Auditory and Vestibular Research

The Relationship between Phonological Working Memory and Mean Length of Utterance in Normal and Hearing-Impaired Persian-Speaking Children

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Highlights:
- Strong correlation between PWM and MLU in children with hearing loss.
- Moderate correlation between PWM and MLU in children with typical development.
- Children with hearing loss performed worse in PWM and MLU.

Abstract
Background & Aim: Hearing impairment in childrn can affect language acquisition and consequently lead to delays in speech and language skills. The purpose of this study was to examine the relationship between phonological working memory (PWM) and mean length of utterance (MLU) in normal and hearing-impaired Persian-speaking children.
Methods: The study included 27 children with profound hearing loss (mean age = 5.42 ± 0.31 years) and 27 typically developing children (mean age = 5.62 ± 0.36 years), matched for age range (5–6 years) and gender (12

boys, 15girls). A nonword repetition task was used to assess PWM, and 50 utterances were selected from the obtained discourse samples to evaluate MLU.
Results: The relationship between these two variables was compared across the two groups. A strong and significant correlation was found between PWM and MLU in children with profound hearing loss (HL). Additionally, the correlation in typically developing children was moderate and significant.
Conclusion: A strong correlation between PWM and MLU was found in children with HL, whereas a moderate correlation was observed in typically developing children. These findings indicate the relevance of PWM to MLU in both groups, with a stronger association in children with hearing loss, without implying causality.
Keywords: Phonological working memory, mean length of utterance, profound hearing loss, children

Introduction

Hearing loss (HL) in infants and children is a significant public health concern due to its high prevalence and profound impact on developmental outcomes [1]. The prevalence of severe or profound HL in neonates is estimated at 1 to 1.5 per 1,000 births [2]. HL can interfere with children's verbal communication and language acquisition [3], often resulting in delays in speech and language development [4].

The auditory system, including the ear and the cerebral cortex, plays a fundamental role in cognition, particularly in memory and learning. The brain is responsible for receiving, retaining, and manipulating auditory information, a process closely associated with working memory (WM). Consequently, hearing loss can impact neural organization and auditory processing, potentially disrupting WM function [5]. Dumanlar et al. showed WM performance of children with HL was poorer than that of their peers with normal hearing [6].

Previous research has demonstrated a strong correlation between WM and the development of speech and language skills [7-9]. For instance, Ming Lo et al. found that the language difficulties observed in children with HL may be attributed to their limited WM capacity [9],. Furthermore, İkiz et al. found a significant correlation between verbal WM and language skills in children with mild to moderate HL [8]. Similarly, Veraksa et al. showed that enhanced verbal WM contributes to more accurate lexical and grammatical language output [7]. It is important to note that phonological levels of representation are primarily involved in verbal WM [10]. Stiles reported that children with weaker WM tend to have a more limited vocabulary range [11].Given the critical role of WM in language acquisition and cognitive development [12], understanding its influence on various linguistic parameters is essential.

WM serves as a bridge between short-term and long-term memory, allowing for the temporary storage and manipulation of information [12]. According to Baddeley’s model, WM consists of the central executive and three subsystems: the phonological loop, the visuospatial sketchpad, and the episodic buffer. The phonological loop, which is responsible for processing phonological information, is particularly relevant to language acquisition, as it supports the encoding and retrieval of phonological representations [4].

The phonological loop plays a crucial role in acquiring new vocabulary, particularly in learning unfamiliar phonetic structures [13]. Research suggests that phonological memory is positively correlated with vocabulary growth, making it a key component of linguistic development [14]. Additionally, studies on typically developing children indicate a strong relationship between vocabulary expansion and Mean Length of Utterance (MLU), an important measure of language development [15].

Given that WM significantly influences language acquisition [12] and that speech and language development are essential for overall cognitive growth, assessing language functions is critical. Language can be evaluated through standardized tests or language sample analysis, with the latter being considered one of the most reliable methods for assessing spontaneous language use in children [16]. Language acquisition refers to the initial process of learning a language, encompassing the acquisition of vocabulary, grammar, and phonological structures, which generally occurs naturally during early life. Language development, on the other hand, refers to the continuous enhancement and refinement of language abilities over time, including the production of larger and more complex sentences and the expansion of vocabulary.

Among language sample analysis measures, MLU is one of the most frequently used, appearing in 91% of clinical language assessments. MLU is typically calculated from a sample of 50 to 100 intelligible utterances [16]. An utterance is a communicative unit that occurs between two breaths, pauses, or silent intervals of the speaker [17].

Previous studies suggest that MLU is shorter in children with HL compared to their typically developing peers [18, 19]. Additionally, Koehlinger et al. found that children with HL face significant challenges in language learning, affecting both vocabulary and syntactic development [19]. Despite extensive research on WM and language development indicators, the precise relationship between phonological WM and MLU in children with HL remains underexplored. Also, Considering the limited availability and accessibility of standardized language tests in Persian, as well as the established validity of analyzing speech samples as a robust method for assessing children's language abilities in both research and clinical contexts [16], MLU was selected as the primary measure for this study.

A review of previous research indicates that the relationship between WM and language abilities in children with hearing impairment has been assessed using a variety of measures [6, 8, 11]. For instance, Dumanlar's study evaluated language abilities through subtests of vocabulary, sentence repetition, and sentence comprehension [6], a methodology similar to that employed by Stiles et al. who also focused on vocabulary-related measures [11]. Regarding WM, Dumanlar utilized verbal and visual memory subscale of WM scale [6], a method comparable to İkiz's study, which primarily focused on verbal memory scale [8]. Additionally, some of these studies show overlapping demographic characteristics, such as HL severity (mild to moderate) [8, 11] and children's age ranges [6, 11].

Previous studies in Persian have examined WM in children [5, 12]. . One study examined the performance of different types of WM in children with cochlear implants [12], while anotherinvestigated the relationship between WM and speech perception in noise [5]. However, neither study directly assessed the correlation between phonological working memory (PWM) and Mean Length of Utterance in morphemes (MLUm). This gap underscores the necessity of the present study, which specifically investigates the relationship between PWM and MLUm in both normal-hearing and hearing-impaired Persian-speaking children.

Despite previous research, key gaps remain: PWM has been less studied, most studies were conducted in non-Persian languages, and language abilities were primarily assessed using standardized subtests rather than MLU. To address these gaps, this study investigated the relationship between PWM and MLU in both normal and hearing-impaired Persian-speaking children.

Methods

This cross-sectional study was conducted between July 2024 and November 2024. The study received approval from the local Ethics Committee (Ethics Code: IR.UMSHA.REC.1403.185).

Study population and study participants

The statistical population encompassed children aged 5 to 6 years who are affected by hearing impairment and reside in the city of Hamadan. In contrast, the target population comprised 5 to 6-year-old children with hearing impairment who were receiving services at Newsha Center. Normal children, appropriately matched for age and gender with the experimental group, were selected from local kindergartens and incorporated into the study. All children in the hearing loss (HL) group were fitted with cochlear implants (CIs) and communicated through oral (spoken) language.

Participants were selected from the chronological age range of 5 to 6 years. Although working memory (WM) continues to develop throughout childhood, phonological working memory (PWM) has been shown to undergo substantial development and relative stability between ages 5 and 6, making this age range appropriate for examining correlations with language measures such as Mean Length of Utterance (MLU) [20].

The inclusion criteria for children experiencing hearing impairment are delineated as follows: diagnosis of profound HL, substantiated by audiometric evaluations performed by an audiologist using pure-tone audiometry (PTA). Children must fall within the age range of 5 to 6 years, as verified through clinical documentation or maternal corroboration. Furthermore, proficiency in Persian as the dominant language, confirmed by parental report and clinical observation of daily communication by a speech-language pathologist. The inclusion criteria for the control group encompassed the absence of HL, as evidenced in clinical documentation and validated through maternal inquiry, along with the demonstration of age-appropriate linguistic and speech capabilities, evaluated via the Newsha Developmental Scale [21, 22]. Exclusion criteria applicable to both cohorts encompassed the presence of comorbid conditions such as intellectual disability, cerebral palsy, seizure disorders. These conditions were evaluated through clinical documentation or by direct inquiry with the mother.

Sample size and sampling method

The sample size was estimated manually using the statistical formula based on a study by Derek J. Stiles et al. on "Vocabulary and Working Memory in Children with Hearing Aids" [11]. Using the forward digit span component and a power analysis with $\alpha = 0.05$ and $\beta = 0.20$, the required sample size for each group was calculated as 27 participants, comprising 12 boys and 15 girls in each group. Also, participants were recruited using a convenience sampling method.

Assessment measures and variables

Phonological working memory assessment

To assess the phonological loop component of WM, a standardized nonword repetition task developed by Afshar et al. for Persian-speaking children aged 4–6 years was administered [23]. Afshar and colleagues initially selected high-frequency words with one to five syllables from The Book of the Most Frequent Words of Today Persian to develop nonword repetition task, ensuring that these were consistent with the book of Persian Language Phonetics based on phonemes and syllable structure. They then matched these words with words containing one to five syllables extracted from the speech of typically developing children. A final list of words was prepared, and in accordance with Persian phonotactic regulations, one or two phonemes (consonants or vowels) were modified to create non-words, ensuring that they did not exist in the Persian lexicon [23].
The reliability of this instrument was validated with an internal consistency of 0.972. The test-retest reliability for the cognitive section of this scale was 0.979 [23]. Before the task, instructions were provided to the children and four practice nonwords were presented to ensure task comprehension. Participants were required to accurately repeat nonwords of varying syllable, including eight one-syllable, nine two-syllable, five three-syllable, and three four-syllable nonwords [23]. Each response was allotted 2 seconds, and scoring was based on correctly repeated syllables, with one point assigned for each correctly produced syllable. with a total score ranging from 0 to 53 [24]. In this study Cronbach's alpha was calculated to assess the internal consistency of the instrument.

Procedure

In the preliminary phase, following a visit to the Newsha Center and the acquisition of written consent from the parents, the clinical records of the children were scrutinized to ascertain the presence and severity of hearing impairment. Subsequently, by visiting the kindergarten and identifying the control group based on the age and gender of the experimental group, and after securing written consent from the kindergarten instructor, the health records of the children were examined to confirm the absence of hearing impairment.
Prior to the initiation of the second phase for typically developing children, the cognitive and expressive language sections of the Newsha Developmental Scale were administered for screening purposes to confirm typical language development and to rule out language disorders in the control group. The Newsha Scale provides a comprehensive and integrated evaluation of developmental progress that helps in identifying any delays in developmental abilities for Persian-speaking children from birth to age six [21, 22]. The required cut-off score for the cognitive section was 6-9, with a test–retest reliability of 0.95 [22], while for the expressive language section, the cut-off score was 2-3, with a test–retest reliability 0.980 [21].
The procedures applied to the HL group were consistent with those used for the typically developing children. The only modification was that the Newsha Developmental Scale was not administered to the HL group; all other procedures, including nonword repetition tasks, speech sample collection, verbal prompts, and recording conditions, were identical across both groups.
In the second phase, PWM was assessed using nonword repetition tasks [23]. All assessments were conducted individually in a quiet room, with only one participant present at a time. After each session, the participant left the room before the next participant entered. All participants were seated comfortably facing the examiner.

In the next stage, 50 utterances were extracted from continuous speech samples of children using a Zoom H6 recorder. Sessions were initiated with open-ended prompts (e.g., 'Can you tell me about your favorite game?', 'What do you usually do when you wake up in the morning?', and 'What would you like to be when you grow up?') to elicit speech samples, which were subsequently followed by free conversation. Each session lasted approximately 10–15 minutes. All children were provided with the same verbal prompts, and no visual cues were used during the sessions. Efforts were made to ensure that the voice recording process was conducted in a quiet environment for all participants. The same procedure and prompts were applied to both HL and typically developing children.

Utterance is defined as a communicative unit occurring between two speaker pauses [17]. A morpheme is the smallest meaningful unit of a word [25]. Based on these definitions and following the speech and language characteristics checklist for Persian-speaking children [26], the transcription process was carried out by the researcher. Subsequently, MLUm was calculated using the following formula: the total number of morphemes obtained divided by the total number of utterances [27].

Statistical analysis

For data Normality and Group Comparisons, following tests were conducted; The Kolmogorov-Smirnov test was used to assess the normality of variable distributions. The independent variable was group membership (control vs. hearing-impaired). Dependent variables included MLU and PWM performance. Pearson correlation coefficients were computed to determine the relationship between MLU and PWM in each group.

The effect sizes were interpreted as follows: weak effect: 0.1 – 0.3, moderate effect: 0.3 – 0.7 and strong effect: 0.7-1.0 [28].

Independent samples t-tests were performed to compare demographic variables (age and birth order) between the groups. Given the significant difference in age, Analysis of Covariance (ANCOVA) was used to compare the dependent variables (MLU and PWM) while adjusting for age as a confounding variable. Also, the eta-squared effect size was calculated, with values of 0.01, 0.06, and 0.14 indicating small, medium, and large effects, respectively [29].

In addition, multiple linear regression analysis was used to examine the effects of group, gender, and age on dependent variables. The coefficient of determination (R^2) was calculated to evaluate the fit of the regression model. The ANOVA was conducted to determine the statistical significance of regression models and assess the influence of predictor variables.

Results

This cross-sectional study involved a total of 54 children, with 27 children having normal hearing and 27 children experiencing profound hearing loss (HL). The two groups were matched as closely as possible in terms of age, gender, and birth order. Table 1 presents a comparison of the mean and standard deviation, along with the mean difference and significance level for the age and birth order variables between the normal and hearing-impaired children. Chronological age was calculated in decimal years by converting months into fractions of a year (months/12). Although a statistically significant difference in mean age was observed between the groups, inspection of individual age values shows that all participants fell within the same restricted age range of 5–6 years. The observed difference in mean age corresponds to approximately 3 months and reflects natural variation in sample distribution rather than a significant developmental difference.

The participants in both groups were matched within the same restricted age range of 5–6 years. Although the mean age differed slightly between the groups (difference = 0.20 years), this small difference reached statistical significance due to the sample size. Inspection of individual age values confirmed that participants in both groups were evenly distributed across the 5–6year range, ensuring appropriate age matching. The observed variance in working memory (WM) scores in the control group reflects natural individual differences rather than a mismatch in age or developmental status (table 2).The mean ± standard deviation of the cognition section in normal-hearing children was 8.40 ± 0.79, while for the expressive language section it was 2.66 ± 0.48..

Also, Cronbach's alpha was 0.95 in the present study sample, indicating excellent internal consistency for the nonword repetition task.

The t-test indicated a significant difference in mean age between the two groups ($p = 0.032$). However, no significant difference was found in terms of birth order ($p = 0.919$). Given the significant age difference, analysis of covariance (ANCOVA) was used to compare Mean Length of Utterance in morphemes (MLUm) and phonological working memory (PWM) while adjusting for age effects.

The gender distribution was identical in both groups. The chi-square test indicated no significant differences between the groups in gender distribution ($p = 1.000$).

The mean ± standard deviation of MLUm for normal hearing children was 5.26 ± 0.70, while for children with HL, it was 2.62 ± 0.75. The mean ± standard deviation of PWM for normal hearing children was 48.07±3.87, and for children with HL. After adjusting for age, ANCOVA indicated a significant difference in PWM between the two groups ($F(1,51) = 165.58$, $p < 0.001$, $\eta^2 = 0.76$, 95% CI [20.97 – 28.73]). Similarly, after adjusting for age, a significant difference in MLUm was observed ($F(1,51) = 183.30$, $p < 0.001$, $\eta^2 = 0.78$, 95% CI [2.35 – 3.16]). These findings indicate that the group variable significantly influences the difference in both PWM and MLUm between normal hearing and hearing-impaired children.

Various regression models were assessed. in one model, PWM was analyzed as the dependent variable using multiple linear regression, with group, gender, and age as predictor variables.

The coefficient of determination for the regression model was $R^2 = 0.779$. The results of the regression analysis indicated that the model explained 77.9% of the variance in phonological WM. The ANOVA results confirmed the statistical significance of the model ($p < 0.001$, $F(3,50) = 58.895$). The analysis of the standardized β coefficients showed that the group variable had the most significant negative impact on PWM ($p < 0.001$, $\beta = -0.900$), while the effects of gender ($p = 0.247$, $\beta = 0.079$) and age ($p = 0.260$, $\beta = 0.080$) were not statistically significant.

in another model, MLUm was analyzed as the dependent variable using multiple linear regression, with group, gender, and age as predictor variables.

The coefficient of determination for the regression model was $R^2 = 0.796$, indicating that the model explained 79.6% of the variance in MLUm. The ANOVA results indicated that the model was statistically significant ($p < 0.001$, $F(3,50) = 65.092$). The standardized β coefficients indicated that the group variable had the most significant negative influence on MLUm ($p < 0.001$, $\beta = -0.920$), while age had a positive significant effect ($p = 0.038$, $\beta = 0.144$). Conversely, the gender variable did not have a significant impact on MLUm ($p = 0.131$, $\beta = 0.099$).

The correlation between MLUm and PWM in the normal hearing group was moderate and significant ($r = 0.61$, $p < 0.001$). In the hearing-impaired group, there was a strong and significant positive correlation between MLUm and phonological WM ($r = 0.87$, $p < 0.001$) (Figure 1).

Discussion

The present study aimed to investigate the differences Mean Length of Utterance in morpheme (MLUm) and phonological working memory (PWM) between normal hearing and hearing-impaired children within the age range of 5–6 years. Specifically, we sought to address the following research questions: (1) Do children with hearing impairment exhibit lower MLUm and PWM compared to their typically developing children? (2) How is the correlation between MLUm and PWM within each group? we hypothesized that hearing-impaired children would demonstrate significantly lower MLUm and PWM than normal hearing children, even after controlling for age. Furthermore, we expected that MLUm and PWM would be positively correlated, particularly in the hearing-impaired group, reflecting the interdependence of language production and phonological memory capacity.

The present study demonstrates that profound hearing loss(HL) significantly impacts both MLUm and PWM in children. MLUm, a key indicator of linguistic proficiency, is closely associated with PWM. Several factors influence both MLUm and PWM, including the severity of hearing impairment (dB) and the use of hearing aids. Children with HL often experience difficulties across multiple domains, which can lead to deficits in academic performance, communication, and social skills.

Working memory (WM) is regarded as a fundamental cognitive skill in language acquisition and development [12]. WM skills in children with hearing impairment can predict language development, learning, and literacy proficiency [6]. The present study found that children with profound HL performed significantly worse on a PWM task compared to their typically developing peers. These findings align with Soleimani et al. who reported that children with cochlear implants exhibited lower scores on the nonword repetition task compared to typically developing children, demonstrating a substantial difference between the two groups [12]. Similarly, Javanbakht et al. observed a significant difference in nonword repetition scores between two groups of children with moderate to severe HL, one with improved speech comprehension and the other with impaired speech comprehension [5]. Additionally, Delcenserie et al. reported that typically developing children outperformed their peers with cochlear implants in nonword repetition tasks, reinforcing the critical role of PWM in language processing [30]. Recent evidence from Dumanlar et al. indicates that children with HL performed considerably worse on WM scale compared to their typically developing peers [6]. Therefore, training and improving WM may positively influence the development of children with HL [6].

The present study also indicates that MLUm is significantly reduced in children with profound HL compared to their typically developing peers. The results show that MLUm in children with profound HL is substantially lower than that of typically developing children. Consistent with these findings, Ahadi et al. reported that Persian-speaking bilingual children with normal hearing exhibited significantly higher MLUm compared to children with cochlear implants [18]. Similarly, Koehlinger et al. demonstrated that hard of hearing children had a shorter MLU in word than their typically developing peers, highlighting the linguistic challenges associated with auditory deficits [19]. In another study conducted by Tavakoli et al. MLU was significantly different between two groups of children with cochlear implants and normal children matched for chronological age, but MLU was not significantly different between two groups of children with cochlear implants and normal children who were the same in terms of hearing age [31]. Hearing age refers to the functional age of the auditory system, which may differ from chronological age. While chronological age simply measures the number of years a child has lived, hearing age assesses the duration and experience of auditory perception. In children with hearing impairment, hearing age specifically refers to the length of auditory experience since the onset of effective hearing, such as after fitting with a hearing aid or cochlear implant. Recent evidence indicates that MLU differs between children with HL and their typically hearing peers [32, 33]. Research by Tuz et al. revealed that children with HL had worse performance compared to their normally hearing peers in narrative abilities, including MLU [33]. Salmani et al. similarly showed that Persian-speaking children with moderately severe HL demonstrated a reduced MLU in comparison to their peers, suggesting that children with hearing loss may be at risk for delayed grammatical development [32].

The current study found a strong and significant correlation between MLUm and PWM in children with profound HL. These results align with Delcenserie et al. who demonstrated that PWM serves as a predictor of language skills in children with cochlear implants [30]. Additionally, Dumanlar et al. provided evidence that WM influences language comprehension, literacy, and language development in hearing-impaired children [6]. Also, İkiz et al. recommended that, due to the significant relationship between language skills and verbal WM in children with HL, this relationship should be considered in clinical and educational practice when planning interventions [8].also, in a study conducted by Waring et al. on two groups of typically developing children with the same chronological age, it was found that children with stronger speech production skills performed better on PWM task compared to those with weaker skills in speech production [20]. Although the participants in the present study, children with hearing impairment, differ from typically developing children, children with HL also tend to have weaker speech and language skills [34]. Consistent with Waring et al.'s findings [20], in children with HL, our findings indicate a similar pattern, where diminished MLUm, as an indicator of speech and language proficiency, correlates with differences in PWM performance.

The present study has certain limitations that should be considered when interpreting the findings. One key limitation is the lack of investigation into sociocultural and economic factors, such as parental education level and socioeconomic status, which may influence PWM and MLUm. Also, variables such as duration of cochlear implant use and age at implantation were not analyzed and are acknowledged as limitations of the present study. Future research should examine these variables to provide a more comprehensive understanding of the interplay between cognitive, linguistic, and environmental factors in language development. Also, to further validate these results, future studies should incorporate larger and more diverse sample sizes, including children with varying degrees of HL and different linguistic backgrounds. Additionally, longitudinal studies would help determine the long-term impact of PWM on language development. Further research should also explore evidence-based intervention strategies designed to enhance PWM, with the goal of improving MLUm and overall language skills in children with HL.

Conclusion

This study demonstrated a significant and meaningful correlation between PWM and MLUm in children with profound HL. The findings suggest that PWM is closely associated with spoken language output in this population. The observed relationship suggests that variations in MLUm are associated with differences in PWM capacity among children with HL. These results underscore the relevance of considering PWM when examining language characteristics in children with HL and may have implications for clinical and educational practices.

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Authors' contribution statements

MC: Study design, acquisition of data, drafting the manuscript
KB: Study design, drafting the manuscript
MF: Statistical analysis and interpretation of the results
BR: drafting the manuscript
SZ: drafting the manuscript
All authors read and approved the final manuscript.

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Table 1: Comparison of mean, standard deviation, mean difference, and significance level of age and birth order variables in normal and hearing-impaired children

	Normal children	Hearing loss		
	Mean± SD	Mean± SD	Mean difference± SE	p-value
Age	5.42±0.31	5.62±0.36	-0.203± 0.92	0.032
Birth order	2.48±1.31	2.44±1.33	0.370± 0.36	0.919

Table 2. information of age by year and month

Age (Years: Months)	**Normal Hearing (n)**	**Hearing-Impaired (n)**
5:0	1	3
5:1	2	1
5:2	5	1
5:3	2	2
5:4	2	1
5:5	4	0
5:6	1	0
5:7	3	2
5:8	1	3
5:9	1	5
6:0	4	9

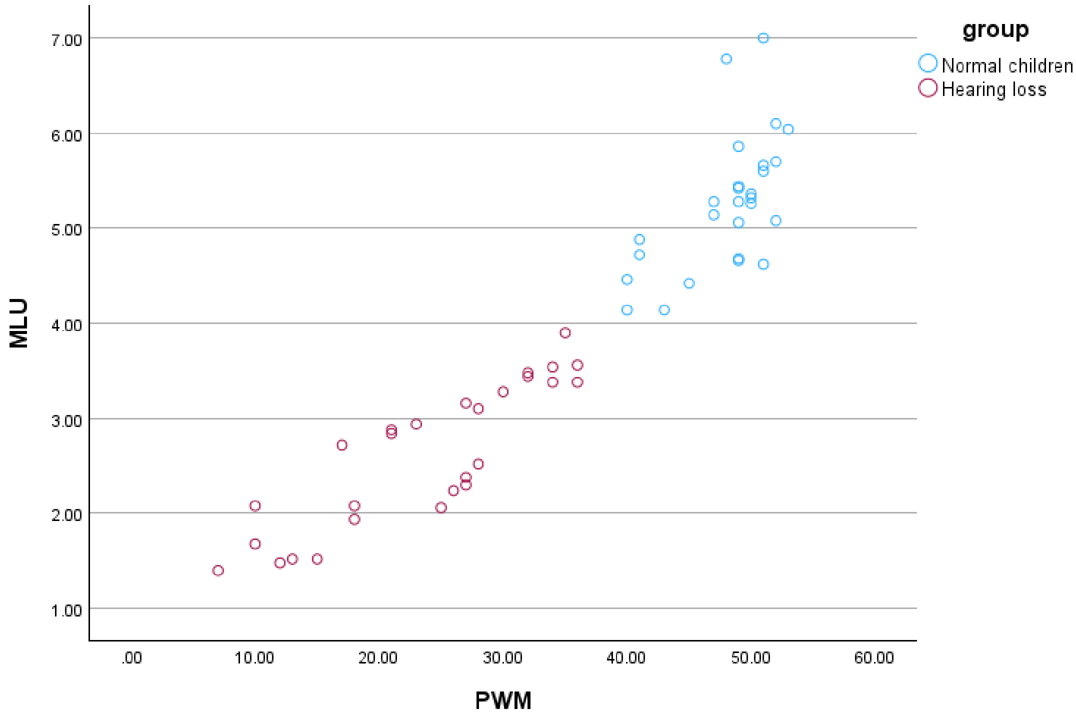

Figure 1. Relationship between percentage of word measures (PWM) and mean length of utterance (MLU)