2 and IEC60318-5. Pure tone thresholds were obtained using the modified Hughson-Westlake method (Carhart and Jerger 1959). Air conduction thresholds at octave frequencies from 0.25 to 8 kHz were measured bilaterally. Hearing loss was defined as a pure tone average of thresholds at 0.5, 1, 2 and 4 kHz of ≥25 dB HL in the better ear (World Health Organization 1991) (better ear pure tone average, or BEPTA).

A recorded South African-English DIN test (Potgieter et al. 2015) was conducted using custom-written software on a laptop computer and Sennheiser HD201 headphones (Wedemark, Germany). The listener was presented with digits being repeated and allowed to adjust the volume to a comfortable level. Participants were asked to repeat all the digits that they heard after each digit triplet presentation. The research assistant used the keyboard to enter the spoken responses for all participants since some participants were not familiar with using a laptop keyboard. The test comprised a series of 24 randomly chosen digit-triplets (zero to nine, including the bisyllabic digit seven) presented diotically in background noise to estimate the SRT. This was recorded as the Digits-In-Noise speech reception threshold (DIN-SRT). The SRT represents the SNR at which the listener correctly recognises 50% of the triplets. An adaptive procedure was used, in which the SNR of each digit-triplet depended on the correctness of the response on the previous digit-triplet, with the subsequent digit-triplet presented at a 2 decibels (dB) higher SNR after an incorrect response and at a 2 dB lower SNR after a correct response. The average SNR of triplet 5 to triplet 24 was calculated to determine the SNR score required to achieve 50% correct triplet recognition (ie the SRT).

Statistical analysis

The distribution of the dependent variables (BEPTA and DIN SRT) was tested for normality using the Kolmogorov-Smirnov statistic, skewness, kurtosis and the Q-Q plot (Field 2009). These showed that BEPTA was normally distributed, but whilst skewness and kurtosis of DIN SRT were within acceptable limits, the Kolmogorov-Smirnov statistic was 0.151 ($p < 0.001$) and the Q-Q plot also showed a substantial deviation from normal distribution. The DIN SRT scores were therefore transformed by $\log_{10}$(DIN SRT + 11.21) before simple regression analyses and designated as DIN SRT_t. The transformed scores were normally distributed on the basis of the results of the four tests mentioned above. The descriptive statistics used scores that were not transformed.

Multiple regression analysis was conducted as follows: (i) with DIN SRT_t as the dependent variable and age, sex, education level, first language, English fluency and BEPTA as independent variables to examine factors affecting the DIN SRT_t and (ii) with BEPTA as the dependent variable, and age, sex, education level, first language, English fluency and DIN SRT_t as the independent variables to examine the predictors of hearing sensitivity. Prior to the multiple regression analysis, a simple regression analysis for each predictor variable was undertaken to identify which variables to enter into the multiple regression analysis. A significant association for the simple regression analyses was indicated when $p < 0.1$ ie for inclusion in the multiple analysis. A significant association for the multiple analysis was indicated when $p < 0.01$. Correlation analysis was performed between DIN-SRT and BEPTA.

Data analysis was conducted using SPSS (Version 26.0. Armonk, NY: IBM Corp).

Results

Participants were removed from the analysis if they did not provide education level ($N = 16$). An examination of outliers in DIN-SRT revealed four instances of |z-score|>3 (DIN-SRT = 9.1, 9.5, 11.0 and 17.1 dB SNR); these participants were also removed from the analysis, leaving a sample of 165 participants.

The mean BEPTA was 25 dB HL (median 24 dB; SD 12; range 3 to 64; IRQ 15 dB HL). A majority (119/164, 72.6%) of participants had at least mild hearing loss (BEPTA ≥25dB HL).

The mean DIN-SRT was −5.7 dB SNR (SD 3.6; range 6.7 to −11.2; IRQ 4.5 dB SNR). The mean DIN-SRT for those with normal hearing (BEPTA < 25db HL; $n = 46$) was −7.3 dB SNR (SD 3.5). DIN-SRT scores were significantly associated with BEPTA ($\beta = 0.165$, $p < 0.001$, 95%CI 0.125 to 0.206) (Figure 1). The Pearson correlation between DIN-SRT and BEPTA was 0.534 (95%CI 0.415 to 0.635) (Figure 1).

DIN testing for individuals in a multi-language setting

Simple regression analysis on each variable separately revealed that as well as BEPTA, the variables age, first language, English fluency and educational status had statistically significant associations with DIN-SRT_t ($p < 0.01$). Lower BEPTA, lower age, English as a preferred first language, higher English fluency and more education were all associated with lower (ie better) DIN-SRT_t scores. Only sex was not associated with DIN-SRT_t ($p = 0.62$).

Multiple regression analysis with all the variables significantly associated with DIN-SRT_t, showed that only BEPTA ($\beta = 0.010$, $p < 0.001$, 95%CI 0.007 to 0.014) and English fluency ($F(1,57) = 7.10$, $p = 0.009$) were significantly associated with DIN-SRT_t. Age ($\beta = 0.008$, $p = 0.031$, 95%CI 0.001 to 0.015), first preferred language ($F(5,57) = 0.955$, $p = 0.448$) and education status ($F(3,57) = 3.63$, $p = 0.015$) were not independent predictors of DIN-SRT_t. Greater English fluency was associated with better DIN SRT scores; those with the highest English fluency had a mean SRT score that was 1.86 dB but not significantly better (two-sided $p = 0.069$) than those with medium fluency and 3.01 dB and significantly better (two sided $p < 0.001$) than those with the lowest English fluency.

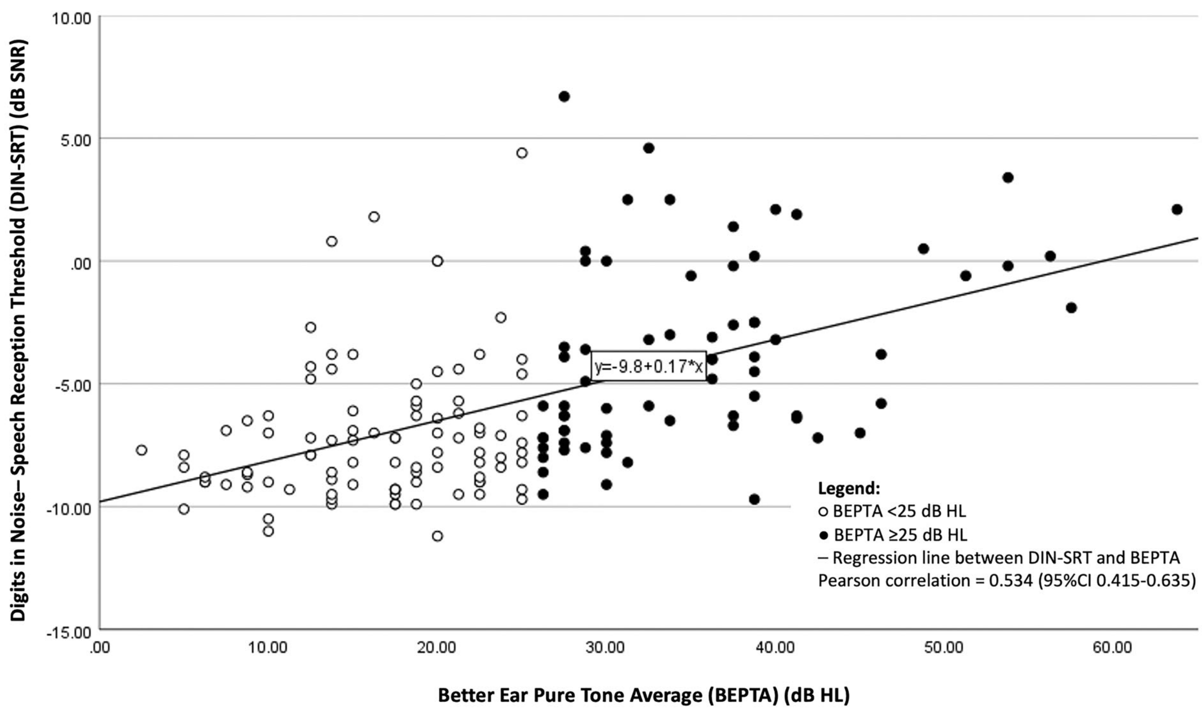

Figure 1. Association between DIN-SRT and BEPTA.

DIN association with PTA

Multiple regression analysis with BEPTA as the dependent variable and age, sex, DIN-SRT$_t$, education, first language and English fluency as independent variables showed that sex ($F(1,128)=9.18$, $p=0.003$) and DIN-SRT$_t$ ($\beta=21.364$, $p<0.001$, 95%CI 16.017 to 26.710) were significant predictors of hearing sensitivity. Age ($\beta=0.321$, $p=0.043$, 95%CI 0.011 to 0.632), first language ($F(5,12)=1.91$, $p=0.097$), English fluency ($F(1,128)=5.31$, $p=0.023$) and education status ($F(3,128)=2.50$, $p=0.063$) were not significant predictors. The mean BEPTA for men (30 dB HL) was 8 dB HL greater than that for women (22 dB HL).

Discussion

Assessment of speech-in-noise recognition in communities such as Singapore, where multiple languages are spoken by relatively small numbers of people, can be problematic. This is because speech-in-noise test materials for most of the relevant languages either do not exist, are not validated, or have been developed in another country. For example, the Standard Mandarin that is spoken in mainland China and Standard Singaporean Mandarin have differences in accent and lexicon. The results of our study show that the DIN test may provide a pragmatic solution to testing in this environment in participants with some degree of English-speaking competence. English DIN-SRT score is independent of preferred first spoken language but is significantly associated with hearing sensitivity and English fluency after multiple regression analysis. The DIN-SRT scores of participants with the lowest English fluency were significantly poorer than those of participants with medium to high English fluency.

Previous use of the DIN test in non-native listeners has shown that the effect of poor language skills is minimised using digits. Non-native listeners have been shown to only need 0.8 dB higher SNR than native listeners to recognise 50% of the digits correctly (Kaandorp et al. 2016). In a study of 458 listeners who represented all 11 officially spoken languages in South Africa, English language-speaking competence has also been shown not to be a significant predictor of DIN-SRT in participants with self-reported English speaking competence of 6 and above (1 = no competence, 10 = perfect competence) (Potgieter et al. 2018). However, subjects with self-reported English-speaking competence of 5 or poorer performed significantly poorer ($p<0.01$) in the DIN test. This complements our findings that show that those with the lowest English fluency (ie English was not their first or second language) had a mean score about 3 dB SNR lower and significantly worse, than those with the best English fluency. However, direct comparison between findings in these two different settings should be done with caution, because the English competence in Singapore is slightly better overall (Ang 2021). The mean DIN-SRT reported in the South African study in normal hearing listeners was −10.2 dB SNR (SD 1.6) in all listeners and −8.7 dB SNR (SD 1.9) in non-native listeners with poorer self-reported English speaking competence, showing slightly better performance and less variability in both groups than seen in the current study population (mean −7.3 dB SNR, SD 3.5 for all listeners with normal hearing. The poorer performance in the current study population may be because the test was presented in South African English rather than in a Singaporean accent. It could also be attributed to the younger demographic of the South African population (age range 16–81 and 16–67 years for all listeners and non-native listeners respectively versus 60–85 years in this study). It has previously been reported that DIN-SRT declines substantially during late middle age in association with declining cognitive processing ability (Moore et al. 2014). Age was not a predictor of DIN-SRT in our study after multiple analysis, though our sample only included a narrow age range.

This study also demonstrates that DIN-SRT is a significant predictor of hearing sensitivity ($p<0.001$) and may therefore be considered for use as a screening test in the multilingual

Singaporean population. The association between DIN-SRT scores and BEPTA has previously been reported. The correlation between four frequency pure tone average (0.5,1,2,4 kHz) and DIN-SRT in a mixed sample of normal hearing and hearing impaired participants has been reported to range from 0.77 (Jansen et al. 2010) to 0.82 (Smits, Kapteyn, and Houtgast 2004). A correlation of 0.66 was found when reporting hearing impaired individuals alone (age range 31 to 75 years, mean 63.4) (Vlaming et al. 2014). These values are similar to the correlations of 0.7 to 0.8 reported between sentence SRTs and PTA for normal-hearing and hearing-impaired listeners (Jansen et al. 2010), indicating that no perfect correlation exists between SRTs in noise and pure tone thresholds. Nevertheless, the correlation of the DIN test with PTA is comparable to that of sentence tests with PTA. The lower correlation in our study of 0.534 may be attributable to a cognitive factor given the older age group of our sample, a different mix of language of the populations in each study, or the fact that our sample is more heterogenous than that in the other studies.

This study is the first to report on the use of DIN-SRT in a multilingual Asian population where the languages spoken include multiple tonal and non-tonal languages. The study was able to capture a good representation of the Singaporean multilingual demographic as it was a prospective population-based sample, comprising a range of participants both with and without hearing loss. One limitation is the lack of power analysis performed, which may result in a lack of statistical power to detect the effect of first language in the population. A nationwide census (Statistics Singapore 2015) showed that the Singaporean population overall are more likely to speak English and less likely to speak a Chinese dialect as their first preferred language than was reflected in our study sample; this can be explained by the older age of our sample compared to that of the census. The limitations of the DIN test in those with poorer English fluency may therefore be less relevant in the population as a whole than in the older population in whom this study was performed. Conversely, the study was limited to participants who were able to communicate in English or Mandarin, as test material for other synchronous studies on the same participants was only available in these two languages; the findings may therefore not be applicable to other language speakers in Singapore. Additional studies are needed to further evaluate the DIN test in a younger cohort with a better mix of participants with low, medium and high English fluency more consistent with the general local population and also to assess the use of DIN-SRT for hearing assistive device selection and fitting to expand the potential roles of the test in this population.

Conclusion

DIN performance was independent of first preferred language in a multilingual ageing Singaporean population after adjusting for age, sex and education. English fluency, based on English as first, second or non-preferred language, had a significant influence on DIN-SRT. The DIN test has the potential to provide a quick, uniform method of both hearing screening and testing speech in noise in multilingual populations.

Further studies are warranted in multilingual populations to establish norms in poorer English speakers, in participants with more severe hearing losses and to facilitate hearing device selection and fitting.

Ethical approval

The study was approved by the National Healthcare Group Domain Specific Review Board (NHG DSRB Ref: 2016/00962).

Informed consent

Informed consent was obtained from all participants

Geolocation information

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

Data not available due to ethical restrictions.

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