Reliability and validity of artificial intelligence–based innovative digital scale for the assessment of anxiety in children

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Abstract

Background Dental anxiety still persists as a potential problem in managing the child in the dental office. There is a need to develop a gold standard scale to measure anxiety in children incorporating newer technology. An innovative self-reported scale known as RMS-Digital Anxiety Scale (RMS-DAS) incorporating artificial intelligence (AI) was developed.

Aim To assess the reliability and validity of an AI-based, innovative digital scale for the assessment of dental anxiety in children.

Methods Seventy-six children (aged 4–12 years) were included in the reliability group. The RMS-DAS test score was recorded on Day 1 where the child was asked to click on the expression produced by AI that matches his/her anxiety level the most at that moment. RMS-DAS retest score was recorded after 7 days. The validity group included 140 children. The anxiety scores were recorded using three scales; RMS-DAS, RMS-Pictorial Scale (RMS-PS) and Facial Image Scale (FIS) during the same visit where the child was asked to click on the expression that matches his/her anxiety level the most at that moment. Reliability was assessed by the internal consistency using Cronbach's alpha and the test-retest was assessed using paired t-test, scatterplot, and coefficient correlation. The validity of RMS-DAS was assessed by correlating it with RMS-PS and FIS using Spearman's correlation coefficient.

Results The internal consistency of RMS-DAS was highly reliable (α=0.810). A strong correlation existed between the test-retest scores (r=0.7). There was a strong correlation when RMS-DAS was compared with RMS-PS (r=0.73) and FIS (r=0.76).

Conclusions RMS-DAS is a reliable and valid scale that can be used as a new digital tool to assess children's dental anxiety.

KEYWORDS Anxiety Scale, Artificial Intelligence, Digital Anxiety Scale, RMS-DAS, RMS-Digital Anxiety Scale, Self-reported anxiety scale.

Introduction

Dental anxiety in children still persists as a potential problem in managing the child in the dental office. The effects of dental anxiety can persist in adulthood, which may lead to dental neglect and avoidance of dental treatment [Hakeberg et al., 1993; Shetty et al., 2015]. Anxiety is defined as "an emotional state that precedes the actual encounter with the threatening stimuli, which sometimes is not even identifiable" [Appukuttan, 2016]. Anxiety that is related to dental visits and procedures is called dental anxiety. The prevalence of dental anxiety in children ranges from 5% to 61% [Klingberg and Broberg, 2007; Raja et al., 2015]. Dental anxiety induces physical, cognitive, behavioural, and emotional responses in the child that may complicate the treatment in the dental office. Delay or avoidance of dental appointments results in visiting the dental office only in case of emergency and unavoidable situations resulting in more complicated treatment, inability to follow instructions for preventive care leading to poor oral health [Akbay et al., 2009; Torriani et al., 2014]. One of the causes of poor oral health in children can be attributed to dental anxiety [Coxon et al., 2019; Chakradhar et al., 2020].

Various methods have been used to assess dental anxiety, such as physiological assessments or objective methods that measure blood pressure, pulse rate and muscle tension. These methods may require experience to interpret the results from special equipment [Kime et al., 2020]. Also, there are subjective methods or self-report assessments that have been used including self-reporting questionnaires, and numerical and pictorial scales [Guinot Jimeno et al., 2011]. Numerical scales can be very difficult for children to understand, especially in the dental environment which can be potentially anxiety-provoking, and may lead to lowering the cognitive ability of the child that's needed to complete the numerical scale [Appukuttan, 2016]. Another disadvantage of the self-reporting method using numerical scales is their impropriety when used to assess dental anxiety in young children.

In order to overcome these difficulties, different images/pictorial scales such as the Facial Image Scale (FIS) and RMS Pictorial Scale (RMS-PS) were introduced and validated [Shetty et al., 2015; Buchanan and Niven, 2002]. RMS-PS contains a row of five faces with scores ranging from 1 (very

happy) to 5 (very unhappy). Two separate sets of photographs representing boys and girls are used. The children are asked to self-report the anxiety by choosing the face they feel like themselves at that moment [Shetty et al., 2015]. FIS consists of a row of five emoji with scores ranging from 5 (very unhappy) to 1 (very happy). The children are asked to point to an emoji they felt like themselves at that moment [Buchanan and Niven, 2002]. However, no anxiety scale can be considered a gold standard to measure anxiety in children [Al-Namankany et al., 2012; Tiwari et al., 2021] and there is a need to further develop an anxiety scale using digital technology. Thus, keeping in mind the ease of newer technology like artificial intelligence (AI), an innovative digital scale using incorporating AI in the mobile application was developed and named Raghavendra Manjunath Shetty's Digital Anxiety Scale (RMS-DAS) that produces five expressions (very happy to very unhappy) of the child's face using the child's own photograph. The child is asked to click on the expression that matches his/her anxiety level the most at that moment. However, the new self-reported single-item anxiety scale needs to be assessed for its reliability and validity. Hence, the present study was designed to investigate the reliability and validity of the innovative RMS-DAS.

Methodology

Research Participants

The participants included children who reported to postgraduate paediatric dentistry clinics at the College of Dentistry, Ajman University. Ethical approval was obtained by the Ajman University research ethics committee (Ethical approval number: AURECJan30/2021). Before the commencement of the study, parents/guardians were informed regarding the nature of the study and written informed consent in English and/or Arabic explaining the design of the study was sought to allow their children to participate in the study.

Children aged between 4–12 years old attending the paediatric dentistry clinics between the 14th of February 2021 and the 30th of January 2022 were included and assigned to the reliability group or validity group according to the eligibility criteria.

Sample size calculation

The sample size was estimated for the reliability group using the formula:

N = [(Zα+Zβ)/C]2 + 3, where, Zα = constant set by convention according to accepted α error (0.05); Zβ = constant set by convention according to the power of the study (90%); C= minimum expected moderate correlation coefficient [Hulley et al., 2013]. Hence, after calculation, at least 69 subjects were required to check the reliability. Assuming a maximum possible attrition rate of 10%, the final estimated sample size was 76.

The sample size was estimated for the validity group using the formula:

N = p(1-p) (Zα/E)2 , where, Zα = constant set by convention according to accepted α error (0.05), P =(84.5%) p=proportion of the population from published data [Kumar et al., 2019], E = desired margin of error (6%). Hence, after calculation, 140 subjects were required to check the validity.

Eligibility criteria and Study groups

Reliability group: A total of 76 children in the age group between 4 and 12 years during their first dental visit with no previous dental visits were included.

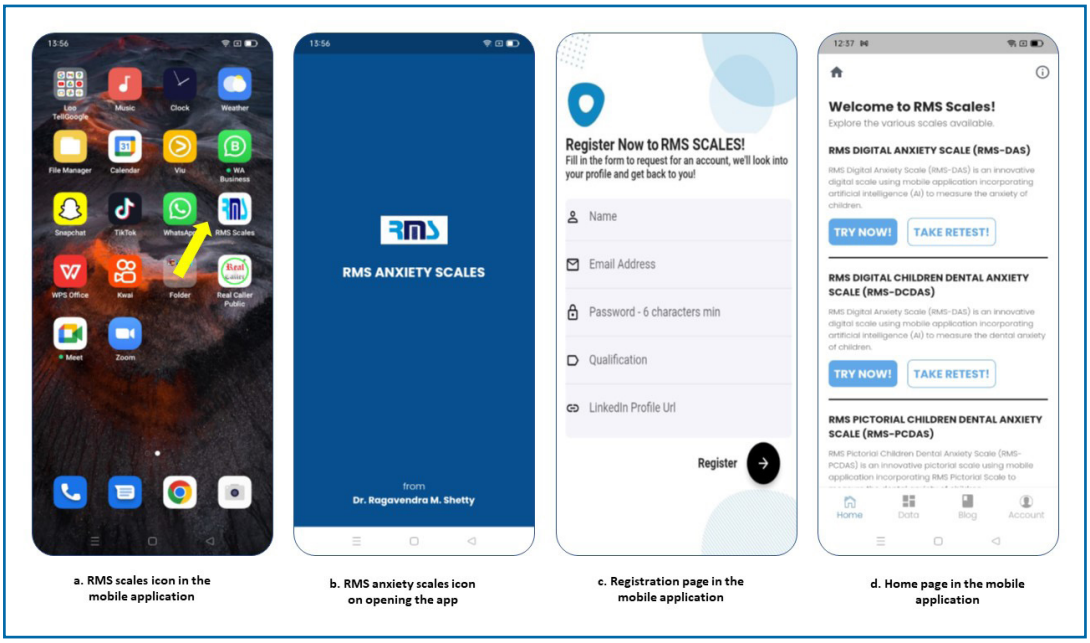
Validity group: A total of 140 children in the age group between 4 and 12 years during their first dental visit or follow-up appointment were included.

The children with special health care needs were excluded from both the above groups.

Research instrument

RMS scales mobile application

The mobile application named "RMS Scales" was developed, in which RMS-DAS is one of the incorporated scales. To move further, registration to 'RMS scales' is required to create a login ID and password. Once the login is done, the home page is displayed with a brief introduction to all the scales including the RMS-DAS (Fig. 1). Clicking the "Try Now' button of RMS-DAS will take it to the patient information page where the patient info



a. RMS scales icon in the mobile application

b. RMS anxiety scales icon on opening the app

c. Registration page in the mobile application

d. Home page in the mobile application

FIG. 1 Login, registration and home page of the RMS Anxiety Scale

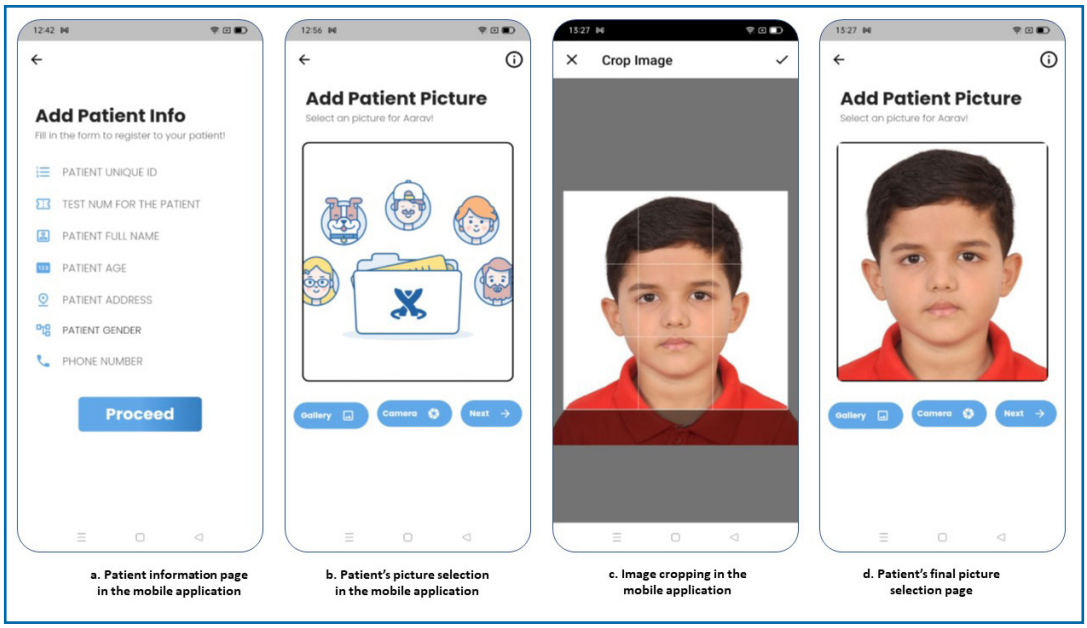


FIG. 2 Patient's information and photo selection page

FIG. 3 Five expressions rendered by artificial intelligence in RMS-DAS

such as patient ID, appointment number, full name, age, address, gender, and phone number should be entered. Once the details are filled it will take you to the 'Add Patient Picture" page where a photograph of the child's face is either imported from the gallery by clicking the "Gallery" button or captured through the camera option of the mobile application by clicking the "Camera" button and cropped to include more of the facial image (Fig. 2). After submitting the photograph, using artificial intelligence (AI) five expressions of the child's face with scores ranging from 1 (very happy) to 5 (very unhappy) will be produced and the child will be asked to click the expression that matches his/her anxiety level the most at that moment (Fig. 3). RMS-DAS application also consists of three different anxiety scales for comparison that includes RMS-PS for boys, RMS-PS for girls, FIS, and VPT. Users can choose one or multiple scales for validity or to compare the result of RMS-DAS with other scales provided in the mobile application. If not interested in comparing, the user can skip it and end the assessment of anxiety by RMS-DAS. In the present study, RMS-PS and FIS were used for comparison. Also, the question "Which scale do you like the most?" is added to the application, which gives the options of various scales (only those scales used by the researcher to compare). In the end, the child needs to click the scale he liked the most.

For reliability or retest of RMS-DAS, the "Retest" button can be clicked on the home page and the search option can be used to select the child's profile from the data saved in the application.

Artificial Intelligence (AI) Incorporation

At the beginning, the image is captured through a mobile camera or gallery as input. The image is captured using the Flutter application (open-source user interface software development kit) and is sent to the Rest-Api-Flask server that is hosted in Heroku (container-based cloud platform).

The five steps involved in extracting the five expressions/emotions by incorporating artificial intelligence (AI) into

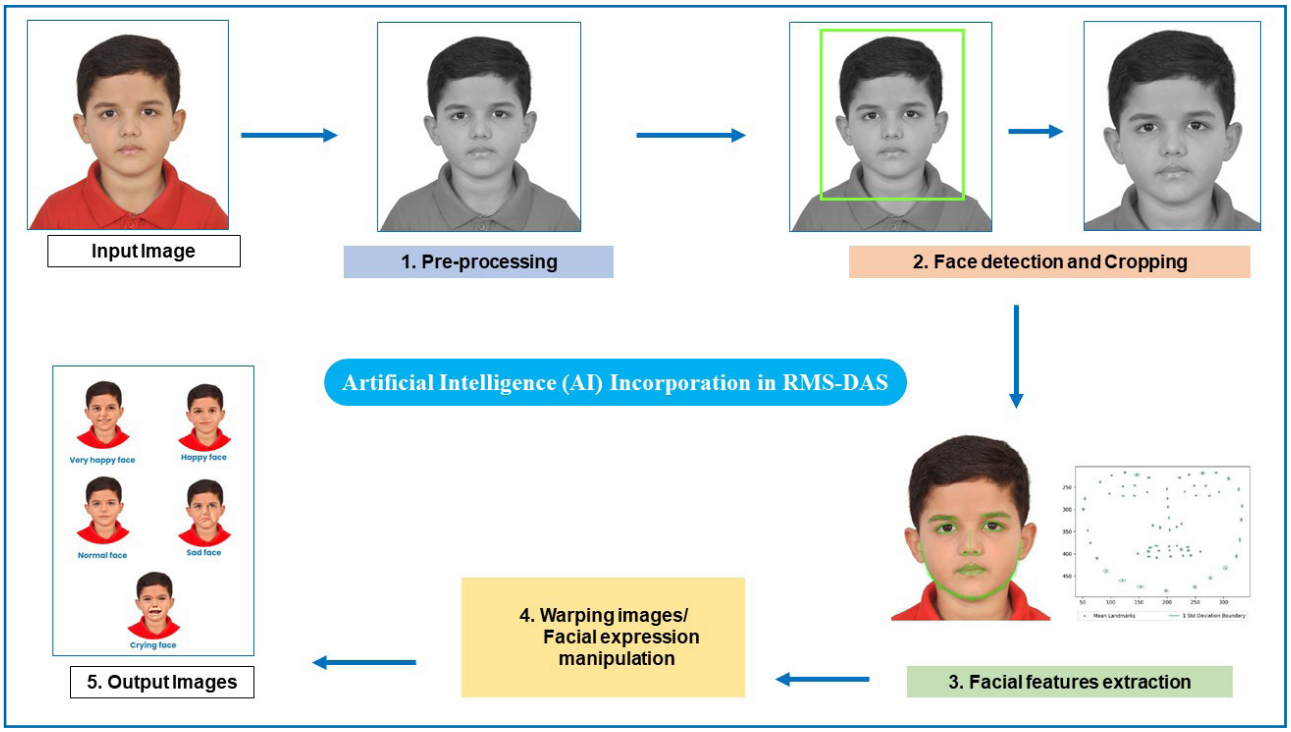


FIG. 4 Steps involved in incorporating artificial intelligence in RMS-DAS

the mobile application are the following (Fig. 4):

a) Pre-processing: The input image is pre-processed to reduce the noise, transform the pixel brightness and converted to grayscale with geometric transformation;

b) Face detection and image cropping: It is based on computer technology that identifies human faces in digital images by locating some set of landmark points in the input image. The 'face coordinates' and 'face boundary' are located in the image using shape_predictor_81 and dlib library. The face is detected and the image is cropped;

c) Facial features extraction: The facial landmark predictor dlib.shape_predictor is loaded from dlib library to identify the facial features. Additionally, for this shape prediction method, shape_predictor_68_face_landmarks.dat file was downloaded. Then, this predictor is used to extract the key facial features from the input image. A numerical feature vector is generated and the common features like eyebrows, eyes, nose tip and lips are extracted using a convolution neural network (CNN);

d) Warping Images/ facial expression manipulation: The image obtained is warped i.e. digitally manipulated to create the five expressions required for the anxiety scale. Warping is done by coupling image morphed with colour interpolation. The input images are gradually distorted and vanished to produce the target image. The suitable expressions are obtained from the trained model using AffectNet.

The AffectNet dataset containing 48x48 pixel grayscale images of the face in five categories (1-Very happy, 2-Happy, 3-Normal, 4-Sad and 5-Crying) is used and incorporated into a CSV file containing two columns. One column includes the emotions with a numeric 1–5 code and another column includes pixels with strings surrounded in quotes for each image; e) Output images with five facial expressions: The mobile application vision model was built using a variant of Convolutional Neural Network (CNN) called Keras and VGG16. The facial expressions are confirmed through this network and if required can classify the expression. After verification, the five expressions (very happy, happy, normal, sad, crying) are superimposed on the warped images using Python OpenCV to obtain the five expressions required in the RMS-DAS.

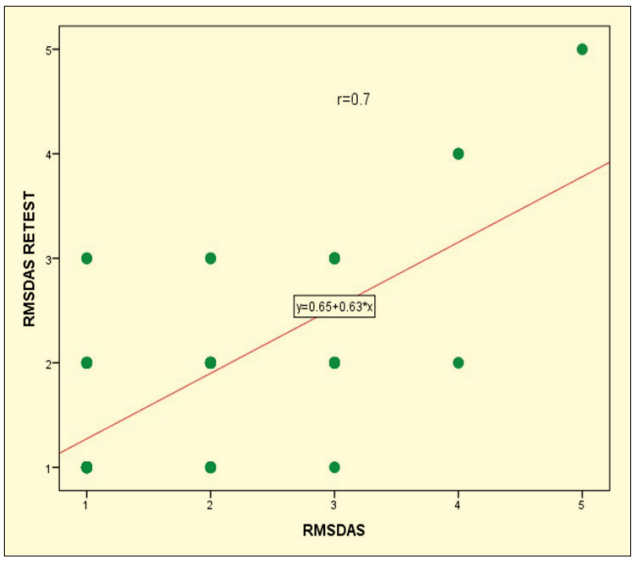


FIG. 5 Scatterplot showing mean test and retest anxiety scores of RMS-DAS

Focus group discussion

A total of 10 paediatric dentists aged between 25–55 years with at least 15 years of experience in academia

were invited to participate in the focus group discussion. The RMS Anxiety Scales mobile applications were downloaded by all the participants and the discussion was carried out online through the Zoom platform. The RMS-DAS scale app was tried with one of the child's images (provided by one of the participants with consent to use the photograph) and the flow of the mobile app was checked. While navigating the RMS-DAS scale through the mobile app, participants provided feedback on the font size, acceptability of colours, orientation of images and quoted references of the other scales (FIS, RMS-PS). They even discussed the clarity of using the app and suggested minor improvements such as increasing the font size of certain text and alignment of images with descriptions. It was also observed that the application was running smoothly except the AI produced five expressions that were smaller in size. The expert team working on the mobile app increased the size of the expressions and incorporated all the changes suggested by the focus group participants.

Data collection

Upon arrival, the child was asked to sit in the waiting area of the postgraduate paediatric dental clinic at the College of Dentistry, Ajman University. Written consent was obtained by the parents/guardian. For the reliability group, children who fulfilled the eligibility criteria were asked to click on the expression that matched his/her anxiety level the most at that moment in RMS-DAS. The score was recorded automatically in the mobile application after the selection of the expression by the child. After one week, the child was recalled for a retest. The scoring of RMS-DAS was repeated by clicking the "Retest" button on the home page of the mobile application in the same waiting area.

For the validity group, dental anxiety was assessed in the waiting room in children who fulfilled the eligibility criteria using RMS-DAS along with the Facial Image Scale (FIS) and RMS Pictorial Scale (RMS-PS) during the same visit. The child was asked to select the expression that matched his/her anxiety level the most at that moment on all three scales (RMS-DAS, RMS-PS, FIS), and the respective scores were automatically recorded in the mobile application.

All the anxiety scores were assessed and recorded by a single observer (OO) in the same waiting area of the Paediatric Dentistry Clinic of the College of Dentistry, Ajman University without the involvement of the parents in choosing the expressions. Obtained data were automatically stored in the mobile application that had password access for security. All information obtained from children remained confidential.

Pilot study

A pilot study was conducted to check the mobile application features that included 8 children to assess the reliability and 18 children to assess the validity. It was observed that the application was running smoothly and the RMS-DAS was reliable and valid in measuring anxiety in children. Participants of the pilot study were included in the final sample size of the study.

Statistical analysis

The data obtained from the mobile application was summarised using appropriate statistical measures. The variables in the study like age and gender were summarised using mean and standard deviation (SD). The distribution of the participants according to age and gender was analysed by the Chi-square test.

The reliability was evaluated using Test-Retest and internal consistency. Test-Retest reliability was assessed using Paired t-test, scatterplot, and Spearman's correlation coefficient. To investigate internal consistency, data were subjected to Cronbach's alpha. Cronbach's alpha values were interpreted as less reliable (0.0–0.20), rather reliable (>0.20–0.40), quite reliable (>0.40–0.60), reliable (>0.60–0.80) and very reliable (>0.80–1.00) [Schober et al., 2018].

Construct validity of the RMS-DAS was assessed by correlating the scale with RMS-PS and FIS using a correlation coefficient. It was also applied to correlate between the RMS-DAS, FIS and RMS-PS according to the age and gender variables. Correlation values were interpreted as very strong (0.8–1.00), strong (0.6–0.79), moderate (0.4–0.59), weak (0.2–0.39) and very weak (0–0.19) [Hair et al., 2010].

The research team used a coding system where the name and personal information were replaced by numbers to ensure full confidentiality and all the researchers were blinded during the statistical analysis. All the analysis was carried out using SPSS version 22.0 (IBM Corp.) and the statistical significance was tested at a 5% level.

Results

Among 76 children in the reliability group, 45 subjects were males with a mean age of 7.14 years and standard deviation (SD) of 2.54 and 31 were females with a mean age of 7.37 years (SD=2.23). Among 140 children in the validity group, 64 subjects were males with a mean age of 7.63 years (SD=2.47) and 76 were females with a mean age of 7.13 years (SD=2.08).

The study population in each group was further categorised into three age groups (4–6 years, 7–9 years and 10–12 years). There was no statistically significant difference found in the distribution of the study population considered for reliability and validity based on gender and age groups (Table 1).

Reliability

Test-Retest

Test-Retest reliability was assessed using paired t-tests and further confirmed with a Scatter plot and Spearman's correlation coefficient.

According to the gender

When RMS-DAS scores were examined for reliability, the comparison of mean differences of test and retest scores showed no statistically significant differences (p>0.05) among males, females and the entire study population as inferred from analysis using paired t-tests (Table 2).

According to the age

Considering test and retest scores for the RMS-DAS scale for different age groups, it was observed that, the comparison of mean differences of test-retest scores among different age groups using paired t-test did not show any statistically significant difference in all three age groups (Table 3).

Reliability Group							
Gender	Mean age± SD (Years)	Age groups (years)				Significance*	
		4 – 6	7 – 9	10-12	Total	x2 value	p-value
Male	7.14±2.54	22	12	11	45 (59.2%)	1.295	0.52 (NS)
Female	7.37±2.23	12	12	7	31 (40.8%)		
Total	7.24±2.40	34 (44.73%)	24 (31.57%)	18 (23.68%)	76 (100%)		
Validity Group							
Gender	Mean age± SD (Years)	Age groups (years)				Significance*	
		4 – 6	7 – 9	10-12	Total	x2 value	p-value
Male	7.63±2.47	25	19	20	64 (45.7%)	5.183	0.75 (NS)
Female	7.13±2.08	32	32	12	76 (54.3%)		
Total	7.36±2.27	57 (40.7%)	51 (36.4%)	32 (22.9%)	140 (100%)		

TABLE 1 Distribution of the study population based on age groups and gender

Descriptive statistics						Paired differences					Significance (2-tailed) *		
Gender	RMS-DAS	N	Mean	SD	SEM	Mean	SD	SEM	95% CI Difference		t	df	P
									Lower	Upper			
Male	Test	45	1.71	0.944	0.141	0.000	0.707	0.105	-0.212	0.212	0.000	44	1.000 (NS)
	Retest	45	1.71	0.920	0.137								
Female	Test	31	1.94	0.964	0.173	0.065	0.772	0.139	-0.219	0.348	0.465	30	0.645 (NS)
	Retest	31	1.87	0.806	0.145								
Overall	Test	76	1.80	0.952	0.109	0.026	0.730	0.084	-0.140	0.193	0.314	75	0.754 (NS)
	Retest	76	1.78	0.873	0.100								

*SD-Standard deviation, SEM-Standard Error Mean, * significance inferred at p≤0.05 based on the paired test, NS-Not Significant*

TABLE 2 Test and retest scores for RMS-DAS based on gender

Descriptive statistics						Paired Differences					Significance* (2-tailed)		
Age Groups	RMS-DAS	N	Mean	SD	SEM	Mean	SD	SEM	95% CI Difference		T	df	p-value
									Lower	Upper			
4-6 Years	Test	34	1.82	0.999	0.171	0.059	0.547	0.094	-0.132	0.250	0.627	33	0.535 (NS)
	Retest	34	1.76	0.987	0.169								
7-9 Years	Test	24	1.63	0.875	0.179	0.000	0.933	0.190	-0.394	0.394	0.000	23	1.000 (NS)
	Retest	24	1.63	0.647	0.132								
10-12 Years	Test	18	2.00	0.970	0.229	0.000	0.767	0.181	-0.381	0.381	0.000	17	1.000 (NS)
	Retest	18	2.00	0.907	0.214								
Overall	Test	76	1.80	0.952	0.109	0.026	0.730	0.084	-0.140	0.193	0.314	75	0.754 (NS)
	Retest	76	1.78	0.873	0.100								

*SD-Standard deviation, SEM-Standard Error Mean, * significance inferred at p≤0.05 based on the paired test, NS-Not Significant*

TABLE 3 Test and retest scores for RMS-DAS based on age groups

Scatterplot and Spearman's correlation coefficient

The reliability was further confirmed by the Scatter plot and Spearman's correlation coefficient. Spearman's coefficient correlation showed a strong correlation between the test and retest scores with the r-value of 0.7 (Fig. 5).

Internal consistency

The overall internal consistency (n=76) was very reliable (0.81) as determined by Cronbach's alpha. According to gender, the internal consistency of RMS-DAS scores in males was very reliable (α= 0.83) and reliable (α= 0.76)

According to gender			
Gender	N	Cronbach's Alpha	Interpretation
Males	45	0.83	Very reliable
Females	31	0.76	Reliable
Overall	76	0.81	Very reliable
According to age groups			
Age Groups (years)	N	Cronbach's Alpha	Interpretation
4-6	34	0.91	Very reliable
7-9	24	0.72	Reliable
10-12	18	0.80	Reliable
Overall	76	0.81	Very reliable

TABLE 4 Internal consistency of RMS-DAS according to gender and age groups

for females. According to the age, Cronbach's alpha value for the age group of 4–6 years was 0.91 (very reliable), 7–9 years was 0.72 (reliable), and 10–12 years was 0.80 (reliable) (Table 4).

Validity

Construct validity

Construct validity was applied to the validity group participants (n=140) to assess the validation of RMS-DAS in measuring dental anxiety in children along with FIS and RMS-PS. Spearman's correlation coefficients showed a 'strong correlation' when RMS-DAS was compared with RMS-PS (0.74) and FIS Scales (0.73). RMS-PS also exhibited a 'strong correlation' (0.75) with FIS scores. All correlation coefficients were statistically highly significant (p<0.001) (Table 5).

Construct validity according to the gender

Among males, RMS-DAS showed a 'moderate correlation' when compared with RMS-PS (0.62) and FIS Scales (0.61). RMS-PS also exhibited a 'strong correlation' (0.63) with FIS scores. Among females, a 'very strong correlation' was observed in the comparison of the RMS-DAS scale with both RMS-PS (0.82) and FIS (0.81). A 'very strong correlation' also existed between RMS-PS and FIS scales (0.83). All correlation coefficients were statistically highly significant (p<0.001) (Table 6).

Anxiety Scale	No. of subjects	Spearman's correlation	Interpretation
RMS-DAS with RMS-PS	140	0.74**	Strong correlation
RMS-DAS with FIS	140	0.73**	Strong correlation
RMS-PS with FIS	140	0.75**	Strong correlation
*** Correlation is highly significant at the 0.01 level (2-tailed)*			

TABLE 5 Construct validity of RMS-DAS with other scales

Construct validity according to the age group

Spearman's correlation coefficients comparing RMS-DAS with other scales for the 4–6-year age group showed a 'strong correlation' with both RMS-PS (0.64) and FIS (0.62) which was statistically highly significant (p<0.001). A 'strong correlation' (0.74) was also noted between RMS-PS and FIS. Similarly, in the 7-9-year age group, it was observed that there was a 'strong correlation' when RMS-DAS was compared with RMS-PS (0.74) and FIS (0.70). A 'strong correlation' also existed between RMS-PS and FIS scales (0.71). In the 10-12 year age group, RMS-DAS showed a 'very strong correlation' with RMS-PS (0.85) and FIS Scales (0.90). A 'strong correlation' was also noted between RMS-PS and FIS scales (0.74). All the above correlations were found to be statistically highly significant. (p<0.001) (Table 6).

Anxiety scores

Children who selected the scores of 1 (very happy), 2 (happy) and 3 (neutral) were considered non-anxious and those who chose scores 4 (sad) and 5 (crying) were considered anxious. In the reliability group, 94% of children were non-anxious and 5.3% were anxious during the first dental visit. RMS-DAS identified 93.6% of children were

Spearman's correlation according to the gender				
Gender	No. of subjects	RMS-DAS with RMS-PS	RMS-DAS with FIS	RMS-PS with FIS
Males	64	0.62**	0.61**	0.63**
Females	76	0.82**	0.81**	0.83**
Overall	140	0.74**	0.73**	0.75**
Spearman's correlation according to the age groups				
Age group	No. of subjects	RMS-DAS with RMS-PS	RMS-DAS with FIS	RMS-PS with FIS
4-6 years	57	0.64**	0.62**	0.74**
7-9 years	51	0.74**	0.70**	0.71**
10-12 years	32	0.85**	0.90**	0.74**
Overall	140	0.74**	0.73**	0.75**
*** Correlation is highly significant at the 0.01 level (2-tailed)*				

TABLE 6 Spearman's correlation for the construct validity of RMS-DAS according to the gender and age groups

Anxiety*	Reliability Group		Validity Group		
	RMS-DASTest Frequency (%)	RMS-DASTest Frequency (%)	RMS-DAS Frequency (%)	RMS-PS Frequency (%)	FIS Frequency (%)
Non-anxious	72 (94.7)	73 (96.1)	131 (93.6)	130 (92.9)	133 (92.9)
Anxious	4 (5.3)	3 (3.9)	9 (6.4)	10 (7.1)	7 (7.1)
Total	76 (100)	76 (100)	140 (100)	140 (100)	140 (100)

**Scores of 1, 2, 3 are categorised as Non-anxious and Scores of 4 and 5 are categorised as Anxious*

TABLE 7 Anxious and non-anxious children in the study groups group

non-anxious and 6.4% were anxious; the RMS-PS identified 92.9% of children were free of anxiety and 7.1% were anxious, whereas the FIS showed 95.0% of children were non-anxious and 5.0% were anxious (Table 7).

Which scale did you like or attract you the most?

The overall distribution of the study population according to their liking of the anxiety scale showed that RMS-DAS (63.6%) was the most liked scale followed by RMS-PS (26.4%) and FIS (10.0%) (Fig. 6).

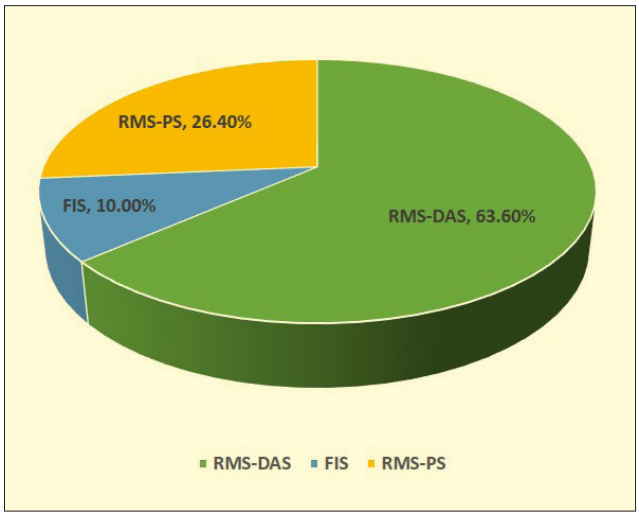


FIG. 6 Distribution of the study population according to their most liked scale

Discussion

Measuring dental anxiety will help paediatric dentists to choose the proper behaviour management or behaviour guidance technique according to different anxiety levels. Hence, the focus of this study was to design an innovative anxiety scale considering the limitations of the previous anxiety scales and to assess its validity and reliability in measuring children's dental anxiety. Reliability is the consistency of a data or result measurement. Validity is defined as 'how accurately a methodology measures a variable that it intends to measure'[Ahmed and Ishtiaq, 2021]. Construct validity is 'the extent to which the measure is consistent with the existing theory and knowledge of the concept that is being measured' [Ahmed and Ishtiaq, 2021].

Artificial intelligence (AI) covers a broad spectrum of technological innovations that continue to have an influence on our daily lives. The advancement of AI enables the evaluation of enormous amounts of data, which gives credible data and enhances decision-making [Chen et al., 2020]. In the present study, AI was used to produce five expressions ranging from very happy to very unhappy using the child's own photograph. Since it is a self-reporting scale the child was asked to click on the expression that matches his/her anxiety level the most at that moment. However, if the photos of the child are taken without their knowledge with the parent's consent, AI can predict the anxiety level of the child by analysing their facial expression at that particular moment. Very young children usually have lower cognitive abilities compared to older age children. Thus, pictorial scales are more suitable and understandable by them compared to questionnaire-based scales which also can be limited by language [Yon et al., 2020]. According to the recent systematic review and meta-analysis of dental anxiety scales used in paediatric dentistry, the most commonly used scales to measure anxiety are FIS, RMS-PS and VPT [Tiwari et al., 2021]. In the present study, RMS-PS and FIS were used to compare with RMS-DAS. In VPT, misinterpretation of the facial expressions drawings has been seen in young children [Shetty et al., 2015].

Moreover, some of the drawings are ambiguous and may take time to complete the scale [Folayan and Kolawale, 2004). The original VPT has only male cartoons which can be confusing to young females and has overstated facial expressions. Although a female version of VPT has been developed by Oliveira et al. [2020] in their modified VPT scale, still, the drawings can be ambiguous for the children. In RMS-PS, though widely used in recent times, children with other ethnicities can have a problem identifying their anxiety situation. Also, the unfamiliarity of the figures in FIS can be a limitation as children can misinterpret the facial expressions in these figures [Yon et al., 2020]. Hence, to overcome these limitations, RMS-DAS was introduced incorporating AI into the mobile application and was checked for its validity and reliability. RMS-DAS demonstrated high internal consistency reliability. These results are comparable to the internal consistency of Venham picture test (VPT) with Cronbach's alpha of 0.838, modified child dental anxiety scale (MCDAS), which reported 0.85 and facial version of MCDAS (MCDASf) with Cronbach's alpha of 0.82 [Venham and Gaulin-Kremer, 1979; Wong et al., 1998; Howard and Freeman, 2007]. Also, no significant difference was found in the reliability group between the gender as

well the different age groups included in the study. This shows that RMS-DAS is reliable in males and females in the age group from 4 to 12 years old. Interestingly, in the present study, it was found that internal consistency reliability in the young age group (4 to 6 years old) was more reliable than in the older age (7 to 12 years old). This indicates that RMS-DAS is reliable even in the younger age group (4 to 6 years) included in the present study.

In regards to validity, a strong correlation was found between RMS-DAS scores when compared to RMS-PS and FIS scores. Similarly, a strong correlation was observed between RMS-PS and FIS, which is not similar to the findings observed by Shetty et al. (2015) and Oliveira et al. (2020) who noted a moderate correlation between RMS-PS and FIS. Anxiety can be identified as state, trait, and situational anxiety [MacIntyre and Gardner, 1991]. State anxiety is a temporary reaction to adverse events, whereas trait anxiety is long-term personality dependent [Spielberger, 1972]. Situational anxiety is the response to a specific situation. Both state anxiety and situational anxiety can be measured by RMS-DAS. RMS-DAS has overcome the limitations of the other scales as it allows children to identify themselves better with their own expressions created by artificial intelligence compared to black and white figures, cartoon figures, or even pictures of other children with certain ethnicities used in other pictorial scales [Venham and Gaulin-Kremer, 1979; Sadana et al., 2016].

According to age, a strong correlation was shown in children aged 4 to 6 years when RMS-DAS was compared to RMS-PS and FIS. In the 7–9-year-old group, a strong correlation was observed between RMS-DAS and FIS scales as well as between RMS-PS and FIS. Comparably when the animated emoji scale (AES) was correlated to FIS by Setty et al. [2019], a strong correlation was noted in children aged 4–14 years old. A very strong correlation was seen between RMS-DAS compared to RMS-PS and FIS in the age group of 10–12 years old. Therefore, RMS-DAS was valid in measuring dental anxiety in children.

A comparison of mean differences in test and retest scores showed no statistically significant differences among males and females. Similar results were noted in RMS-PS and animated emoji scale (AES) studies [Shetty et al., 2015; Setty et al., 2019]. Moreover, no statistical difference was observed between the mean differences in test and retest scores according to the age groups.

Our findings are in agreement with Chhabra et al. [2012] who reported that the prevalence of dental anxiety in children aged 5-10 years was 6.3%. The low levels of anxiety can be because the anxiety tests were taken in a friendly environment. In the literature, dental anxiety scales were evaluated in different settings. The hospital-based setting was used in FIS and RMS-PS, whereas the school setting was the environment used in the Smiley Faces Program (SFP) and faces version of the Modified Child Dental Anxiety Scale (MCDASf) [Howard and Freeman, 2007; Buchanan and Niven, 2002; Shetty et al., 2015). RMS-DAS was completed in the waiting area of the Paediatric Dentistry Clinics at Ajman University which had a colourful and fun setup along with a desensitising area, where children could draw, colour or paint. Accordingly, this surrounding atmosphere can lower the child's dental anxiety in the dental clinic. However, dental anxiety assessment can also be recorded in the future on the dental chair before treatment. RMS-DAS was the most liked scale (63.6%) followed by RMS-PS (26.4%) and FIS (10.0%) when the children were asked to choose the scale they liked the most among the three scales used in the study. RMS-DAS holds the attention of the child and uses the newer technology on the phone that may establish a good experience between the paediatric dentist and the child patient to record the anxiety. Moreover, this scale takes a very short time to be completed and is universal as no questionnaires or languages are needed and easily holds the attention of the child. The scoring of anxiety in children and storing the data is simple through the mobile application.

When compared to RMS-PS, FIS and animated emoji scales, RMS-DAS could be more child-friendly and attract the attention of the child. Though the Chotta Bheem-Chutki scale has incorporated cartoon characters to attract the attention of the child, the cartoon characters are not very familiar globally.

Limitations and Future Scope

One of the limitations of the present study was including children during their first dental visits and children with previous experience in the validity group due to the lack of new patients during the peak time of the COVID-19 pandemic. Though it has not affected the assessment of the validity, these participants could have been added to estimate the prevalence of anxiety in the first dental visit along with the reliability group.

Also, another limitation at present could be the output images that are not 100% matching to the child's real expression. However, by training the AI model by using the app frequently the refinement in the images can be obtained.

The sample used in this study was minimum and included children residing in only one country. In the future, the reliability and validity of RMS-DAS can be assessed in various parts of the globe in a larger sample. Global data on anxiety can also be collected in a uniform standard manner with different age groups and gender from different areas in the world. This data on the anxiety scores can be acquired, compared, and saved in the mobile application.

RMS-DAS can be used in both medical and dental setups to measure anxiety in children. The items or questions regarding dental situations (examination, restoration, extraction, sedation, general anaesthesia) can be incorporated into the mobile application to make it a self-reported dental anxiety scale. Further research can be conducted to evaluate the socio-economic status and its relationship to anxiety levels in children.

The advantages of RMS-DAS can be summarised as follows:

- The mobile application can be easily downloaded from Play Store and iOS and used to measure anxiety in children without any training.
- RMS-DAS due to its innovative technology makes the scale simple and easy to score and interpret anxiety even at a younger age.
- RMS-DAS mobile application can be also used in every visit to assess anxiety and plan treatment with the appropriate behaviour guidance technique.
- Data can be stored safely in the mobile application and can easily be retrieved whenever required.

Conclusions

Within the limitations of the present study, the RMS digital anxiety scale (RMS-DAS) is a reliable and valid anxiety scale to measure dental anxiety in children aged 4–12 years. RMS-DAS was the most liked scale followed by RMS-PS and FIS respectively. Hence, the innovative RMS-DAS using mobile applications incorporating artificial intelligence (AI) can be used as an alternative to the Facial Image Scale and RMS Pictorial Scale to measure anxiety in children.

Authors' contribution

RMS and OTSO participated in the study conception and design as well as coordinated the study. OTSO collected the data. RMS and OTSO drafted the manuscript. RMS supervised the study. TW made substantial contributions to the conception and design of the study and overall supervision of the project. All authors read and approved the final manuscript.

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