# Is phonological awareness related to pitch, rhythm and speech-in-noise discrimination in young children?

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## Abstract

**Purpose:** Phonological awareness (PA) requires the complex integration of language, speech and auditory processing abilities. Enhanced pitch and rhythm discrimination have been shown to improve PA and speech-in-noise (SiN) discrimination. The screening of pitch and rhythm discrimination, if non-linguistic correlates of these abilities, could contribute to screening procedures prior to diagnostic assessment. This research aimed determine the association of PA abilities with pitch, rhythm- and SiN discrimination in children aged five- to seven-years old.

**Method:** Forty-one participants’ pitch, rhythm and SiN discrimination and PA abilities were evaluated. To control for confounding factors, including biological and environmental risk exposure and gender differences, typically developing male children from high socio-economic statuses were selected. Pearson correlation was used to identify associations between variables and stepwise regression analysis was used to identify possible predictors of PA.

**Results:** Correlations of medium strength were identified between PA and pitch, rhythm and SiN discrimination. Pitch and diotic digit-in-noise discrimination formed the strongest regression model (adjusted $R^2 = 0.4213$, r = .649) for phoneme-grapheme correspondence.

**Conclusion:** The current study demonstrates predictive relationships between the complex auditory discrimination skills of pitch, rhythm and diotic digit-in-noise recognition and foundational phonemic awareness and phonic skills in young males from high socio-economic statuses. Pitch, rhythm and digit-in-noise discrimination measures hold potential as screening measures for delays in phonemic awareness and phonic difficulties and as components of stimulation programs.

## Keywords

Phonological awareness, pitch and rhythm discrimination, speech-in-noise discrimination, young children

## Introduction

After reviewing 30 years of research, the foundational role of phonological awareness (PA) in reading acquisition was confirmed by *The National Reading Panel* in America (Moritz et al., 2013; National Reading Panel, 2000). PA requires the complex integration of language, speech and auditory processing abilities (François et al., 2015; Patscheke et al., 2016; Ritter et al., 2013) and does not develop naturally but must be stimulated directly (Goldstein et al., 2017; Henbest & Apel, 2017). In conversation, children predominately focus on the message being conveyed rather than the linguistic structure. Young children do not spontaneously extract phonological information from continuous speech streams (Lundberg et al., 2012). The behaviourist perspective of literacy development highlights the role of educators in facilitating literacy acquisition in young pre-school and school children through explicit instruction (Hall et al., 2015).

A growing body of research, investigating ways to stimulate PA and literacy, details the relationship between music skills, PA and literacy abilities (Bhide et al., 2013; Christiner & Reiterer, 2018; Herrera et al., 2011; Kraus et al., 2014; Moritz et al., 2013). Music and reading abilities are related when considering that phonemes are to language what notes are to music (Degé & Schwarzer, 2011; Heydon et al., 2018). Activation of areas in the brain traditionally involved with language processing during music exposure is proof of this relationship (Gordon, Fehd, et al., 2015; Kaviani et al., 2014; Moreno et al., 2011). The relationship between music and literacy-related skills, such as PA, appears to be the shared dependence on auditory discrimination (Christiner & Reiterer, 2018; Gromko, 2005).

Young children require strong auditory discrimination abilities, such as speech-in-noise (SiN) discrimination, to develop skills, like PA, in noisy natural settings like classrooms (Corriveau et al., 2010; Flaugnacco et al., 2015; Tierney & Kraus, 2013). PA requires children to extract target speech-sounds from interfering background sounds (e.g., noise) in the auditory environment and then categorise the phonemes using short timing differences (François et al., 2015; Ritter et al., 2013). SiN discrimination ability is therefore closely associated with PA and later literacy abilities (Chobert et al., 2014; Kraus & Slater, 2015; Kulkarni & Parmar, 2017).

Music abilities have been proposed to increase the auditory system's ability to overcome the impact of noise on learning (Patscheke et al., 2016; Strait et al., 2012; Tierney & Kraus, 2013). Pitch and rhythm discrimination are dependent on auditory discrimination, similar to PA (Christiner & Reiterer, 2018; Flaugnacco et al., 2015; Kraus & Slater, 2015). Pitch can be described as the perceived sounds that correspond to specific frequencies and can be organised on a musical scale (Banai et al., 2009). Rhythm is the pattern of time intervals categorised by sensory and/or motor events (Moritz et al., 2013). Music exposure develops pitch and rhythm discrimination, which in turn, due to shared sound processing mechanisms, may be useful for PA development (Culp, 2017).

PA and early literacy development depend on the ability to discriminate and encode speech acoustics (Banai et al., 2009). Patel (2011) describes the relationship between musical and speech processing through the 'OPERA' hypothesis. Music abilities are proposed to improve speech processing abilities due to *overlap* in the brain networks that process music and speech acoustics, *precision* as music production places a higher cognitive demand on precise performance than speech production, *emotional* activation due to strong positive feelings evoked by musical activity, musical *repetition* that reinforces engagement of the shared neurological areas, and *attention* skills as music demands great cognitive focus (Patel, 2011).

Both rhythm- and pitch discrimination are reportedly associated with PA abilities, including rhyme, isolation, blending, segmenting and phonemic decoding (Anvari et al., 2002; Moritz et al., 2013; Rautenberg, 2015), and reading performance (Dellatolas et al., 2009; Patel, 2011; Rautenberg, 2015). In other studies, however, rhythmic discrimination only predicted reading ability and not PA (Forgeard, et al., 2008; Gordon, Shivers, et al., 2015) and pitch was found to be significantly associated to PA, including rhyming and deletion, but not to reading development (Goswami et al., 2013). Conversely, Degé & Schwarzer (2011) identified that rhythmical exercises appear to be associated with the large phonological units of rhyming, segmenting, and blending. Pitch and rhythm may influence PA and literacy skills but with possibly differing effects (Patscheke et al., 2018).

Enhanced pitch and rhythm discrimination also appear to improve SiN discrimination (Moreno et al., 2009; Patscheke et al., 2018; Slater et al., 2015). More specifically, rhythm was found to be associated with sentence-in-noise discrimination, but not word-in-noise discrimination (Slater & Kraus, 2016). Stronger neural processing of fundamental frequency in speech, a pitch cue, has been associated with improved SiN discrimination in co-located and spatially separated listening conditions (Thompson et al., 2019). The associations between pitch and rhythm pattern discriminate and speech processing may be because of the shared reliance on timing and stress pattern recognition (Patscheke et al., 2018). Furthermore, auditory discrimination of timing and stress features of speech are critical for manipulation and analysis of words, syllables and phonemes during PA tasks (Thompson et al., 2013). Predictive associations between PA and pitch and rhythm discrimination should therefore be explored further.

Associations between non-linguistic music abilities, such as pitch and rhythm discrimination, and PA and SiN discrimination; may assist with clinical decision making. SiN discrimination and PA assessment measures are typically based on linguistic stimuli such as sentences produced in the presence of competing noise and the isolation of syllables and phonemes from presented words (Krizman et al., 2017; Wilsenach, 2016). Accurate assessment of SiN discrimination and PA becomes challenging if language difficulties or differences co-occur (François et al., 2015; McNeil, 2017; Tierney & Kraus, 2013). Furthermore, children from multilingual settings are often assessed using assessment measures that are not normed for their population (Wilsenach, 2016).

Auditory discrimination and PA difficulties may be overshadowed or exaggerated due to additional language differences (Patscheke et al., 2016). Conversely, over diagnosis may take place and children with additional language differences may be identified with auditory discrimination and PA difficulties due to the linguistic basis of assessment measures (Krizman et al., 2017; Moonsamy & Kathard, 2015). The accurate assessments of SiN discrimination and PA are essential to obtain a baseline performance measurement at the beginning of formal school or if the need for literacy support is suspected. Screening associated; non-linguistic abilities, prior to the administration of formal PA and SiN discrimination measures, may contribute to differential diagnoses.

Possible associations between pitch, rhythm and SiN discrimination and PA could have beneficial clinical implications for educators and speech-language therapists (Slater et al., 2015). Gordon, Fehd et al., (2015) postulate that if strong music abilities are associated with higher language skills then the converse must be true; individuals with lower language abilities should present with poorer music abilities. Consequently, if music abilities are related to auditory discrimination and PA skills, then lower pitch and rhythm discrimination may be associated with difficulties in SiN discrimination and PA abilities.

Phonological and auditory discrimination abilities are known to predict reading and written language acquisition (Bolduc, 2009; Corriveau et al., 2010; Herrera et al., 2011), and should be stimulated for the academic benefit of young learners (Goldstein et al., 2017). The screening of pitch and rhythm discrimination, if non-linguistic correlates of these abilities, could contribute to screening procedures prior to diagnostic assessment. Therefore, the following research question was posed: Is phonological awareness related to pitch, rhythm and speech-in-noise discrimination in in children aged five- to seven-years old?

## Method

Institutional research broad clearance to conduct the study was obtained (GW20171130HS). Permission to conduct the study was granted from two independent schools in the Tshwane District, Gauteng Province of South Africa. Forty-one children provided assent once their parents had consented to their participation in the study.

### Schools and participants

The quintile four to five schools followed the Independent Examinations Board (IEB) curriculum and served families with high socio-economic status. Analysis of the 2006 Progress in International Reading Literacy Study (PIRLS) results showed that the proportion of South African quintile four learners scoring above national average was comparable to quintile two learners in Russia and America. South African quintile five learners' performance was, however, comparable to those in the same category in Russia and America. Strikingly, only 22% of South African learners from quintile one scored above the national average (Taylor & Yu, 2009). Children from low socio-economic settings are exposed to more biological and environmental risk factors than children from higher economic settings, which reduces their developmental potential (Banks et al., 2017; Olivier et al., 2010).

The culmination of risks results in a high prevalence of developmental delays in South African children from low socio-economic settings and thus can result in poorer literacy achievements and academic performance (Abdoola et al., 2019; du Toit et al., 2020; Rowe et al., 2016; Van der Linde et al., 2015). To control for confounding risk factors, the associations between phonological awareness and pitch, rhythm and SiN discrimination were investigated in typically developing children from high socio-economic statuses. The inclusion criteria for participation thus encompassed typically developing males with normal hearing and expressive language in Grade R or Grade One at an IEB school without having repeated a grade. Only males were selected as one of the participating schools was a school for boys, therefore, males were selected from the other school to control for the possible influence of gender differences. PA abilities have been shown to be more developed in preschool girls compared to boys (Lundberg et al.,

2012) and difference may continue up until the end of Grade One (Chatterji, 2006). Children's home language and language of learning and teaching had to be English. Children's ages were within a tight range of 61 to 84 months (mean age 75 months, 6.15 months SD).

Forty parents (98%) returned the biographical case history. Racial and ethnicity were not probed in the biographical questionnaire to maintain cultural sensitivity, but the languages spoken by the participants do reflect the diversity of the sample. Many participants had home languages additional to English as is characteristic of South Africa's diverse population (Samuels et al., 2012). Twenty-four parents (60%) indicated additional home languages including Afrikaans (37.5%), Setswana (21%), isiZulu (12.5%), isiXhosa (8%), Northern Sotho (8%), Sesotho (4%), Tsonga (4%), Portuguese (4%), Italian (4%) and Korean (4%). Most parents (51%) held postgraduate qualifications and 94.5% were actively employed, which are positive predictors for children's school performance (van der Linde et al., 2015).

### Procedures

At the beginning of the academic year (February to March 2018), hearing and expressive language abilities of all participants were screened to rule out any hearing and language difficulties. Participants that passed the screenings were then assessed with the test battery that included PA and SiN, pitch and rhythm discrimination measures. The first author, a qualified speech-language therapist, and senior speech-language therapy undergraduate students administered the assessment batteries. All students received training in conducting the test battery from the first author. Assessments took place over two 90 min sessions, that included breaks, conducted on Saturday mornings either at the selected schools or at the Department of

Speech-Language Pathology and Audiology, University of Pretoria. The order effect was counterbalanced as groups of four participants rotated between four stations administering different measures simultaneously.

## Measures

### *Screening measures for inclusion*

Participants’ hearing and expressive language abilities were screened to rule out any contributing hearing and language difficulties. Hearing was screened using the hearScreen$^{TM}$ mobile application (Swanepoel et al., 2014) on a Samsung J2 phone with Sennheiser HD280 Pro headphones, calibrated to ISO/ANSI standards. Specificity and sensitivity equivalent to conventional school hearing screening programs (Swanepoel et al., 2014). The application refers for further audiological evaluation when sounds are not identified, by raising a hand, at an intensity of 20 dB or more at 1000, 2000 or 4000 Hz in either ear. The Renfrew Action Picture Test (RAPT) (Renfrew, 2003) was used to screen participants’ expressive language vocabulary and grammar skills in connected speech by answering specific questions based a picture card.

### *Biographical case history*

A comprehensive case history form, compiled by the researchers, collating participants’ biographical information was returned by 40 parents. The case history gathered information pertaining to family characteristics and participants’ developmental, medical and educational history.

### *Phonological Awareness Test 2 Normative Update (PAT-2: NU) (Robertson & Salter, 2018)*

The PAT-2: NU evaluated participants' phonological processing and the phonics related early literacy skills of phoneme-grapheme correspondence and phonemic decoding. The PA subtest includes the auditory assessment of rhyming (discrimination and production), segmentation (sentences, syllables and phonemes), isolation (initial, final and medial sounds), deletion (compounds, syllables and phonemes), phoneme substitution and blending (syllables and phonemes). In the phonics subtest, audio-visual tasks assess phoneme-grapheme correspondence in various contexts (consonants, long and short vowels, consonant blends, consonant digraphs, R-controlled vowels, vowel digraphs and diphthongs). The application of phonemic decoding to nonsense words (vowel-consonant words, consonant-vowel-consonant words, consonant digraphs, consonant blends, vowel digraphs, R-controlled, long vowel words and diphthongs) is also evaluated.

### *Primary Measures of Music Audiation (PMMA)* (Gordon, 2002)

The PMMA measured participants' pitch and rhythm discrimination. The test consists of tonal (pitch) and rhythm subtests and participants are presented with example trials, followed by 40 pairs of sounds to discriminate in each subtest. Half of the pairs differed either by one or more notes (tonal subtest) or in rhythm (rhythm subtest). The short musical phrases were presented online via Gia Music Assessment and listened to on Sennheiser HD 280 Pro headphones. Participants indicated whether they perceived the sound pairs to be the same or different by selecting either a smiling (same) or sad (different) face on the laptop screen by pointing or using the mouse. Upon responding, an animation of a dog would move 'closer to home' to encourage participation.

### *Digit-in-noise application (DiN) (Potgieter et al., 2016)*

The DiN is a mobile health SiN test that measures speech reception thresholds (SRTs). The discrimination of digits is considered less linguistically loaded than the discrimination of words (Potgieter et al., 2016). Three random digits (one to nine) are presented by a female speaker in the presence of masking noise. Digits are proceeded and followed by 500 ms of masking noise presented through Sennheiser HD280 Pro headphones, calibrated to ISO/ANSI standards. Participants heard 23 three-digit sets and recorded the three digits heard using the application's keypad. The DiN was presented binaurally three times, once dichotically as a training task then twice more using dichotic and diotic presentation respectively. The signal-to-noise ratio (SNR) increased in integrals of 2 dB from easiest (-2 dB) to most difficult (-20dB) depending on participants' responses. SRTs were calculated when listeners recognized 50% of the digit-triplets (i.e. 4-7-2) correctly (Potgieter et al., 2016).  Masking level difference calculated as the difference between diotic and dichotic.

### *Speech-in-noise discrimination in simulated virtual acoustic environment*

The SiN discrimination measure was adapted from the Children's Coordinate Response Measure, as described in Vickers et al. (2016). A detailed description of this measure and its procedures can be found in a related study by MacCutcheon et al. (2019). Participants were required to identify two words within the carrier phrase; "Show the dog where the <colour><number> is." Possible colours were black, red, green, white, blue, or pink and number options ranged from one to nine, omitting the disyllabic number seven. The assessments were conducted on DELL Latitude E6430 laptops using Sennheiser HD 650 headphones. Each participant was presented with a picture of a dog next to six colored blocks of numbered buttons, representing all possible combinations. Speech perception was assessed by measuring SRT scores at 50% correct speech intelligibility. Thresholds were measured in four experimental conditions including speech-shaped or single-talker noise maskers either co-located with the talker at 0° azimuth or spatially separated by 90˚ from the talker. The target speech levels started at 68 dB and the masker levels were set at 55 dB. SRTs were obtained using an adaptive up–down procedure with variable step sizes. The initial step size to change the SNR was 8 dB. The step size decreased to 4 and 2 dB, respectively, after the first and second reversal, to obtain 50% positive responses. Participants then had an additional five reversals to finish the block. SRT scores were calculated based on average SNR values of the last four reversals. Forty-eight colour/number combinations were randomly presented for each condition.

### Data analysis

Raw scores were used for all calculations as not all measures included in the assessment battery were standardized for the South African population. Participants' ages were not correlated to the predictor variables and therefore, raw scores were not adjusted for age in the analysis.

The Pearson correlation (Cohen et al., 2003) was calculated to identify possible associations between variables using SAS software (SAS Institute Inc., 2014). Cohen's standard (Cohen, 1988) indicated strength of the correlation. According to this standard, coefficients between 0.1 and 0.29 represent a small association, coefficients between 0.3 and 0.49 represent a medium association and coefficients above 0.5 represent a strong association or relationship. The Bonferroni correction was applied to lower the critical value in order to control for Type 1 errors (false positives) which have an increased likelihood of occurring when conducting multiple correlation tests. Seventy correlations were performed between PA variables and pitch, rhythm and SiN discrimination variables and hence to apply the Bonferroni correction, the initially selected critical value of .05 was divided by 70. Therefore, the individual tests were deemed significant if $p < .0007$ (alpha = 0.0007). Twenty-one correlations were calculated between SiN, pitch, and rhythm discrimination variables resulting in a Bonferroni-adjusted level of significance of $p < .0002$ (alpha = 0.002).

Through linear regression, the pitch, rhythm and SiN discrimination variables significantly associated with each PA subtest were used to identify possible PA predictors. A stepwise regression approach was applied to remove any predictor variables that did not contribute significantly to the model fit. The adjusted R-square value (Montgomery et al., 2006) was used to assess the model fit where 1 indicated a perfect fit and 0 indicated no fit at all. Variables were included in the model if they met the significance threshold of $p < .15$, which is the default significance threshold in the SAS software for a variable to remain in the model. The F statistic of all models was significant at $p < .05$. Cohen's *f*-squared (Cohen, 1988) was used to indicate effect size where $f^2 \geq 0.02$ $f^2 \geq 0.15$, and $f^2 \geq 0.35$ respectively represent small, medium, and large effect sizes.

## Results

The mean PA scores of the participants were average and above across all subtests. Positive correlations of medium strength were identified between four PA subtests (segmentation, isolation, deletion and phoneme-grapheme correspondence) and pitch and rhythm discrimination variables (Table 1). Negative correlations of medium strength were also identified between six PA subtests (rhyme, isolation, deletion, substitution, blending and phoneme-grapheme

**Table 1: Pearson correlations between phonological awareness subtests and pitch, rhythm and speech-in-noise discrimination results**

| **PA$^{\#}$ subtest** | **Music discrimination** | | | **DiN** | | | **SiN in virtual acoustic environment** | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pitch | Rhythm | Composite | Dichotic | Diotic | Masking level difference | S1N1 | S1N2 | S2N1 | S2N2 |
| | *r* (*p*-value) | *r* (*p*-value) | *r* (*p*-value) | *r* (*p*-value) | *r* (*p*-value) | *r* (*p*-value) | *r* (*p*-value) | *r* (*p*-value) | *r* (*p*-value) | *r* (*p*-value) |
| **Rhyming** | 0.084 (0.600) | -0.026 (0.871) | 0.032 (0.842) | -0.475 (0.002) | -0.413 (0.007) | 0.148 (0.356) | -0.366 (0.019) | 0.091 (0.571) | 0.045 (0.781) | -0.122 (0.447) |
| **Segmentation** | 0.400 (0.010) | 0.185 (0.247) | 0.324 (0.039) | -0.225 (0.157) | -0.201 (0.207) | 0.077 (0.634) | -0.067 (0.676) | -0.014 (0.929) | 0.082 (0.611) | -0.291 (0.065) |
| **Isolation** | 0.487 (0.001) | 0.479 (0.002) | **0.537 (<0.0007*)** | -0.289 (0.067) | -0.383 (0.014) | 0.238 (0.134) | -0.258 (0.103) | 0.093 (0.565) | -0.053 (0.744) | -0.332 (0.034) |
| **Deletion** | 0.304 (0.053) | 0.338 (0.031) | 0.357 (0.022) | -0.103 (0.522) | -0.245 (0.122) | 0.208 (0.192) | -0.316 (0.045) | 0.161 (0.313) | -0.082 (0.609) | -0.0621 (0.700) |
| **Substitution** | 0.293 (0.063) | 0.172 (0.283) | 0.258 (0.104) | -0.078 (0.627) | -0.302 (0.055) | 0.289 (0.067) | -0.344 (0.028) | -0.052 (0.746) | -0.281 (0.075) | -0.076 (0.636) |
| **Blending** | 0.157 (0.327) | 0.074 (0.647) | 0.128 (0.425) | -0.272 (0.086) | **-0.545 (<0.0007*)** | 0.433 (0.005) | -0.093 (0.561) | -0.096 (0.550) | -0.049 (0.760) | -0.028 (0.861) |
| **PGC$^{+}$** | 0.39 (0.011) | 0.269 (0.089) | 0.367 (0.018) | -0.299 (0.058) | **-0.539 (<0.0007*)** | 0.408 (0.008) | -0.241 (0.129) | -0.087 (0.587) | -0.087 (0.587) | -0.221 (0.164) |

$^{\#}$PA phonological awareness, $^{+}$PGC phoneme-grapheme correspondence, *Statistical significance p < .0007 with Bonferroni correction applied correspondence) and SiN discrimination variables. In this instance, negative correlations indicate that these PA abilities improved as SRTs improved, i.e. more negative SRT scores in dB SNR, suggesting a direct relationship between PA and SiN discrimination performances. Positive correlations of medium strength were identified between masking level difference and phonological blending and phoneme-grapheme correspondence. Bonferroni-adjusted levels of significance for post hoc comparison indicated three significant correlations. Significant positive correlation of strong strength was identified between isolation and the pitch and rhythm discrimination composite score (*r* = .537; *p* <.0007) [Figure 1]. Significant negative correlations of strong strength were found between diotic digit-in-noise discrimination and both blending (*r* = -.545; *p* <.0007) and phoneme-grapheme correspondence (*r* = -.539; *p* <.0007) [Figure 2]. No significant correlations were identified between pitch and rhythm discrimination and any SiN discrimination results after the Bonferroni-adjusted level of significance was applied.

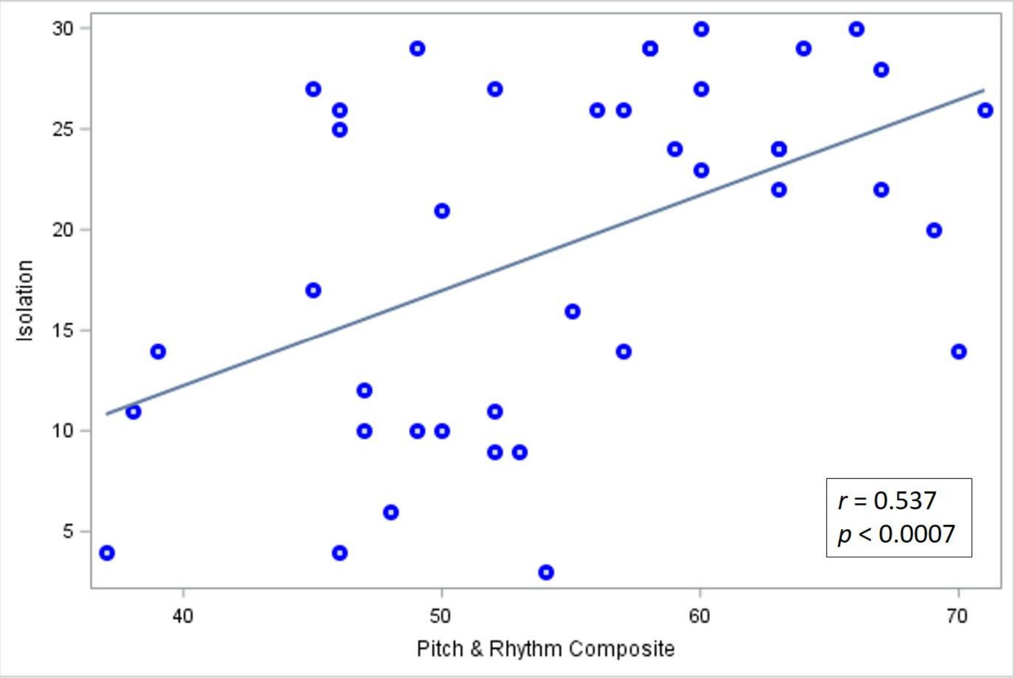
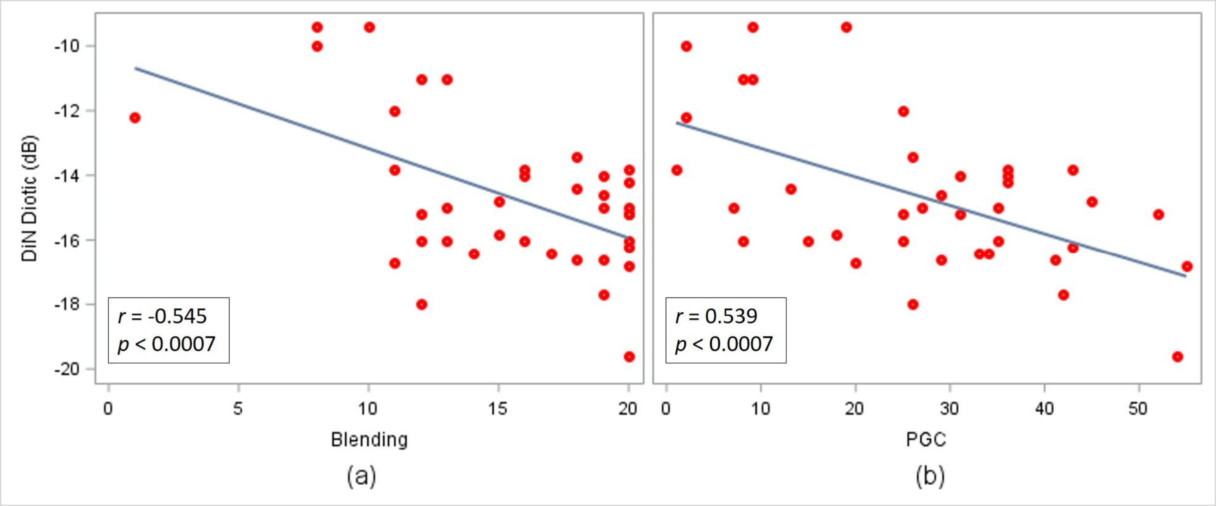


**Figure 1.** Relationship between phonological isolation and pitch and rhythm composite



(a) (b)

**Figure 2.** Relationship between diotic DIN discrimination and phonological blending (a) and PGC (b). DiN = digits-in-noise; PGC =phoneme–grapheme correspondence.

From the stepwise regression analysis, four significant predictive models were calculated (Table 2). Pitch and diotic digit-in-noise discrimination formed the strongest regression model (F(2, 38) = 15.56, *p* < .0001) with an adjusted R2 of 0.421, predicting 42.1% of the variance in the phoneme-grapheme correspondence subtest with a large effect size ($f^2$ = . 727). Pitch and rhythm discrimination (F(2, 38) = 7.69, *p* = .0016) and their composite score (F(1, 39) = 15.78, *p* = .0003) indicated medium and large effect sizes ($f^2$ = . 335; $f^2$ = .370) for isolation with adjusted R2 values of 0.251 and 0.270 respectively. Diotic digit-in-noise discrimination was a significant predictor (F(1, 39) = 16.51, *p* = .0002) predicting 27.9% of the variance in the blending subtest with a large effect size of 0.387.

**Table 2: Stepwise regression analysis predicting phonological awareness scores from pitch, rhythm and speech-in-noise discrimination variables**

| | **Model** | | | | **Parameter Estimates** | | | |
|---|---|---|---|---|---|---|---|---|
| **PA$^{\#}$ subtest** | **Predictor variables** | ***Adjusted $R^2$*** | ***r*-value** | ***F*-value** | **Parameter** | **β-value** | **Standard error** | ***p*-value** |
| **Isolation** | pitch and rhythm | 0.251 | 0.501 | 7.69 | Intercept<br>Rhythm<br>Pitch | -9.926<br>0.505<br>0.548 | 7.422<br>0.307<br>0.310 | 0.189<br>0.109*<br>0.085* |
| | composite | 0.270 | 0.520 | 15.78 | Intercept<br>Composite | -9.879<br>0.526 | 7.301<br>0.133 | 0.184<br><0.001* |
| **Blending** | diotic digit-in-noise | 0.279 | 0.528 | 16.51 | Intercept<br>Diotic digit-in-noise | -4.425<br>-1.301 | 4.718<br>0.320 | 0.354<br><0.001* |
| **PGC+** | pitch and diotic digit-in-noise | 0.421 | 0.649 | 15.56 | Intercept<br>Pitch<br>Diotic digit-in-noise | -60.847<br>1.215<br>-3.60 | 15.702<br>0.365<br>0.796 | <0.001<br>0.002*<br><0.001* |

$^{\#}$PA phonological awareness, $^{+}$PGC phoneme-grapheme correspondence, *Statistical significance $p < .15$

## Discussion

Correlation analysis identified numerous associations of medium strength between PA and pitch, rhythm and SiN discrimination demonstrating a positive and direct relationship between these variables in young male children from high socio-economic statuses. Furthermore, stepwise regression results showed pitch, rhythm and diotic digit-in-noise discrimination significantly predicted isolation, blending and phoneme-grapheme correspondence. Isolation and blending are complex PA skills but form the simplest phonemic awareness abilities (Konza, 2011; Paul & Norbury, 2012). Phonemic awareness refers to the analysis and manipulation of individual phonemes within a word (Degé & Schwarzer, 2011) and relies heavily on auditory discrimination (Schellenberg, 2015). This may explain why isolation and blending were predicted by the complex auditory discrimination skills of pitch, rhythm and diotic digit-in-noise discrimination.

Music discrimination abilities have been proposed to specifically predict phonemic awareness abilities because the auditory stimuli of musical tones and speech phonemes are processed in shared areas of the brain (Gromko, 2005; Patel, 2008). Phonemic awareness underlies the understanding that written words are encoded letters formed from the sound properties of a spoken word. Similarly, pitch and rhythm discrimination improve children's ability to process sound and associate visual symbols, notes, to specific tones (Gromko, 2005). Previous studies have also identified predictive roles between pitch and rhythm discrimination and phonemic awareness (Benz et al., 2016; Corriveau et al., 2010; Forgeard et al., 2008; Jung et al., 2015; Moritz et al., 2013). In the current study, isolation was the only phonemic awareness ability predicted by music discrimination skills although correlations of medium strength were identified with the more complex phonemic awareness skills of segmentation and deletion.

The ability to isolate phonemes provides a foundation for phonological blending to develop, the next tier on the phonemic awareness hierarchy  (Konza, 2011; le Roux et al., 2017). Results from the stepwise regression showed that the diotic digit-in-noise discrimination scores of male children from high socio-economic statuses predicted blending. The predictive relationship between PA, specifically phonemic awareness in this case, and diotic digit-in-noise discrimination abilities could be related to how the auditory stimuli are processed by each skill set. PA depends on both bottom-up and top-down processing (Banai et al., 2009; Helland et al., 2011; Sohoglu et al., 2012) while word-in-noise discrimination requires predominately bottom-up processing (Hutka et al., 2015; Shuai et al., 2014), as it is less linguistically loaded than a continuous speech stream. Bottom-up processing refers to the analysis of auditory information in the superior temporal gyrus before abstract linguistic analysis in the inferior frontal gyrus

(Sohoglu et al., 2012). Top-down processing first interprets linguistic information using pre-existing knowledge and experience stored in long-term and working memory prior to sensory-related processing (Helland et al., 2011). The ability to discriminate digits-in-noise that are co-located to noise sources is a complex task (MacCutcheon et al., 2019). Likewise, when learning to read, children have to isolate the sound properties of phonemes and then encode or blend them to form a word that has additional semantic meaning (le Roux et al., 2017). Stronger digit-in-noise discrimination abilities may support the auditory analysis involved in bottom-up PA processing and relieve cognitive demand to increase working memory capacity for top-down processing (Rönnberg et al., 2013). Therefore, diotic digit-in-noise discrimination abilities predict and influence PA, and in particular phonemic awareness, capabilities (Heagy, 2018; Horowitz-Kraus et al., 2017; Krizman et al., 2017).

PA and SiN discrimination contribute to the development of phonics (Corriveau et al., 2010). Phonics related abilities include phoneme-grapheme correspondence and phonemic decoding and require the complex audio-visual integration of phonemes. Phoneme-grapheme correspondence, also known as “alphabet knowledge”, refers to associations made between phonemes and letters, which are essential for decoding and encoding in literacy (Kilpatrick, 2015). Consequently, this skill is considered the single best predictor of later reading success (Goldstein et al., 2017). Essential PA skills continue to develop as children explicitly learn to associate sounds with letters and come to understand the role of letters within reading (Erickson, 2017; Patscheke et al., 2016), paving the way for accurate word recognition and reading fluency (Nichols et al., 2008). In the sampled populations, the combination of pitch and diotic digit-in-noise discrimination abilities as predictors of phoneme-grapheme correspondence was the best-fitting model identified from the stepwise regression analysis. The predictive relationship between pitch and diotic digit-in-noise discrimination and phoneme-grapheme correspondence suggests shared mechanisms for pitch and digit-in-noise discrimination and PA, such as bottom-up processing of auditory information and stress pattern recognition, could be important for mapping sounds to letters in phoneme-grapheme correspondence. Many literacy interventions recommend the incorporation of phoneme-grapheme correspondence training due to its importance for later reading success (Cole, 2012; Erickson, 2017; Goldstein & Olszewski, 2015). The stimulation of phoneme-grapheme correspondence via pitch and diotic digit-in-noise discrimination training should be investigated in future intervention studies. Pitch, rhythm and SiN discrimination abilities appear to support phonemic awareness and phonics by discerning important timing and stress cues (François et al., 2015).

Pitch discrimination was found to be a predictor in three out of the four models identified from the stepwise regression. Previous studies also reported predictive associations between pitch discrimination and PA related abilities (Anvari et al., 2002; Forgeard et al., 2008; Lamb and Gregory, 1993 in Gordon et al., 2015; Goswami et al., 2013). Pitch discrimination may be an important foundational skill for reading development because it improves stress pattern recognition and assists phonemic awareness and phonics abilities in the segmentation of continuous speech streams into individual phonemes (Slater et al., 2014).

In contrast, no associations were identified between pitch and rhythm discrimination abilities and SiN discrimination. Similarly, Slater & Kraus (2016) found that neither musical rhythm nor pitch discrimination predicted word-in-noise discrimination although rhythm did predict sentence-in-noise discrimination. Both of the SiN measures used in the present study were word-in-noise discrimination tasks, one of which required the recognition of two words in a carrier sentence while the other involved the recognition of three digits in noise. The neural processing of fundamental frequency, a pitch cue, has however been associated with SiN discrimination in co-located and spatially separated listening conditions in a similar aged population (Thompson et al., 2019). In the study, pitch cues in continuous speech streams were investigated whereas the current study examined pitch discrimination of non-speech, musical tone pairs. The processing of acoustic cues already embedded in speech, such as fundamental frequency, appears to be more closely associated with SiN discrimination across spatial conditions than the discrimination of music abilities.

Interestingly, the current study found that diotic digit-in-noise and co-located SiN (S1N1) discrimination were more frequent correlating variables, of medium and strong strength, to PA subtests than any of the other SiN conditions. Both the digit-in-noise and SiN measures presented noise stimuli co-located with the target speech source, which is harder to discriminate than noise that is spatially separated from the speech stimulus. Co-located SiN discrimination requires increased cognitive demand during segregation of the competing auditory signals without the assistance of spatial cues (Cameron & Dillon, 2007; Litovsky, 2005; MacCutcheon et al., 2019; Thompson et al., 2019). The association between the cognitively demanding task of SiN discrimination in co-located listening conditions and PA abilities should be investigated further in future research.

Classrooms have an increasing number of additional language learners at-risk for literacy difficulties due to phonological differences across language systems (Garcia-Lecumberri & Gallardo, 2003; Master et al., 2016; Moonsamy & Kathard, 2015). The assessment of linguistic-based abilities, such as PA, is challenging in multilingual populations where language differences could influence the assessment outcomes (François et al., 2013; McNeil, 2017; Williams & McLeod, 2012). The results of the current study indicate that pitch, rhythm and diotic digit-in-noise discrimination are significant predictors of phonological isolation, blending and phoneme-grapheme correspondence in male children from high socio-economic statuses. The use of these less-linguistically loaded discrimination abilities as screeners for early literacy difficulties would be clinically valuable for professionals involved in the evaluation of literacy and should be trialled in research.

Additionally, the use of music abilities to facilitate the development of PA as part of remedial or classrooms programmes could also be clinically valuable for young children and should be explored (Heydon et al., 2018; Kraus & White-Schwoch, 2017). The application of music, to augment explicit literacy instruction, provides an indirect and motivating approach for young children and the use of music to stimulate other academic skills is receiving growing attention (Boyd et al., 2020; Cloete & Delport, 2015; Liebeskind et al., 2014; Tierney & Kraus, 2013). The predictive relationship between pitch, rhythm and digit-in-noise discrimination, phonemic awareness and phonics abilities could provide an opportunity to develop young children's early literacy abilities through music activities that stimulate shared sound processing mechanisms. Educators require support and innovative approaches to provide literacy education to a diverse population of learners (Olivier et al., 2010; Vally et al., 2015).

Diverse populations may include multilingual additional language learners, children with language, hearing or literacy difficulties or vulnerable populations such children from low-resourced settings that are exposed to multiple risk factors. Multilingual children, in comparison to monolinguals, struggle to discriminate speech in the presence of noise. These challenges are further exacerbated for children from low-resourced settings that typically show reduced vocabulary sizes (Slater et al., 2015). The majority of South African children are English additional language learners and from low-resourced settings (Howie et al., 2012; Spaull & Hoadley, 2017). Digit-in-noise discrimination holds clinical potential as a screener for early literacy difficulties in additional language learners as the repetition of digits in a language that differs from listeners' first language can still be used as an accurate assessment of SiN discrimination (Potgieter et al., 2016).

The current study only included typically developing males to control for confounding factors (Tierney & Kraus, 2013). Prospectively, the correlations and predictions identified should be investigated in male and female children from diverse populations where literacy difficulties are prominent. Females make up half the school going population of South Africa (Statistics South Africa, 2020) and it would be limiting to not consider the associations between PA and pitch, rhythm and speech-in-noise discrimination in this population future analysis. Children with syntax and reading difficulties, including dyslexia, have been shown to perform worse in music tasks (Bhide et al., 2013; Gordon, Shivers, et al., 2015). Rhythm discrimination difficulties have also been identified in children with ADHD and Specific Language Impairment and music interventions show potential for management of these conditions (Puyjarinet et al., 2017; Zuk et al., 2018). The contribution of pitch, rhythm and diotic digit-in-noise discrimination to diagnostic and intervention procedures should be considered for diverse atypical populations with possible early literacy difficulties (Virtala & Partanen, 2018).

## Conclusion

The current study demonstrates predictive relationships between the complex auditory discrimination skills of pitch, rhythm and diotic digit-in-noise recognition and foundational phonemic awareness and phonic skills in young males from high socio-economic statuses. Pitch and diotic digit-in-noise discrimination produced the largest effect size in predicting phoneme-grapheme correspondence, identified as the single best predictor of later literacy abilities due to the complex audiovisual integration of phonemes (Goldstein et al., 2017; Patscheke et al., 2016). Pitch, rhythm and digit-in-noise discrimination measures hold potential as screening measures for phonemic awareness and phonic difficulties and as components of early literacy stimulation programs.

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### Conflict of Interest

The authors declare that there is no conflict of interest.

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