The use of the *Feather Squadron* to identify auditory processing disorders in South African children: A comparative study

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ABSTRACT

Objective: Development of the *Feather Squadron* (FS) has created a cost-effective, accessible form of assessment through tele-audiology. As accessibility to reliable, cost-effective assessment of auditory processing (AP) skills is limited in South Africa (SA), this study aims to establish whether there is correlation between the FS and traditional tests of AP viz. Frequency Pattern and Dichotic Digits Test, and to establish its relevance to the SA population.

Design: Retrospective, within-subject, comparative design used to compare performance on the FS and the traditional tests. Data were considered in two ways: Firstly, using the traditional −2SD cut-off on some subtests of the FS compared to the same traditional tests, and secondly, by comparing the Z-scores obtained on the FS compared to Z-scores on the same traditional tests obtained by applying a double arcsine transformation.

Study sample: Sixty-six subjects (35 males, 31 females) aged between 8.08 and 9.75 years (mean = 8.73; $SD = 0.51$) seen for AP assessments between 2016 and 2019.

Results: −2SD criteria yielded no significant association ($p > 0.05$). Z-score comparison suggested a statistically significant correlation ($p < 0.05$).

Conclusion: A statistically significant correlation between certain subtests of FS with traditional tests of AP to merit its use in the SA population is suggested.

KEYWORDS: *Feather Squadron*; dichotic digits; frequency pattern; auditory processing; South Africa

Introduction

Audiologists are fully cognisant that hearing does not stop at the level of the 8th nerve but is part of a process that involves both neuroanatomical and neurophysiological components and includes both cognitive and auditory aspects (Chermak et al. 2018). However, there has been a "disconnect" between what happens in a clinical practice and what is presented in research studies, in part, due to the terminology and definitions used in describing auditory processing (AP) and auditory processing disorders (APDs), and the understanding of the relationship between cognition and auditory processing, making this field a controversial and complex one (Kraus and White-Schwoch 2015) (Iliadou et al. 2019).

The definitions proposed by the American Speech-Language Hearing Association (ASHA 2005) are supported by the American Academy of Audiology (American Academy of Audiology 2010) with variations proposed by a number of authors (DeBonis 2015; Kraus and White-Schwoch 2015; Moore 2016), but highlight that the controversies are not only limited to the ambiguity of the definitions but also the effect this has on diagnosis and intervention.

According to ASHA (2005), the presence of APDs may lead to higher-order language, learning and communication difficulties and may impact language processing, particularly pre-literacy skills, behavioural, emotional and social effects. Tomlin et al. (2015) add to this by raising concerns regarding associated deficits which include concentration, attention, memory and literacy, hearing in background noise, reading, poor academic achievement and reduction in non-verbal Intelligence Quotient. This was reiterated by Iliadou et al. (2017) who added that the impact of low self-esteem, anxiety and depression resulting from APDs in children might continue into adulthood, negatively impacting progress in the learning and work environments. If these reported negative consequences are the case then it stands to reason that the earlier one identifies and manages the difficulties associated with APDs, the less significant the impact would be on a wide range of skills.

It has been suggested that traditional audiological assessment of auditory processing disorders be supplemented or in fact replaced by the addition of questionnaires, such as the Children's Auditory Processing Performance Scale (CHAPPS) (Smoski, Brunt, and Tanahil 1998) and the Evaluation of Children's Listening and Processing Skills (eCLIPS) (Barry et al. 2015), while relatively quick to administer, do not provide the information that formal audiological testing provides regarding the functioning of the auditory system. Traditionally, the test principles have included reference to assessment tools that are best administered through an audiometer and in a soundproof booth (Bellis 2003) using tests that have been carefully developed and clinically validated, with a fairly extensive time allocation. This has proven to be a limiting factor in the assessment of AP in South Africa as healthcare resources are directed mainly at fighting disease, and limited personnel and financial resources are available to address communication disorders, such as APDs (Pascoe and Norman 2011). Further, limited normative data and insufficient documentation to support a diagnosis, negatively influence the willingness of audiologists to assess APDs in South Africa. (Fouch,e-Copley, Govender, and Khan 2016). This has resulted in those requiring assessment and management of APDs to go unidentified. The negative impact of undiagnosed and untreated APD previously mentioned, will adversely affect the life of the individual and place a burden on the family and community if they are not able to become economically independent as a result of their condition.

The innovation of mobile technology applications in healthcare (mHealth), tele-health or tele-audiology needs to be considered as possible tools for providing a more cost-effective, accessible and standardised approach to the early identification of APDs. Developments in mHealth, including the rapid advances in technology and the extensive global connectivity, could allow the provision of the new service delivery models in under-serviced and previously inaccessible communities, from screening, assessment and diagnosis to management and monitoring of this condition - in this case APDs. Not only will mHealth provide access to these services, but it will also improve the well-being of previously underserviced communities, of which South Africa is one (Swanepoel 2006). Audiologists in South

Africa are faced with providing appropriate services to a racially, linguistically, economically and culturally diverse population where access to services—financially, linguistically and geographically - is challenging. Prior to the onset of the COVID-19 pandemic, tele- medicine was tightly controlled in South Africa (HPCSA 2014) requiring a previously existing relationship between medical practitioner and patient before a service could be offered, together with signed consent and explanation regarding the use of telemedicine. This has now been reviewed and has opened new opportunities for telemedicine contact between patient and practitioner (HPCSA 2020).

With changes in technology and service delivery models, a new approach to identify APDs that is more efficient, faster and engaging needed to be considered (Barker and Purdy 2016). The development of a tablet-based assessment tool for APDs may address a number of the current limitations that have been identified in the assessment of APDs using a traditional service delivery model, which include the time-consuming nature of the testing, monotony of the tasks thus increasing the risk of inattention negatively affecting performance, cost and geographical barriers (Saunders and Jacobs 2015). While the total use of digital media in South Africa is not growing at quite the rate of that in the US, which was at 40% from 2013 to 2017 (Schuler 2019), South Africans are becoming more familiar with using digital technology, such as smartphones and tablets, and have greater access to internet services. It is estimated that in South Africa, 75% of website traffic comes from mobile devices and that 52% of the population uses the internet in some form (Digital Statistics in South Africa 2017). Using these tools in mHealth or tele-audiology does not introduce a new and separate medical entity. Rather, it provides a service delivery model that could overcome the previously mentioned barriers to hearing health- care, of which identification and management of APDs is one area, in an efficient and effective manner (Krupinski 2015).

Barker and Purdy (2016) have developed a computer-based assessment of AP (known as *Feather Squadron* - FS) which measures five of the six areas identified by both ASHA (2005) and AAA (2010) as primary to the investigation of an APD. These areas include sound localisation and lateralisation; auditory pat- tern recognition; temporal aspects of audition, temporal discrimination, temporal ordering; auditory performance in competing acoustic signals; and auditory performance with degraded acoustic signals (Barker 2017). Features of this assessment tool include its engaging design and reduced duration required for administration. Additional aspects include the consistency in test administration as the test instructions and feedback relevant to the individual's responses are embedded within the software, the low linguistic load of the test stimuli and that the assessment tasks are presented in the same order, allowing for greater consistency. Its purpose is not to replace the current AP assessment batteries and associated assessment tasks in domains, such as memory, attention, phonological awareness and language development, but rather to provide a novel and engaging tool which may be less affected by attention and support traditional assessment protocols. Subsequent research demonstrated the concurrent validity of the FS and it found that the test was feasible, reliable, valid and time-efficient (Barker and Purdy 2016).

In considering an optimal test battery using traditional test (Musiek et al. 2011) suggest that a two-test battery utilising the DDT and FPT, with strict criteria, proved to be a better combination as they demonstrated higher specificity and thus proved to be the optimal battery when compared to the other test combi- nations used in their study. Using these two assessment tools also allowed for the investigation of two areas of AP, namely temporal processing and dichotic processing.

Correlation between acknowledged, optimal and traditional tests of AP and similar subtests of the FS could provide insight into the validity of the FS as a reliable, cost-effective, accessible tool to assess APDs in South Africa. The aim of this study was to compare results of Tonal-Pattern Temporal Processing (2 Birds 3 Tones) and Dichotic Listening (non-linguistic and linguistic) subtests of the FS to the DDT and FPT, which are considered to be the optimal or best-balanced test pairing in AP assessment, to identify the presence of APDs in 8–9-year-old South African children educated in English.

Method

A retrospective paradigm for this study was selected as the data for analysis had already been collected over a number of years.

Participants

A retrospective analysis of the test performance was conducted of 66 subjects (35 males, 31 females) aged between 8.08 and 9.75 years (mean = 8.73; *SD* = 0.51) seen for AP assessments at a private practice between 2016 and 2019. Only participants with normal hearing were selected for this study, i.e. a pure tone aver- age (calculated from the average pure tone thresholds for 500, 1000, and 2000 Hz) <16dB (Northern and Downs 2002) and normal immittance measures on tympanometry that produced Type A traces (peak > –100 daPa and compliance from 2:0.2 ml) (MRC Multicentre Otitis Media Study Group 2008) as measured with the Maico MI 24 Tympanometer. Normal hearing was required as peripheral hearing loss impacts the quality of auditory input that is transmitted through the Central Auditory Nervous System (CANS) for processing and changes the structure and function of the cortical and subcortical regions (Cameron et al. 2014). Participants whose parents had consented and who themselves had assented to their information being used were included in the study.

Material and apparatus

Traditional tests:

These were administered as part of an extensive test battery to investigate auditory processing skills and the sequence of administration of the tests was not consistent. They were administered using a two channel, diagnostic audiometer in a soundproof booth with the output level set at 50 dB HL on TDH39 headphones.

Dichotic Digits Test (DDT):

This test was used from the “Tonal and Speech Materials for Auditory Perceptual Assessment Disc 2.0” (Wilson and Strouse 1998) as suggested in previous research conducted on the South African population (Saleh, Campbell and Wilson 2003) and based on the test developed by Musiek (1983). This task consisted of 25 sets of two-pair dichotic digit stimuli using the mono-syllabic number 1, 2, 3, 4, 5, 6, 8, 9, and 10 with a 5 s interval between each. The test presentations were preceded by practice presentations. The participant was required to repeat all four numbers that they heard, and in any order. The score obtained was calculated as a percentage of correct responses of the total number of digits presented to each ear. The normative data used was that presented by Bellis (2003) using the normative data from Musiek (1983).

Frequency Pattern Test (FPT):

This test was used from the “Tonal and Speech Materials for Auditory Perceptual Assessment Disc 2.0” (Wilson and Strouse 1998) as suggested in previous research conducted on the South African population (Saleh, Campbell, and Wilson 2003) and based on the test described by Dr F Musiek (1994). This task contained 30 frequency pattern sequences. This consisted of six patterns which were randomly presented. The low frequency tone was 880 Hz and the higher frequency tone was 1122 Hz. Both tones were 150 ms in length with 10 ms rise-fall times. Each sequence had an interstimulus interval of 200 ms and an inter-pattern interval of 6 s. In the first series of presentations, the participant was required to hum the frequency pattern that they had heard. In the second series of presentations, the participant was required to verbally label the frequency pattern that was heard, i.e. if the presentation was 880–880–1122 Hz then they were required to say low–low–high. The test task was preceded by practice presentations. The participant’s score was calculated as the number of correct sequences identified and presented as a percentage correct.

The normative data used was that presented by Bellis (2003) who noted that her normative data were in general agreement with that of Musiek (1994).

Subtests of the Feather Squadron:

The FS is a tablet-based application, presented as an interactive video game. It was developed by Matt Barker and Suzanne Purdy in 2016 who state that it is not their intention that the FS replace all other assessments of AP (Barker and Purdy 2016). The norms were obtained following assessment of 945 children between the ages of 5 and 14 years in New Zealand. It was administered using an Apple iPad with the volume set at 50% and KOSS UR10 headphones, as recommended by the developers. The output of the head- phones had been equated to recently calibrated TDH39 head- phones. The FS Diagnostic Assessment uses nine subtests to measure five areas of auditory processing including sound localisation and lateralisation, auditory pattern recognition, temporal aspects of audition, auditory performance in competing acoustic signals and auditory performance with degraded acoustic signals, and is always presented in the same sequence. For the purpose of this study, the results from the following subtests were ana- lysed in order to obtain information regarding association and correlation with traditional tests of auditory processing:

Tonal-Pattern Temporal Processing (“Whistle code breaking” in the App):

This task uses tones near the octave frequencies of 500, 1000, and 2000 Hz which are presented with a duration of 500 ms and a silent interval of 250 ms between presentations. This is a diotic task. The participant was required to tap on the birds on the tablet screen in response to the pattern which they have heard. This is a four-stage task where each stage increases in difficulty but the participant was only able to move to a more difficult task if they had successfully completed the easier stage. The results from the “Two Bird, Three Tones” level (level 2) (2B3T) were used as this task most closely resembles the traditional frequency pattern task. For this task, the participant was required to correctly identify three whistles in sequence, e.g., high-low-high, by tapping on the two birds which were visible on the screen.

Dichotic Double Sounds (“Double Animal Codes” in the App) - non-linguistic task:

This task was dichotically presented where the participant was shown eight common animals on the screen and a series of two different target animal sounds were presented to each ear simultaneously with a total of four animal sounds being heard. There was a 0.5 s silence between each presentation. Twenty sets of target sounds were presented with a total of 40 sounds per ear. The participant was required to tap on the correct animals in no particular sequence. This was a non-linguistic task.

Dichotic Double-Words (“Double Codes” in the App) - linguistic task:

This task was dichotically presented. The participant was required to listen to two different numbers between 1 and 10 and excluding 7, presented simultaneously in a two-series presentation to each ear, i.e. four numbers. There was a 0.5 s silence between each presentation. There were 20 sets of target numbers presented, totalling 40 numbers in each ear. The participant was required to tap on the numbers heard. This was a linguistic task.

Procedures

The data for this study were collected from the year 2016 in personal, individual assessment sessions. Following a peripheral hearing assessment which included pure tone air and speech audiometry, immittance measures and acoustic reflex testing, the FS was administered together with the dichotic digits test and frequency pattern test. While the subtests of the FS were always presented in the same order, the test administration sequence of the remaining traditional tests and at what stage of the assessment session the FS was administered, varied depending on the needs of each participant, e.g. for a child who appeared to be more anxious, more breaks were offered whereas a child who had travelled some distance prior to testing, more bathroom or snack breaks may have been required, meaning that the administration of a test may have happened before a break for one child but after a break for another. The FS report was purchased online for each participant and the results of the dichotic digits and frequency pattern tests were manually calculated.

Data analysis

The results of the DDT and FPT were obtained as percentages and compared to established normative data (Bellis 2003; Musiek 1983). They were also transformed to Z-scores using a double arcsine transformation (Tomlin, Dillon, and Kelly 2014) and the interested reader is referred to this document for more details regarding this transformation. The transformation to Z-scores was applied as one of the limitations of a using a simple comparison of a cut-off score does not allow for the understanding of the degree of deficit, and two scores varying by a very small amount can have significant differences in interpretation and management. Having the Z-scores allows for a clear expression of the individual's performance.

Using the criteria presented by ASHA (2005) and AAA (2010) that a diagnosis of APDs is based on the performance above or below a cut-off score of 2 or 3 SD below the mean for at least one ear on two or more different behavioural tasks, the results obtained on the FS and the traditional tests, FPT and DDT, were analysed using the Pearson Chi-squared tests of association on this dichotomous data.

For continuous variables, the Shapiro–Wilk test was applied to establish whether the underlying process distribution of the continuous variables differed from normality. Since it was found that these variables were not normally distributed, the non-parametric counterpart to the Pearson correlation, the Spearman correlation, was applied to establish whether a statistically significant correlation existed between the subtests of the FS and the FPT and DDT. The specific correlations are documented in Table 1 below.

Table 1.

Pairs of correlated variables

Continuous Variable 1 -Feather Squadron	Continuous Variable 2 -traditional tests
Tonal-Pattern Temporal Processing (2B3T)	FPT—labelling FPT—humming
Dichotic Double Sounds—left ear	DDT—left ear
Dichotic Double Sounds—right ear	DDT—right ear
Dichotic Double-Words—left ear	DDT—left ear
Dichotic Double-Words—right ear	DDT—right ear
Dichotic Double Sounds—weaker ear	DDT—weaker ear
Dichotic Double Sounds—stronger ear	DDT—stronger ear
Dichotic Double-Words—weaker ear	DDT—weaker ear
Dichotic Double-Words—stronger ear	DDT—stronger ear

Results

The data were analysed using two approaches:

For categorical variables, the Chi-square test is used to test for association. If the *p*-value is <0.05, there is a statistically significant association. As demonstrated in Table 2, in the initial analysis, using the −2SD criteria yielded no significant association when comparing the Dichotic Digits FS *vs.* DDT, or when comparing Temporal Pattern FS *vs.* FPT in the humming or labelling conditions ($p > 0.05$). The Chi-square and Fisher's Exact tests were computed; the latter is used when there are cells in the Chi-square cross-tabulations that are <5. Stated simply, the *p*-value of the Fisher's Exact test is interpreted instead of the *p*-value of the Chi-square test for smaller sample sizes. Table 2 clearly demonstrates the results of this comparison to establish whether an association exists.

Table 2.
Comparison between the Feather Squadron and traditional tests using the -2SD criteria (dichotomous variables)

<table>
<tr><th>Test compared and cross-tabulations</th><th>Chi-square test statistic</th><th>p-value of Fisher's Exact test</th></tr>
<tr><td>
<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">FPT - Labelling</td><td rowspan="2">Total</td></tr>
<tr><td>2SD or more below the mean</td><td>Any score above 2SD below the mean</td></tr>
<tr><td rowspan="2">Tonal - Pattern Temporal Processing - Pointing</td><td>2SD or more below the mean</td><td>7</td><td>1</td><td>8</td></tr>
<tr><td>Any score above 2SD below the mean</td><td>27</td><td>31</td><td>58</td></tr>
<tr><td colspan="2">Total Participants</td><td>34</td><td>32</td><td>66</td></tr>
</table>
</td><td>4.720</td><td>0.055</td></tr>
<tr><td>
<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">FPT - Humming</td><td rowspan="2">Total</td></tr>
<tr><td>2SD or more below the mean</td><td>Any score above 2SD below the mean</td></tr>
<tr><td rowspan="2">Tonal - Pattern Temporal Processing - Pointing</td><td>2SD or more below the mean</td><td>0</td><td>8</td><td>8</td></tr>
<tr><td>Any score above 2SD below the mean</td><td>6</td><td>52</td><td>58</td></tr>
<tr><td colspan="2">Total Participants</td><td>6</td><td>60</td><td>66</td></tr>
</table>
</td><td>0.910</td><td>1.000</td></tr>
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<tr><td colspan="2" rowspan="2"></td><td colspan="2">DDT – Left Ear</td><td rowspan="2">Total</td></tr>
<tr><td>2SD or more below the mean</td><td>Any score above 2SD below the mean</td></tr>
<tr><td rowspan="2">Dichotic Double Words FS – Left Ear</td><td>2SD or more below the mean</td><td>4</td><td>3</td><td>7</td></tr>
<tr><td>Any score above 2SD below the mean</td><td>27</td><td>32</td><td>59</td></tr>
<tr><td colspan="2">Total Participants</td><td>31</td><td>35</td><td>66</td></tr>
</table>
</td>
<td>0.325</td>
<td>0.698</td>
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<tr>
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<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">DDT – Right Ear</td><td rowspan="2">Total</td></tr>
<tr><td>2SD or more below the mean</td><td>Any score above 2SD below the mean</td></tr>
<tr><td rowspan="2">Dichotic Double Words FS – Right Ear</td><td>2SD or more below the mean</td><td>5</td><td>7</td><td>12</td></tr>
<tr><td>Any score above 2SD below the mean</td><td>16</td><td>38</td><td>54</td></tr>
<tr><td colspan="2">Total Participants</td><td>21</td><td>45</td><td>66</td></tr>
</table>
</td>
<td>0.656</td>
<td>0.499</td>
</tr>
</table>

Twenty three participants met the AAA (2010) and ASHA (2005) criteria for having an APD when considering their performance on the traditional tasks, i.e. a score of –2SD or more below the mean for at least one ear on at least two different behavioural central auditory tests. Two participants met this criterion when considering their performance on the FS and the same two participants met the criteria on both the FS and traditional tests.

As seen in Table 3 below, using the Z-score comparison, a statistically significant correlation was obtained when comparing the Temporal Pattern FS *vs.* Frequency Pattern Traditional Test, labelling condition ($p < 0.05$) and Dichotic Digits FS Linguistic *vs.* Dichotic Digits Traditional Test ($p < 0.05$) when applying the Spearman correlation.

Table 3.
Classification for the strength of correlation (Akoglu 2018)

Range for absolute values of the correlations	**Interpretation**
1	Perfect correlation
$0.8 \leq r < 1$	Very strong correlation
$0.6 \leq r < 0.8$	Moderate correlation
$0.3 \leq r < 0.6$	Fair correlation
$0 < r < 0.3$	Poor correlation
0	No correlation

When correlations are statistically significant, the strength is interpreted in Table 4 following the recommendations of Akoglu (2018). As the interpretation of the strength of correlation by Akoglu (2018) is not very clear and does not provide intervals, but only values, a conservative approach was taken by using the following ranges and absolute values to interpret the strength of the correlation.

Table 4.
Comparison of the Feather Squadron and traditional tests using the Z-score criteria (continuous variables)

	Spearman correlation	
Tests compared	**Correlation coefficient (if significant, direction and strength indicated)**	**p-value**
Tonal-Pattern Temporal Processing FS vs. FPT—labelling	0.318 (positive, fair)	0.009*
Tonal-Pattern Temporal Processing FS vs. FPT—humming	0.028	0.821
Dichotic Double Sounds FS—left ear vs. DDT—left ear	-0.008	0.948
Dichotic Double Sounds FS—right ear vs. DDT—right ear	0.277 (positive, poor)	0.025*
Dichotic Double Words FS—left ear vs. DDT—left ear	0.266 (positive, poor)	0.031*
Dichotic Double Words FS—right ear vs. DDT—right ear	0.289 (positive, poor)	0.019*
Dichotic Double Sounds FS—weaker ear vs. DDT—weaker ear	0.055	0.659
Dichotic Double Sounds FS—stronger ear vs. DDT—stronger ear	0.295 (positive, poor)	0.016*
Dichotic Double Words FS—weaker ear vs. DDT—weaker ear	0.323 (positive, fair)	0.008*
Dichotic Double Words FS—stronger ear vs. DDT—stronger ear	0.177	0.154

There were correlations that were not statistically significant when comparing Dichotic Sounds FS *vs.* DDT when considering ear effect, i.e. left ear *vs.* left ear or when comparing stronger ear with stronger ear ($p > 0.05$). Reference to weaker ear or stronger ear is based on the test performance, i.e., the ear in which thepoorer score was obtained was referred to as the weaker ear whereas the ear from which the better score was obtained was referred to as the stronger ear.

Whilst the association between the FS tests and traditional tests was poor when using the −2SD criteria to consider the categorical variables, there clearly appears to be a relationship between the Tonal-Pattern Temporal Processing FS tests and FPT, and the Dichotic Double Sounds and Double Words and DDT. Despite the strength of the correlations one can see that, based on the significance, these correlations are not a random occurrence. From the scatterplots - Figures 1-6 (available as Supplemental Material), the positive relationship between these tests can visually be seen and this is corroborated by the positive correlations.

Discussion

Despite controversies surrounding the definition and description of auditory processing and auditory processing disorders (Kraus and White-Schwoch 2015; Moore 2016; Rosen 2005), it is evident that such a disorder exists (Chermak et al. 2017). With a clear philosophy regarding its nature, a valid and feasible assessment and intervention approach can and has been developed. The FS (Barker and Purdy 2016) is one such tool that aims to provide an efficient, engaging and swifter method of assessing auditory processing disorders. Its relevance and application in the South African context needed to be established by correlating the results obtained on the FS with the optimal pairing or best-balanced combination of traditional tests of frequency pattern and dichotic digits, which appeared to be a good starting point (Barker and Purdy 2016; Musiek 1994; Weihing et al. 2015).

This study considered the association and correlation between the more recently developed FS application and traditional tests of auditory processing. Using the broad diagnostic criteria off −2SD to determine the presence of auditory processing disorders espoused by both AAA (2010) and ASHA (2005), did not produce a close association between the traditional FPT and DDT and their equivalent subtests on the FS. This presented a challenge, as the calculations were based on the mean and standard deviations of asymmetrical data on the traditional tests when percentages were used. Thus, using this method of calculating the mean and standard deviation of the percentages obtained, may be inappropriate use of the statistics (Barker and Purdy 2016). Using a “pass/fail” criteria around a cut-off, based on a percentage, is too broad and simplistic, as this does not indicate a degree of deficit, a concept which is emerging in the auditory processing literature (Cameron and Dillon 2008; Dillon et al. 2012). When using this approach, a very small difference between two scores can result in opposite findings from each other, e.g., a score of −1.92 SD is a pass whereas a score of −2.01SD, is a fail. This difference may have resulted from an error on only one test item rather than a trend or a pattern of weakness (Tomlin, Dillon, and Kelly 2014). Therefore, using the −2SD cut-off as a criterion for diagnosis and comparison can be inaccurate and lead to the misdiagnosis or failure to identify those with auditory processing difficulties as the trend suggesting skills deficit, has been missed. Two children scoring on either side of the −2SD cut-off, may present in a similar manner in the real world but one will be diagnosed with an APD whereas the other will not, one will receive services and the other may not. When considering the association of the FS to the traditional tests of frequency pattern and dichotic digits, this broad approach may not be relevant. From the results obtained in this study, only two participants would have met the criteria based on their performance on the FS, whereas 23 participants would have met the criteria based on their performance on traditional tests. However, the degree of deficit is unclear, and the pattern of skills deficit may be more apparent when using the Z-scores and not a hard cut-off.

Following the recommendations of Tomlin, Dillon, and Kelly (2014) and Barker and Purdy (2016), a transformation process (the double arcsine transformation) was applied to the percentages obtained on the traditional tests in order to convert these scores to Z-scores, presenting the results in standard deviations of the population tested, relative to the mean of the same. This allows one to consider the degree of deficit, relative to the normative population used and allows for more precise data with which to perform correlation studies.

The correlations for the DDT with the similar task on the FS met the criteria of $p < 0.05$, indicating that when a more precise analysis of the data was applied, the correlation was statistically significant. The correlation between the dichotic digits testing on both the traditional test and FS when considering Left Ear *vs.* Left Ear (*p* ¼ 0.031) and Right Ear *vs.* Right Ear (*p* ¼ 0.019) indi- cated that on the linguistic tasks, there was a statistically significant, positive correlation. There was no statistically significant correlation when comparing the dichotic listening—non-linguistic on the FS *vs.* DDT when considering Left Ear *vs.* Left Ear (*p* ¼ 0.948) but a statistically significant correlation when considering Right Ear *vs.* Right Ear (*p* ¼ 0.025). A similar pattern of inconsistency was evident when substituting specific ear, i.e., Left *vs.* Left with weaker ear *vs.* weaker ear and stronger ear *vs.* stron- ger ear, on the non-linguistic task of the FS with the DDT. This somewhat confounded our ability to obtain clear and consistent correlations when considering ear specific (left *vs.* left, right *vs.* right) and strength (weaker ear *vs.* weaker ear, stronger ear *vs.* stronger ear) when the stimulus used in the test was different. Thus, when the stimulus used in the presentation differs, i.e., sounds *vs.* digits, although the underlying process of integration is consistent, it is not possible to obtain a statistically significant correlation.

The correlation scores for the FPT with the FS produced a statistically significant correlation ($p = 0.009$) when a response mode other than humming was required. On the Tonal-Pattern Temporal Processing task of the FS, a manual response of tapping the tablet screen was required, and, on the FPT, the responses were separated into humming and labelling responses. When comparing the FS with the humming response on the FPT, there was no significant correlation ($p = 0.821$) but when comparing the FS tapping response with the FPT labelling response, a statistically significant correlation was obtained ($p = 0.009$). Better results are obtained on frequency pattern tasks when the response mode is humming rather than labelling or pointing. This suggests that different mechanisms or brain regions are involved as a result of the brain's network mechanism which directs the action required for verbal and manual responses when compared to the less demanding task of humming. As both the manual tapping/pointing and verbal labelling responses require some interhemispheric integration, the impact of the corpus callosum on these tasks cannot be ignored. This gives rise to the need for further studies considering the role of auditory and multi-modality cortical areas in processing these frequency patterns and the current test requirements (Balen et al. 2019).

The positive relationships obtained between the traditional tests and the similar subtests of the FS indicate that these are not random occurrences and suggest that this tablet-based application may be a valuable tool in providing access to consistent, efficient and affordable auditory processing assessment that would help to identify who requires more in depth assessment and thereafter, management for children in South Africa. The correlation of other subtests of the FS to standardised, equivalents, will still need to be established.

This form of low-contact or no-contact assessment is particularly relevant in a COVID-19 environment and in a technology- driven industry, such as audiology. In a country where physical and financial access to auditory processing assessment has been limited, the use of the FS can be considered a reliable and valid tool, mitigating the concerns raised in previous studies (Barker and Purdy 2016; Campbell and Wilson 2003; Fouch,e-Copley, Govender, and Khan 2016). It has been advised that should a child pass all subtests of the FS, there is a strong likelihood that an APD does not exist. However, if a score below normal is obtained, this would be an indicator for further investigation (Barker 2019).

This is the first study conducted to establish the use of the FS as a tool for assessment of auditory processing disorders in South Africa. The current pandemic has highlighted the need for tools that enable audiologists to continue providing equitable services and for patients to have access to those services while minimising the risk of infection and preventing the delay of intervention. The strength of this correlation study has provided the audiologist with the information to make an informed decision about the tools available. However, it is limited by the type (middle-class, English educated), number and age of the participants. Further, local norms for traditional tests are not currently available and international norms have been used as findings show that these norms are consistent across a number of English-speaking countries (Barker and Purdy 2016). Future research should include a wider age range as the FS is available from 5 years into late adulthood. Its use with non-English educated participants should also be considered. Finally, the efficacy and feasibility of conducting a tablet-based assessment remotely should be investigated as success in this area will ensure that the outcome of the current study is achieved.

Conclusion

The FS is a reliable and valid tool to use to assess at least two areas of auditory processing in 8 to 9- year-old South African children. Providing widespread access to auditory processing testing offers the opportunity for early identification and intervention for auditory processing disorders, thus minimising the associated effects and the concomitant burden on society that this can produce.

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