Title

Unveiling the potential of the Digit-in-Noise test as a hearing screening tool for older adults with cognitive impairment

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Running title

Digit-in-noise in cognitive impairments

Keyword: Alzheimer's disease, Hearing tests, Hearing loss, Cognitive dysfunction, Speech perception

Abstracts

Background: The Digit-in-Noise (DIN) test is recognized as a promising hearing screening tool due to its feasibility and reliability, particularly in noisy environments. Although endorsed by the World Health Organization for general population hearing screening, it hasn't been validated in older adults with cognitive impairment, such as mild cognitive impairment (MCI), and dementia, including Alzheimer's disease.

Objective: To address this gap, this study aimed to evaluate diagnostic accuracy of DIN compared to pure tone audiometry, marking the first validation of the DIN test in this specific group.

Methods: Participants with MCI and dementia were recruited from memory clinics. Each participant underwent an audiologic evaluation, including the Hearing Handicap Inventory for Elderly (HHIE), Pure tone audiometry (PTA), and smartphone-based Digit-in Noise Test. Additionally, the Montreal Cognitive Assessment (MoCA), was administered.

Results: Among 93 adults (mean age 71.9), an optimal Speech Reception Threshold (SRT) cutoff of –3.5 dB yielded 90.5% sensitivity and 50% specificity for detecting moderate hearing loss. The area under the curve was 0.649 for mild hearing loss and 0.746 for moderate. A significant weak positive correlation was observed between SRT and PTA ($\rho = 0.35$, $p < 0.001$)

Conclusion: Our findings underscore the potential of the DIN test in detecting disabling hearing loss among cognitively impaired individuals, which warrants immediate hearing intervention to improve their quality of life.

Trial Registration: Thai Clinical Trials Registry (TCTR20221222004)

https://www.thaiclinicaltrials.org/

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Introduction

There is a global shift towards an aging population, accompanied by a rising prevalence of age-related conditions such as dementia and hearing loss, which together pose a significant public health challenge.[1, 2] Hearing loss is particular common in memory clinic populations, affecting up to 90% of cases.[3] Given the well-established association between hearing loss and cognitive impairment, hearing loss stand out as the largest potentially modifiable risk factor for dementia at population level.[4]

Although dementia remains an irreversible condition, mild cognitive impairment (MCI) serves as a transitional state between normal cognitive function and dementia. Approximately 80% of individuals with MCI are anticipated to progress to Alzheimer's disease within a six-year follow-up, although spontaneous reversion to normal cognitive function is observed in up to 26% of cases.[5-7] This variability makes MCI a critical window for intervention.

While individuals with MCI can generally achieve comparable standard audiometry to those with normal cognition, subtle deficits in auditory-cognitive processing may still affect test performance in certain aspects, such as response time.[8, 9] Recent studies have reported that hearing interventions, such as hearing aids, may be associated with slower cognitive decline, particularly among individuals at higher risk for dementia, highlighting the importance of timely intervention.[10-12] Therefore, early identification of hearing impairment in this population is strategically important. However, several barriers hinder the implementation of hearing screening, including high patient volumes, limited access to standard hearing tests, such as pure-tone audiometry, and cognitive challenges.[13] These limitations underscore the need for a practical and effective screening option tailored to the needs of this at-risk group.

Digits-in-noise (DIN) test has gained attention as a promising screening tool for detecting hearing impairment.[14] In the DIN test, sets of three spoken digits are embedded in speech-like noise to determine the speech reception threshold (SRT), which is measured relative to the noise level in dB SNR (signal-to-noise ratio). This test offers several advantages, including rapid administration, self-automation, high diagnostic performance, availability across multiple platforms, minimal learning effects, and robustness to age-related performance changes.[15, 16] Moreover, the DIN test may effectively assess listening difficulties in noisy environment, a common feature of central auditory processing disorder (CAPD), which is frequently observed in adults with age-related hearing loss and cognitive decline.[17-19]

Although the World Health Organization endorses the DIN test for hearing screening in older adults,[1] there is a paucity of studies examining its performance in individuals with cognitive impairment.[20] This study aims to bridge this gap by evaluating the screening accuracy of the DIN test, as compared to standard pure-tone audiometry, in this specific cohort.

Materials and Methods

Participants

This cross-sectional study consecutively enrolled participants from the memory clinic at the King Chulalongkorn Memorial Hospital, Thailand, between December 2022 and June 2023. The inclusion criteria stipulated that the participants were 50 years of age or older and had a diagnosis of mild cognitive impairment (MCI) or dementia, regardless of etiology. Cognitive diagnoses were established by experienced neurologists or geriatric psychiatrists based on comprehensive clinical evaluations and neuropsychological testing in accordance with the ICD-10 criteria.[21] Both of which involve subjective and objective cognitive decline, such as impairments in memory or attention, while dementia is further characterized by significant functional impairment in daily activities. The MoCA served as a supplementary tool to inform clinical judgment but was not used as the sole criterion for diagnosis. The study protocols were approved by the Institutional Review Board of the Faculty of Medicine, Chulalongkorn University (IRB No. 0513/65), and registered in the Thai Clinical Trials Registry (TCTR20221222004). All participants provided written informed consent before participation.

Measures

Participant characteristics. Demographic data, including age, sex, and the highest level of education, were collected. The diagnosis of the type of cognitive impairment was documented. To assess self-perceived hearing difficulty, a global question was posed to determine self-reported hearing issues ("Do you have a hearing problem now?" with a yes/no response), and the Hearing Handicap Inventory for the Elderly Screening version (HHIE-S) was administered. Additionally, the Montreal Cognitive Assessment (MoCA), a neuropsychological test, was conducted.

Pure-tone audiometry. Audiometric testing was performed using an AC40 clinical audiometer (Interacoustics A/S, Denmark) with calibrated supra-aural headphones or inserted earphones in a soundproof booth. We used the average air conduction pure tone average (PTA) over the frequencies of 500, 1000, 2000, and 4000 Hz of the best ear to report hearing thresholds. The severity of hearing loss was classified as mild (≥ 20 dB to < 35 dB HL) and moderate hearing loss and worse (≥ 35 dB HL) based on the World Health Organization classification.[22]

Digits-in-Noise test. The Digit-in-noise (DIN) test was conducted using a smartphone-based "EarTest by Eartone." available for both iOS and Android platforms. The test was selfadministered in a quiet office setting, with the app automatically checking the ambient noise levels before beginning the test. Testing was not initiated if the noise level exceeded an acceptable threshold. Two pre-calibrated devices were used for this test: 1) a Samsung Galaxy Tab A8 with Sennheiser HD 280 Pro headphones and 2) an iPad Mini 6 with Apple AirPods2. According to study of Nilchaeng et al. (2024), the mean difference between the two devices was -0.725 dB SNR ($p < 0.001$), with 97.5% agreement within a 2 dB SNR range. After setting a comfortable listening level and conducting training trials, triplets were presented via headphones in the presence of a speech-shaped background noise. Participants were asked to press the three numbers they heard on the screen, including all digits from 0 to 9. A total of 24-digit triplets were utilized. The signal-to-noise ratio varied adaptively according to the previous response answers. The speech reception threshold (SRT) was determined by calculating the dB SNR required for the participant to correctly identify 50% of the triplets presented at a certain signal-to-noise ratio. Pure tone audiometry and digit-in-noise tests were conducted in randomized order.

Statistical analyses

All statistical calculations were performed using STATA version 17.0. Frequencies were determined for nominal and ordinal variables and means and standard deviations (SD) for normally distributed continuous variables. Pearson's correlation coefficient (r) and Spearman's rank correlation coefficient (ρ) were computed for variables that were or were not normally distributed. Sensitivity, specificity, and receiver operating characteristic (ROC) curves were also determined, and ROCs were used to examine the area under the curve (AUC) values for the optimal cut-off points to define hearing impairment. The significance level for Type I error was established at 0.05 for all analyses.

Results

Demographics

A total of 93 individuals were recruited for the study. After obtaining informed consent, participants completed both pure-tone audiometry and the Digit-in-Noise (DIN) test. The mean age was 71.9 ± 7.7 years, and 74.2% were female. The most common level of education was a bachelor's degree (39.8%), followed by high school (23.7%). Seven participants were identified as having dementia, and the overall mean MoCA score was 22.2 ± 3.3.

HHIE scores ranged from 0 to 40, with a mean of 5.3 ± 9.9. Based on a cut-off score of 8, 20.4% were classified as having a hearing handicap. According to audiometric testing, 69.8% had hearing impairment in the better ear, with 48.3% showing mild hearing loss and 21.5% having at least moderate hearing loss (PTA ≥ 35 dB). Notably, all participants in the dementia group had hearing impairment, with higher mean hearing thresholds compared to the MCI group. A summary of baseline characteristics is presented in Table 1.

Variables		**Total participants (n=93)**	**MCI (n= 86)**	**Dementia (n=7)**
Age, years	Mean (SD)	71.9 (7.7)	71. 3 (7.6)	71.8 (4.5)
Gender	Male, n (%)	24 (25.8%)	22 (25.5%)	2 (28.5%)
MoCA score	Mean (SD)	22.2 (3.3)	22.6 (3.1)	17.0 (4.1)
Self-reported hearing problem	%yes	45.1%	44.1%	57.1%
HHIE score	Mean (SD)	5.3 (9.9) 20.4%	4.8 (9.7) 15.1%	10.0 (14.9) 28.6%

	Handicap based on HHIE score			
Hearing threshold (Average $PTA_{0.5,1,2,4}$ the better ear)	Mean (SD)	26.9 (13.5)	25.7 (12.7)	44.7 (14.8)
	PTA 20.0-34.9 dB, n (%)	45 (48.3%)	41 (47.6%)	4 (57.1%)
	PTA ≥ 35 dB, n (%)	20 (21.5%)	17 (19.7%)	3 (42.8%)
	Hearing impairment (PTA ≥ 20 dB) (%)	65 (69.8%)	58 (67.4%)	7 (100%)

Table 1. Demographic data of participants

Sensitivity and Specificity of DIN test

Several SRT cutoff criteria from the DIN test were employed to determine the sensitivity and specificity for detecting mild hearing loss (HL) and worse (PTA values equal or more than 20 dB) and moderate HL and worse (PTA values equal or more than 35 dB) in the better ear, as detailed in Table 2.

	$PTA_{0.5,1,2,4} \geq$ 20 dB HL		$PTA_{0.5,1,2,4} \geq$ 35 dB HL	
SRT (dB SNR)	Sensitivity (%)	Specificity (%)	Sensitivity (%)	Specificity (%)
-5.5	89.1	27.6	90.9	21.1
-4	78.1	48.3	95.2	38.9
-3.5	68.8	58.6	90.5	50.0

Table 2. Values of SRT cut-off points and predictive accuracy for detecting mild/moderate hearing loss and worse

The performance of the DIN test in differentiating between impaired and normal hearing sensitivity was evaluated by plotting a Receiver Operating Characteristic (ROC) curve.

Additionally, the rea Under the Receiver Operator Curve (AUC-ROC) was computed, as shown in Figure 1. The AUC-ROC values for detecting mild HL and greater, and moderate HL and greater were 0.649 and 0.746, respectively. The optimal cutoff for SRT, estimated by maximizing the Youden index, was SRT of -3.5 dB SNR for differentiating moderate hearing loss and above (PTA ≥ 35 dB HL) from normal hearing.[23]

Correlation between SRT and other variables

As shown in Figure 2, a significant weak positive correlation between the SRT and $PTA_{0.5,1,2,4}$ (pure tone average threshold across 500, 1000, 2000, and 4000 Hz) in the better ear was observed, with Spearman's rank correlation coefficient (ρ) of 0.35 ($p < 0.001$).[24]

There were non-significant correlations between SRT and age (r= 0.14, p= 0.17), MoCA score (ρ = -0.15, p= 0.16), and HHIE score (ρ= 0.19, p= 0.06).

Correlations between PTA and other variables

There were significant moderate positive correlations between PTA and age, as well as PTA and HHIE score, with Spearman's rank correlation coefficients of 0.49 (p= 0.00) and 0.48 (p= 0.00), respectively, as illustrated in figure 3. A moderate negative correlation was observed between MoCA score and age ($r = -0.326$, $p < 0.05$).

For the significant correlations, r^2 values were calculated to assess the proportion of variance explained. The SRT accounted for 12.1% of the variance in PTA. Age explained 24.6% of the variance in PTA and 10.6% of the variance in MoCA scores. PTA was also significantly associated with HHIE-S scores, accounting for 23.2% of the variance. Table 3 presents Pearson and Spearman's rank correlation coefficient among variables.

Variables	SRT	PTA	Age	MoCA score	HHIE-S score
SRT	1				
PTA	0.3478*	1			
Age	0.1435	0.4964*	1		
MoCA score	-0.1455	-0.1403	-0.326*	1	
HHIE-S score	0.1926	0.4812*	0.1419	-0.1182	1

* Significant correlation at the 0.05 level

Table 3. Pearson (Spearman) Correlation Coefficients Analysis

Discussion

Hearing loss is a highly prevalent condition among older adults, particularly among those with cognitive impairment. The high prevalence of hearing loss in memory clinics underscores the importance of effective screening. Detection of hearing impairment is imperative because hearing interventions are considered cost-effective and have been associated with potential benefits in cognitive function and quality of life.[1, 11] One such method recommended for hearing screening is the Digit-in-Noise test. Our study results, corroborated by existing studies, suggest that the DIN test is a valuable and promising tool for hearing screening in this population.

Our findings indicate that the DIN test demonstrates high sensitivity in detecting hearing loss among older adults with cognitive impairment, rendering it an appropriate screening instrument.[25] At an SRT cutoff of -5.5 dB, sensitivity for identifying PTA ≥ 20 dB and ≥ 35 dB was 89.1% and 90.9%, respectively, while specificity was low (27.6% and 21.1%). Increasing the cutoff to -3.5 dB reduced sensitivity for PTA ≥ 20 dB (68.8%) but maintained high sensitivity for ≥ 35 dB (90.5%), with improved specificity (58.6% and 50%). These values align with previous studies reporting sensitivities ranging from 55–95% for detecting various degrees and frequency ranges of hearing loss across different populations.[15] Notably, the test showed stronger diagnostic performance for moderate hearing loss, with AUC-ROC values of 0.649 (≥ 20 dB) and 0.746 (≥ 35 dB). This is consistent with a large cohort study by Koole et al. (2016), which reported higher AUC-ROC for detecting moderate compared to mild hearing loss in older adults using the DIN test.[26]

However, the AUC values observed in our study were lower than those reported in some previous studies.[26] This may be explained by several factors. Individuals with cognitive impairment may exhibit guessing behavior or variability in attention, which can affect response accuracy and reduce the test's discriminative ability. Moreover, the chosen cutoff point (−3.5 dB) was selected to prioritize sensitivity and minimize missed cases, which may have compromised specificity. These factors, combined with the inherent limitations of speech-in-noise tests in distinguishing mild hearing loss from normal hearing, likely contributed to the moderate AUC values observed.

In our study, at the −3.5 dB cutoff, the DIN test demonstrated high sensitivity for detecting moderate hearing loss, with a low false-negative rate (2.2%), minimizing missed cases. However, the high discrepancy rate, largely due to a substantial number of false positives (38.7%), raises concerns about over-referrals and potential anxiety. As the test requires sustained attention, lapses in concentration or cognitive impairment, particularly in individuals with more advanced dementia, may adversely affect performance. Furthermore, the regression analysis revealed a weak positive correlation between DIN SRT and PTA (ρ = 0.35), with an R^2 of 0.12, indicating that only a small proportion of the variance in PTA can be explained by DIN scores. These findings support the DIN test as a useful initial screening tool, though not sufficient for diagnostic purposes on its own.

As expected, significant moderate positive correlations were found between PTA and age (ρ = 0.49, p= 0.00), and between PTA and HHIE-S scores (ρ = 0.48, p= 0.00). Notably, our study revealed a statistically significant but weak positive correlation (ρ= 0.35, $p < 0.05$) between SRT from the DIN test and PTA obtained from pure tone audiometry. This finding diverges from previous research, which has demonstrated stronger correlations in different populations.[15, 16, 27] It is hypothesized that the DIN test may capture aspects of auditory processing and auditory ability in real-world scenarios, extending beyond hearing sensitivity measured by pure-tone audiometry in a quiet setting. In older adults with MCI and dementia, central auditory processing deficits tend to be more pronounced than in those with normal cognition,[19, 28, 29] and may not align with hearing sensitivity in audiograms. The discrepancy between DIN test results and pure-tone audiometry underlines the potential limitations of relying solely on conventional hearing assessments when evaluating hearing ability of older populations in individuals with cognitive impairments. Similar findings were reported in studies such as Utoomprurkporn et al. (2021) which were conducted in older adults with cognitive impairment, where self-reported questionnaires, the modified Amsterdam inventory for auditory disability (mAIAD) and the speech, spatial and qualities of hearing scale (SSQ), reflected hearing difficulties in sound localization, but the scores were not associated with hearing sensitivity in audiograms.[30] Future research should explore whether combining results from various auditory tests could yield a more comprehensive understanding of the hearing abilities and their impact on daily functioning in these populations.

A weak correlation was observed between SRT and HHIE-S score ($p = 0.06$). Although the HHIE-S is brief and convenient, its use instead of the full version may have contributed to underestimation of hearing loss, particularly in cases of mild impairment. Previous studies have shown that HHIE-S can yield false-negative rates of up to 36% when compared with pure-tone audiometry.[31] Several factors, such as older age, limited self-awareness of hearing deficits, and cognitive ability may also influence self-reported perceived hearing assessments.[32-35] While the HHIE-S offers practical advantages in clinical settings, it is important to balance feasibility with diagnostic depth, especially in memory clinic populations.

Our research proposes that an SRT cut-off of -3.5 is optimal for detecting moderate hearing impairment (PTA ≥ 35 dB) or level of disabling hearing loss. This finding is in agreement with multiple studies that have used similar cut-off score for the DIN test, indicating that an SRT above -3.5 dB SNR signifies poor auditory performance.[36, 37] Disabling hearing loss has a significant adverse impact on daily communication, with challenges in hearing and engaging in conversations even in quiet environments.[22] Individuals with more severe hearing impairment are thus more inclined to consider and adopt hearing aids.[38] Consequently, this threshold is often reflected in hearing aids reimbursement policies, e.g. in Thailand. We propose that individuals in memory clinics who fail DIN screening should be strongly encouraged to undergo a comprehensive evaluation, such as pure tone audiometry, to inform the need for hearing rehabilitation.

A large cohort study assessing speech-in-noise skills demonstrated that individuals with insufficient speech-in-noise ability (SRTn ≥ -5.5 dB to ≤ -3.5 dB) and poor speech-in-noise ability (SRTn ≥ -3.5 dB) exhibited an increased risk of dementia compared to those with typical speech-in-noise hearing, with hazard ratios (HR) of 1.61 and 1.91, respectively.[17] This suggests that the DIN test may be useful in identifying individuals at risk for dementia. Although its role in monitoring cognitive decline over time has not yet been established, the test's simplicity, lack of learning effect, and real-world applicability support its potential for future research as a monitoring tool in memory clinic populations.[14, 16]

Limitations

This study had several limitations. First, although it was conducted in a memory clinic setting, the majority of participants had only mild cognitive impairment, limiting its generalizability to those with more advanced dementia. Second, the relatively high false-positive rate at the selected cut-off may reduce the specificity of the DIN test and result in unnecessary follow-up assessments. Third, while the DIN test was administered via a smartphone and potential barriers related to age and impaired cognition exist, all participants were able to complete the test successfully.[39] Nevertheless, further research is needed to confirm the feasibility and diagnostic accuracy of the DIN test across varying levels of cognitive function and in more diverse real-world clinical settings.

Conclusion

Our findings indicate that the Digit-in-Noise (DIN) test is a practical screening tool for identifying disabling levels of hearing loss that warrant timely intervention in older adults with cognitive impairment. Although not a substitute for comprehensive audiometric evaluation, the DIN test provides useful insights into hearing performance, reflecting real-world listening difficulties. Incorporating the DIN test into memory clinic protocols may enhance the detection and management of hearing loss in this population, particularly within resource-limited or high-demand settings. Such integration could ultimately improve hearing health care and quality of life for patients in memory clinics.

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Statements and declarations

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Legends

Table 1. Demographic data of participants (N=93)

Table 2. Values of SRT cut-off points and predictive accuracy for detecting mild/moderate hearing loss and worse

Table 3. Pearson (Spearman) Correlation Coefficients Analysis

Figure 1. Receiver Operating Characteristic (ROC) curve for detecting mild hearing loss ($PTA_{0.5,1,2,4} \geq 20$ dB) and moderate hearing loss ($PTA_{0.5,1,2,4} \geq 35$ dB)

Figure 2. Scatter plot comparing $PTA_{0.5,1,2,4}$ in the better ear and SRT

Figure 3. Scatter plots of relationships between a) age and $PTA_{0.5,1,2,4}$ in the better ear b) HHIE-S score and $PTA_{0.5,1,2,4}$ in the better ear

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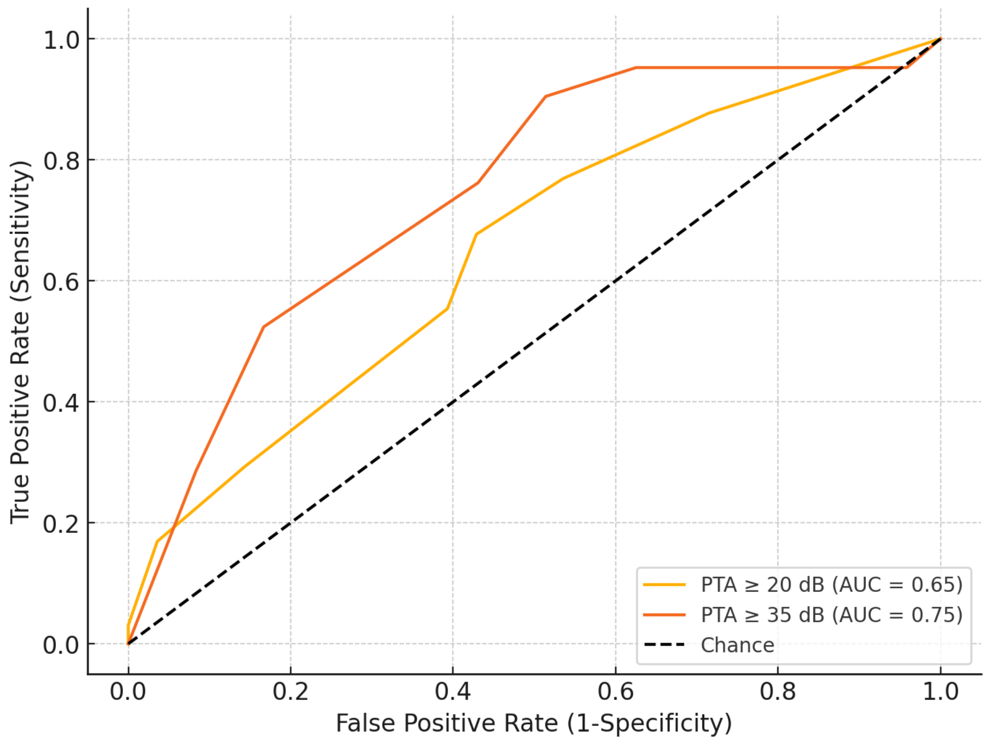

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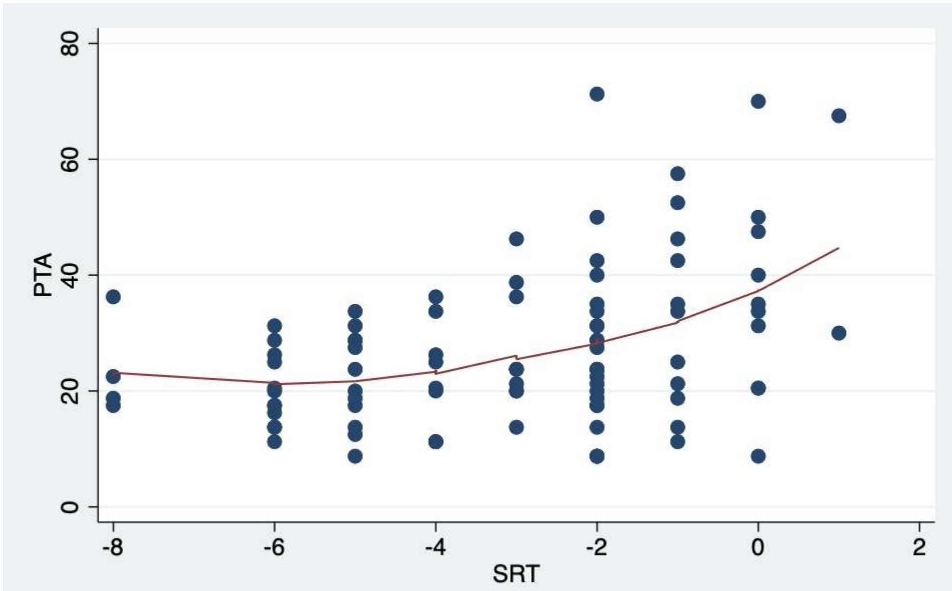

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