The reliability of video otoscopy recordings and still images in the asynchronous diagnosis of middle-ear disease

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Abstract

Objective: To compare the asynchronous assessment of video otoscopic still images to recordings by an audiologist and ear, nose and throat surgeon (ENT) for diagnostic reliability and agreement in identifying middle-ear disease.

Design: A prospective cross-sectional study, asynchronously assessing video otoscopy, tympanometry and case history (Dx1). A subset was re-diagnosed (Dx2).

Study sample: Video otoscopy and data from 146 children recruited at two public community events; a sub-set of 47 were re-assessed.

Results: The intra-rater diagnostic agreement between Dx1 and Dx2 was moderate (k=0.445-0.552) for the ENT surgeon, and almost-perfect (k=0.928) for the audiologist, in both procedures. The agreement between the two procedures was substantial (k= 0.624) and moderate (k=0.416) for the ENT surgeon in Dx1 and Dx2 respectively, and almost-perfect for the audiologist (k=0.854-0.978) in both rounds. In Dx1, the inter-rater agreement between the clinicians was substantial using still images (k=0.672) and moderate using recordings (k=0.593); in Dx2 it was moderate using both procedures (k=0.477-0.488).

Conclusion: Both video otoscopic procedures, in addition to tympanometry and case history information, can be reliably used for asynchronous diagnosis of childhood middle-ear disease. An audiologist has a potential role in triaging children with middle-ear abnormalities and, therefore, improving access to ear-health services.

Introduction:

Visualisation of the tympanic membrane (TM) is an essential part of assessment of hearing and middle-ear health. Unfortunately, limited access to ear-health services is a worldwide issue that impacts both low-, middle- and high-income countries (Swanepoel et al., 2010). This was highlighted by Peer et al. (2018) who reported that in 11 African countries, the number of Ear, Nose, and Throat (ENT) surgeons and audiologists ranged from 0.024 to 1.045 and 0.001 to 1.035 per 100,000 population, respectively. In a high-income country such as the United Kingdom, the ratio of ENT surgeons and audiologists was 2.2 and 3.6 per 100,000 population, respectively. At present, access to face-to-face outpatient appointments and travel to underserved areas have become more limited due to COVID-19 restrictions. This has consequently become another barrier to the early identification and intervention of middle-ear disease. Timely intervention for middle-ear disease such as otitis media, and the subsequent hearing loss is particularly important in paediatric populations to avoid potential adverse impact on developmental outcomes (Kong & Coates, 2009; Hancock et al., 2017; Da Costa et al., 2018; Brennan-Jones et al., 2020). It is also important to avoid the progression of disease arising from prolonged exposure to untreated otitis media including serious extracranial (i.e. TM perforations) and intracranial (i.e. meningitis) complications (O'Connor et al., 2009).

In places where face-to-face examination by an ear-health specialist is not possible, video otoscopy has been found to be a valid tool that can allow images of the TM and ear canal to be remotely assessed by ENT specialists (Aronzon et al., 2004; Eikelboom et al., 2005; Swanepoel & Hall, 2010). A systematic review by Metcalfe et al. (2021) has shown that video otoscopy can be safely and effectively used to assess middle-ear disease via tele-medicine. Video otoscopy has been associated with perceptions of increased patient centredness and parental satisfaction compared to traditional otoscopy, as it allows TM images to be displayed on a screen (Rimon et al., 2015). This can also help distract hard-to-test children and increase their cooperation during testing (Lundberg et al., 2008) or at least allow for limited TM glimpses to be captured and thoroughly assessed afterwards (Richards, 2015).

Accurate diagnosis is essential for an accurate management plan. Previous research has focused on either video otoscopy still images or recordings, and have revealed good diagnostic agreement for each of these procedures according to a range of different otoscopic reference standards including onsite otoscopy (Eikelboom, Mbao et al., 2005; Biagio et al., 2013; Mandavia et al., 2018) and otomicroscopy (Patricoski et al., 2003; Kokesh et al., 2008; Biagio et al., 2014), with or without findings from case history and/or other tests. Two studies have compared the asynchronous diagnostic capability (Binol et al., 2020a), accuracy and confidence (Binol et al., 2020b) using enhanced frame-selected and composite images (both generated from video otoscopy recordings obtained by experienced clinicians) to the original recordings. It is still unknown, however, whether video otoscopy still images or recordings can facilitate more reliable remote diagnosis than the other.

The asynchronous diagnosis of middle-ear disease with the use of video otoscopy has also been investigated in different groups of clinicians, including otolaryngologists (Patricoski, Kokesh et al., 2003; Eikelboom, Mbao et al., 2005; Smith et al., 2006; Kokesh, Ferguson et al., 2008; Smith et al., 2012; Biagio, Swanepoel et al., 2013; Sebothoma & Khoza-Shangase, 2018), otologists (Biagio, Swanepoel et al., 2014; Lundberg et al., 2014) and general practitioners (Biagio, Swanepoel et al., 2014; Lundberg, Biagio et al., 2014; Lundberg et al., 2017). Another comparison between a group of audiologists and otolaryngologists has shown a substantial agreement in the diagnosis of otitis media in a group of Aboriginal children, with audiologists posting a higher false positive rate in the diagnosis of TM perforations compared to otolaryngologists. (Gunasekera et al., 2018). In their study, however, the diagnoses of audiologists were made onsite using video otoscopy, while those of otolaryngologists were made asynchronously. We have not identified any studies to date that have examined the agreement between audiologists and ENT specialists with regard to both professional groups providing asynchronous diagnosis of middle-ear disease.

Our previous study compared video otoscopy still images to recordings in terms of the clarity of the view and the suitability for making an asynchronous diagnosis (Alenezi et al., 2021), showing that video otoscopy recordings were preferred by clinicians for asynchronous assessments. There was no significant impact of the role of the reviewer or the role of the person conducting the video otoscopy, in the majority of the rated domains.

The present study aims to address the current gaps in the literature by comparing the diagnostic reliability of the two video otoscopic procedures and exploring the agreement in the asynchronous diagnosis of middle-ear disease between an ENT surgeon and audiologist. These findings may help inform which video otoscopic procedure can facilitate more reliable asynchronous diagnosis. It may also help elucidate the role of audiologists – who tend to be more available in many areas than ENT specialists – in triaging children with middle-ear disease.

Methods

Participants

A total of 157 children were recruited at the Telethon Weekend Expo and Cockburn Integrated Health National Aborigines and Islanders Day Observance Committee (NAIDOC) public community events in Perth, Western Australia in October, 2019 (Spring in the Southern Hemisphere). Recruitment was through self-presentation for inclusion and was offered to all children who attended the events with their parents/guardians and met the inclusion criteria of the study. The recruited children were de-identified using unique ID numbers and their parents/guardians had to complete an electronic informed consent form prior to any study procedure. Inclusion criteria were children aged six months to 15 years, a signed informed consent form, and absence of contraindications, including any ear surgery or discharge in the past six weeks. Children with recent ear surgery were not eligible to the study due to potential pain and discomfort that can be caused during video otoscopic examination, while ear discharge was an exclusion criterion as it is a contraindication for tympanometry.

Parental questionnaire

Following informed consent, the parents/guardians were asked to electronically complete a brief questionnaire administered by a research assistant. The questionnaire included questions about the child's demographics (e.g. age, sex, and postal code), ear-health history and parental concerns regarding hearing, speech, and language. Information about the child's Aboriginal or Torres Strait Islander (TSI) status was collected as this group of children have higher risks of developing middle-ear disease (Jervis-Bardy et al., 2014). The questionnaire was also used to identify any contraindications, mentioned previously, prior to testing. Informed consent and parental questionnaire were administered by the same research assistant and were immediately followed by video otoscopy examination and tympanometry, by two different testers.

Equipment

A hearScope attachment connected to the hearScope app version 2.0 (hearScope, HearX Group, Pretoria, South Africa) and installed on a Samsung Galaxy A3 smart phone (2017) with a 4.7-inch screen (1280x720-pixel resolution) was used to obtain video otoscopy still images, and 10-second recordings of the tympanic membrane (TM) and ear canal of each ear. The equipment in this study was selected for its convenience for telehealth services since it is portable and allows results to be securely stored in a server for asynchronous evaluation. The equipment also has the advantage of being easily operated by non-clinicians with limited training and in community settings. Video otoscopy was carried out by a group of testers, including research assistants, audiologists, and an ENT specialist.

Tympanometry was conducted using Titan Middle Ear Analyser (Interacoustics, Denmark) by either audiologists or research assistants to test the middle-ear health and TM mobility. A study audiologist immediately reviewed and classified all the tympanograms obtained by the research assistants. Since testing younger children can be challenging, only experienced audiologists tested children younger than two years old. Research assistants were provided with half-day training on how to conduct video otoscopy and tympanometry and how to securely store results by study audiologists. Following the training, the study audiologists assessed the research assistants' skills to confirm their capability for testing.

Review procedure

All video otoscopy still images and recordings were stored in a secure server and forwarded for asynchronous evaluation. Four to six months post testing, still images and recordings were randomly and independently presented to an audiologist with over 10 years clinical experience, and a consultant ENT surgeon. Only the audiologist was one of the testers conducting video otoscopy and tympanometry on the day of testing. They were blinded to whether the still images and video recordings were related to the same child. The ENT surgeon reviewed the images and recordings using 13-inch MacBook Air (1440x900-pixel resolution), while the audiologist used 13.3-inch HP EliteBook (1920x1080-pixel resolution).

The first part of the review process comprised a subjective evaluation of the quality of video otoscopy still images and recordings and their suitability for making an asynchronous diagnosis. These results were reported separately (Alenezi, Jajko et al., 2021).

The second part, reported here, included an evaluation of the suitability of video otoscopy still images and recordings, in addition to tympanograms classification and case history information, for making an asynchronous diagnosis by asking the reviewers to record their 'ability to make an accurate diagnosis' in light of this information. They were then asked to make a diagnosis by selecting one of three diagnostic categories: normal, abnormal – clinically insignificant (i.e., referral for treatment not required), or abnormal – clinically significant (i.e., referral for treatment required). There were no predetermined criteria for each of the diagnostic categories and the clinicians made a diagnosis based on their clinical experience. The reviewers were instructed to describe all abnormal findings. The diagnosis was made at child level (i.e. using findings from both ears). Referral letters to a general medical practitioner were provided by either audiologists or ENT specialists to parents/guardians of children with clinically significant abnormal findings identified on the day of testing or the review process. Diagnoses made at this part of the review process will be referred to as 'Dx1' in this study.

Re-diagnosis (Dx2)

At least eight months post Dx1, the video otoscopy results, tympanometry and case history information of 50 children, were forwarded to the same clinicians for re-diagnosis (Dx2). Twenty-five of these children with normal middle-ear status found in Dx1 were randomly selected for re-diagnosis. The other 25 children were randomly selected from a total of 28 children with abnormal middle-ear status, either clinically significant or insignificant, reported by at least one clinician in Dx1. The reviewers were asked to make a re-diagnosis by repeating the second part of the review process while being blinded to Dx1 results. For inclusion in the re-diagnosis sub-group, children must have had a full set of paired images and recordings collected bilaterally, and at least one clinician should have indicated that they were able to make a diagnosis in Dx1 based on case history and the results of the two video otoscopic procedures, and tympanometry.

Ethics

Ethics approval was obtained from the Child and Adolescent Health Service Human Research Ethics Committee, the Western Australia Aboriginal Health Ethics Committee, and The University of Western Australia Human Research Ethics Committee.

Analysis

Descriptive statistics, including mean, standard deviation (SD) and frequencies were used to describe the characteristics of the study population and to summarise the results from Dx1 and Dx2. The reliability of each video otoscopic procedure was investigated by testing the intra-rater diagnostic agreement between the Dx1 and Dx2, using Cohen's Kappa statistics. The statistics were also used to quantify the intra-rater diagnostic agreement between the two otoscopic procedures from the same clinician, and inter-rater diagnostic agreement between the two clinicians with the same otoscopic procedures in the two rounds (Dx1 and Dx2). The kappa values k = 0.00–0.20 corresponded to 'slight agreement'; k = 0.21–0.40 to 'fair agreement'; k = 0.41–0.60 to 'moderate agreement'; k = 0.61–0.80 to 'substantial agreement'; and k = 0.81–1.00 to 'almost perfect agreement' (Landis & Koch, 1977). All the significance levels were set at the 5% level ($p \leq 0.05$) and the statistical analysis was carried out using IBM Statistical Package for the Social Sciences (SPSS),-version 26.

Results

Diagnosis 1 (Dx1)

A total of 157 children were recruited to the study. Children with missing video otoscopy still images and/or recordings bilaterally due to child's poor compliance, or where technical issues prevented saving of data, were excluded from the analysis (n= 7) (Figure 1). We also excluded four other children from the analysis due to incomplete information on the ability to make a diagnosis and/or the diagnostic category by at least one clinician at Dx1. This resulted in 146 children being successfully diagnosed by the two clinicians using both video otoscopic procedures in Dx1 (mean age 7.21 years; Standard Deviation (SD) 3.41; 39.7% male; 9.6% Aboriginal or TSI). Seven out of the 146 children included in the analysis only had one video otoscopy still image and/or one recording available. Both the ENT surgeon and audiologist reported that 82.2% of children had normal ears when assessed from still images in Dx1. This varied only slightly when assessing the recordings in that the audiologist reported one fewer normal case (Table 1). The ENT surgeon reported that 11% and 4.8% of children had clinically significant and insignificant abnormal findings, respectively using still images compared to 11.6% and 3.4%, respectively when recordings were used. As for the audiologist, 4.8% and 13% children were reported to have clinically significant and insignificant findings respectively, using both procedures. In all scenarios, the percentage of children whom clinicians were unable to provide a diagnosis in Dx1 was less than 3%.

Table 1. Distribution of the initial diagnosis (Dx1) made by ENT surgeon and audiologist using video otoscopy, case history, and tympanometry results. (n = 146 children).

Category	Video otoscopic procedure	ENT *n* (%)	Audiologist *n* (%)
Unable to make a diagnosis	Still image	3 (2.1)	0 (0)
	Recording	4 (2.7)	1 (0.7)
Normal	Still image	120 (82.2)	120 (82.2)
	Recording	120 (82.2)	119 (81.5)
Abnormal – clinically insignificant	Still image	7 (4.8)	19 (13)
	Recording	5 (3.4)	19 (13)
Abnormal – clinically significant	Still image	16 (11)	7 (4.8)
	Recording	17 (11.6)	7 (4.8)

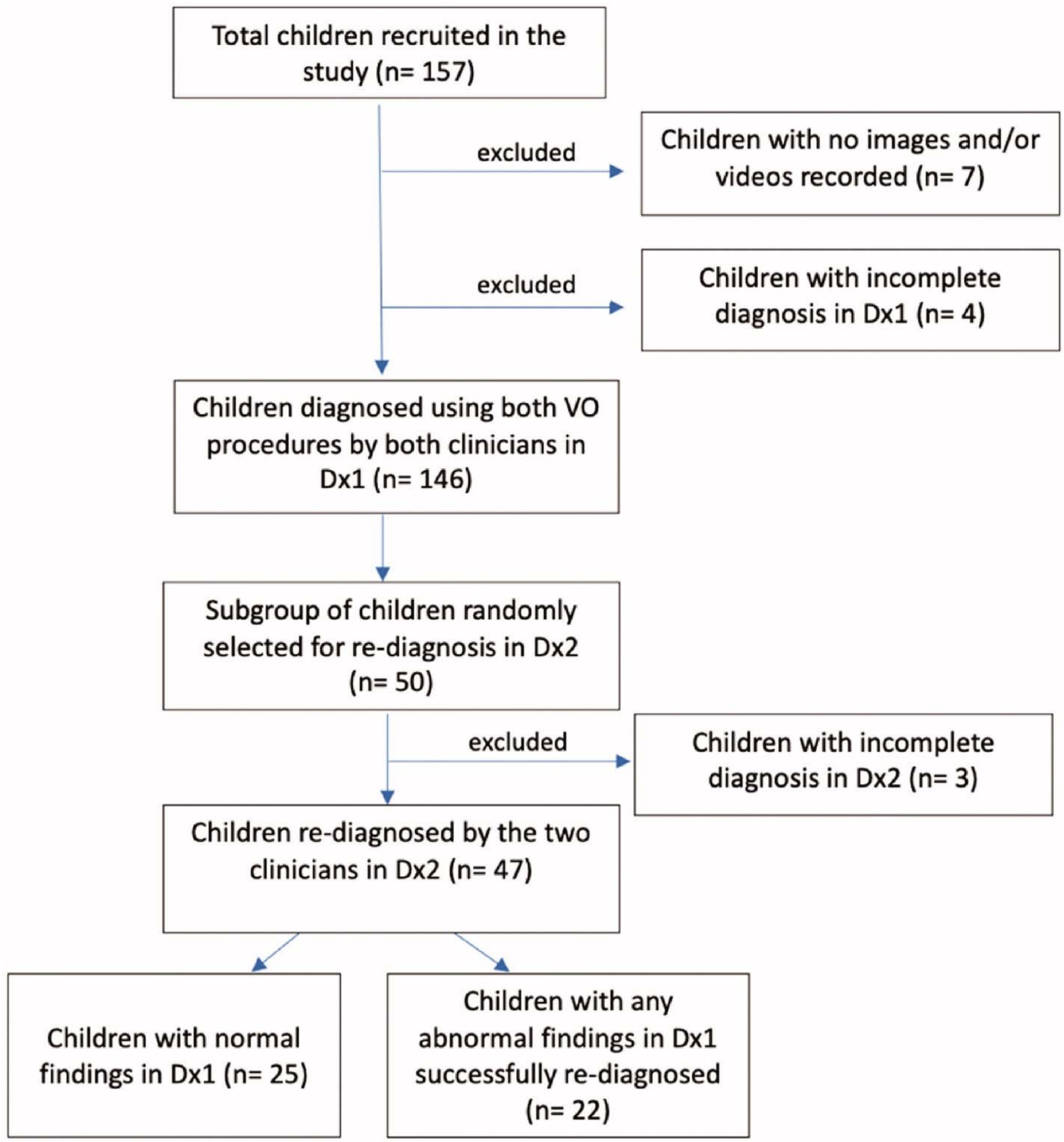

Figure 1. Flowchart of the inclusion/exclusion of participants in the analysis. (Table1 near here)

Diagnosis 2 (Dx2)

Three children with missing data from Dx2 were excluded from the analysis, leaving 47 children re-diagnosed by the two clinicians using the two video otoscopic procedures with tympanometry and case history information. A summary of the Dx2 results is presented in Table 2.

Table 2. Distribution of the initial diagnosis (Dx1) and re-diagnosis (Dx2) made by ENT surgeon and audiologist using video otoscopy, case history, and tympanometry results. (n = 47 children).

Category	Video otoscopic procedure	Dx1 ENT *n* (%)	Dx2 ENT *n* (%)	Dx1 Audiologist *n* (%)	Dx2 Audiologist *n* (%)
Unable to make a diagnosis	Still image	1 (2.1)	6 (12.8)	0 (0)	0 (0)
	Recording	2 (4.3)	4 (8.5)	0 (0)	0 (0)
Normal	Still image	25 (53.2)	26 (55.3)	24 (51.1)	25 (53.2)
	Recording	23 (48.9)	29 (61.7)	24 (51.1)	24 (51.1)
Abnormal – clinically insignificant	Still image	7 (14.9)	3 (6.4)	16 (34.0)	16 (34)
	Recording	5 (10.6)	5 (10.6)	16 (34.0)	18 (38.3)
Abnormal – clinically significant	Still image	14 (29.8)	12 (25.5)	7 (14.9)	6 (12.8)
	Recording	17 (36.2)	9 (19.1)	7 (14.9)	5 (10.6)

Intra-rater diagnostic agreement between Dx1 and Dx2

There was a moderate diagnostic agreement in the diagnosis made by the ENT surgeon in Dx1 and Dx2 using still images and recordings (k= 0.445-0.552) (Table 3). This diagnostic agreement was found to be almost-perfect for the audiologist using both still images and recordings (k=0.928).

Intra-rater diagnostic agreement between still images and video recordings

A substantial diagnostic agreement was found between the two video otoscopic procedures, in addition to other supporting information by ENT surgeon in Dx1 (k=0.624) while a moderate diagnostic agreement was found in Dx2 (k=0.416) (Table3). For the audiologist, this agreement was almost perfect in both Dx1 and Dx2 (k=0.854-0.978).

Table 3. Intra-rater agreement and inter-rater agreement values (n = 47 children).

	Kappa values (k)	95% CI	*p*-value	Classification of k agreement
Intra-rater agreement between Dx1 and Dx2				
ENT				
Still images	0.552	0.383–0.722	<0.001	Moderate
Recordings	0.445	0.266–0.625	<0.001	Moderate
Audiologist				
Still images	0.928	0.832–1.000	<0.001	Almost perfect
Recordings	0.928	0.833–1.000	<0.001	Almost perfect
Intra-rater agreement between still images and video recordings				
Dx1				
ENT surgeon	0.624	0.491–0.757	<0.001	Substantial
Audiologist	0.978	0.935–1.000	<0.001	Almost perfect
Dx2				
ENT surgeon	0.416	0.269–0.653	<0.001	Moderate
Audiologist	0.854	0.723–0.986	<0.001	Almost perfect
Inter-rater agreement between ENT surgeon and audiologist				
Dx1				
Still images	0.672	0.545–0.798	<0.001	Substantial
Recordings	0.593	0.476–0.710	<0.001	Moderate
Dx2				
Still images	0.477	0.321–0.634	<0.001	Moderate
Recording	0.488	0.315–0.662	<0.001	Moderate

Inter-rater diagnostic agreement between Audiologist and ENT surgeon

In Dx1, the inter-rater agreement between the ENT surgeon and audiologist was substantial (k=0.672) and moderate (k=0.593) using still images and recordings, respectively (Table 3). In Dx2, the agreement was found to be moderate using both still images and recordings (k=0.477-0.488).

Discussion

This study set out to determine the reliability of making a diagnosis from video otoscopy still images or recordings, by comparing diagnosis made in two rounds, and by comparing the diagnosis made by an ENT surgeon to those made by an audiologist. Ensuring the availability and use of an objective measure of middle-ear function (e.g. tympanometry) with video otoscopy will help to identify middle-ear disease more confidently and reliably. Previously, we have found that in 57.3% and 46.7% of the cases, an ENT surgeon was unable to make a diagnosis when only using video otoscopy still images and recordings, respectively (Alenezi, Jajko et al., 2021). In the present study however, the same ENT surgeon, when the case history information and tympanometry results were also made available, was unable to make a diagnosis in less than 3% for both still and video recordings. Eikelboom, Mbao et al. (2005) have highlighted the importance of incorporating a comprehensive case history and other audiometric results with good-quality video otoscopy images to make a confident asynchronous diagnosis and management plan of middle-ear disease in children. Others have also reported the value of using both TM images and tympanograms in the diagnosis of middle-ear disease (Aronzon, Ross et al., 2004; Sebothoma & Khoza-Shangase, 2018).

The diagnostic agreement for video otoscopy still images and recordings between two different rounds of diagnosis (Dx1 and Dx2) was consistent for each clinician. The diagnostic agreement between the two procedures ranged from moderate to almost perfect in each round. These findings mean that there were no test-retest differences for either video otoscopic procedure and therefore both, with the addition of supporting information from tympanometry and case history, could be reliably used for making a diagnosis of middle-ear disease in children asynchronously.

Each video otoscopic procedure has its own limitations. For instance, recordings can have large digital size, leading to issues in storing and forwarding data, as this requires sufficient internet bandwidth, which is not available in some locations. Still images generally have a smaller digital size compared to recordings, which could be more practical and feasible alternative for forwarding results for an asynchronous assessment (Kokesh, Ferguson et al., 2008). In our study we have found that still images digital size ranged from 18 to 229 kilobytes (KB) while recordings digital size ranged from 713 to 4527 KB. However, there are also limitations that have been previously identified with using still images that could possibly affect the reliability of the diagnosis. These disadvantages included reduced depth perceptions (Patricoski, Kokesh et al., 2003; Kokesh, Ferguson et al., 2008) and difficulties in correctly identifying TM retractions (Patricoski, Kokesh et al., 2003; Binol, Niazi et al., 2020b). On the other hand, recordings have been found to be superior in terms of depth perceptions (Kokesh, Ferguson et al., 2008; Biagio, Swanepoel et al., 2013) and also in identifying TM retractions as well as perforations (Jones, 2006).

The moderate and substantial diagnostic agreement between the ENT surgeon and the audiologist found in the present study showed that audiologists may have a role in the process of triaging children with significant middle-ear disease to ENT services. A substantial agreement between the asynchronous diagnosis of otitis media using video otoscopy still images, pneumatic videos and tympanograms by otolaryngologists and the onsite diagnosis by audiologists in a group of Aboriginal children was also found by Gunasekera, Miller et al. (2018). They found that the audiologists had not missed any TM perforations but they had higher false positives in the diagnosis of TM perforations compared to the asynchronous diagnosis of ENT specialists as a reference standard of the study. Pokorny et al. (2019) also found that an audiologist with advanced training in otitis media diagnosis and management is capable of triaging children with middle-ear disease and reduce waiting times, especially with semi-urgent referrals. This increased the ability to see more children at the ENT clinic and improved its capacity by 77%. Waiting times for ventilation tubes insertion as a surgical treatment for otitis media was significantly reduced through this independent advanced audiology service (Pokorny et al., 2021). In addition to being effective, the service was found to be safe in discharging children not requiring treatment, referring those who need surgical intervention to ENT specialists, and reviewing children post-ventilation tubes insertion (Pokorny et al., 2020).

The percentage of children reported to have normal middle-ear function in the two different diagnostic rounds, was either the same between the clinicians or slightly less for the audiologist. However, we found some discrepancies between the audiologist and the ENT surgeon related to the clinical significance of the abnormal findings. As per the audiologist’s notes, those discrepancies were mainly caused by the laterality of the disease as the audiologist classified unilateral abnormalities as being clinically insignificant. Such discrepancies, and potential risks of not referring some children for treatment, might have been avoided by predetermined diagnostic criteria. According to Metcalfe, Muzaffar et al. (2021), however, the clinical value of identifying children with normal ears may be higher than identifying the particular abnormalities, as this would help in triaging children with abnormal finding to ENT clinics only. Due to the lack of a gold standard in our study (i.e. confirmation with otomicroscopy), we are unable to verify the sensitivity or specificity of the diagnosis made by the clinicians using the two video otoscopic procedures.

There is an apparent difference in the intra-rater agreement, with the audiologist having a greater level of agreement. After examining the audiologist’s notes, it appeared that the audiologist was putting more emphasis on tympanometry results than on the images and recordings compared to the ENT surgeon who appeared to have made a diagnosis based mostly on the appearance of the TM. This may explain the higher consistency and agreement found for the audiologist’s diagnosis compared to the ENT surgeon as relying on findings from a closed set (i.e. Jerger classifications for tympanometry (Jerger, 1970)) may be less prone to variations. It is possible that the ENT surgeon devoted less time to thoroughly review the findings, which may reflect real-life clinical practice where ENT specialists often have less availability. However, our findings extended the previously reported findings on the audiologist ability to prioritise children who need to be seen and assessed, thereby reducing waiting times and the subsequent issues that may arise from prolonged middle-ear disease episodes (Gunasekera, Miller et al., 2018; Pokorny, Wilson et al., 2019; Payten et al., 2020; Pokorny, Wilson et al., 2020; Pokorny, Thorne et al., 2021) to telehealth services.

Limitations

The generalisability of the findings in the present study is subject to some limitations. As this study was carried out at public community events, and also due to our exclusion criteria, the sample of children participating in this study might not be representative of other children with recent ear surgery, or those at risk of middle-ear disease that are more clinically significant (e.g. discharging ears) such as Aboriginal children, or those attending ENT clinics or emergency departments, who are unlikely to attend such events. Our sample may, however, be representative of children attending a community hearing screening with their families. A public community event can also be a challenging environment to examine children, which may have been a reason for the inability to obtain images and/or recordings from some children, who were consequently excluded from the analysis (n=7).

Our findings are limited by the equipment used for conducting video otoscopy and for reviewing the results, as they may not apply to other devices with different screen resolutions. A further equipment-related limitation was that the two clinicians have used two different devices, with different screen resolutions, to review the same images and recordings. Although the agreement between the two clinicians was at least moderate, this difference in the devices used, might have negatively affected the degree of the inter-rater agreement between the clinicians.

In the absence of a gold standard (i.e. confirmation with otomicroscopy), it was not possible to assess and compare the diagnostic accuracy of the two video otoscopic procedures, which is a potential area for future studies. Lack of extra training on triaging children with middle-ear disease asynchronously, and a predetermined criteria for diagnosis and referral might have contributed to some discrepancies between the audiologist and the ENT surgeon, particularly those related to the clinical significance of the disease. Finally, we were also unable to examine and compare the inter-rater asynchronous diagnostic agreement of video otoscopy still images against that of the recordings within the same clinical group, as we only had a single ENT and a single audiologist reviewing the findings.

Conclusion

To our best knowledge, this is the first study that makes a comparison between video otoscopy still images and recordings, and between an ENT surgeon and audiologist, in terms of the asynchronous diagnostic reliability. The agreement between the two different rounds of diagnosis using each video otoscopic procedure did not vary with either clinician. These findings indicate that both video otoscopic procedures, in addition to case history and tympanometry, can be reliably used to asynchronously diagnose middle-ear disease in a paediatric population. The agreement between the two clinicians also highlights the role of audiologists in triaging children with middle-ear disease, which can potentially help in improving access to ENT services.

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References

Alenezi E.M., Jajko K., Reid A., Locatelli-Smith A., McMahen C.S., et al. 2021. Clinician-rated quality of video otoscopy recordings and still images for the asynchronous assessment of middle-ear disease. *J Telemed Telecare*.

Aronzon A., Ross A.T., Kazahaya K. & Ishii M. 2004. Diagnosis of middle ear disease using tympanograms and digital imaging. *Otolaryngol Head Neck Surg*, 131, 917-920.

Biagio L., Swanepoel D.W., Adeyemo A., Hall J.W., 3rd & Vinck B. 2013. Asynchronous video-otoscopy with a telehealth facilitator. *Telemed J E Health*, 19, 252-258.

Biagio L., Swanepoel D.W., Laurent C. & Lundberg T. 2014. Video-otoscopy recordings for diagnosis of childhood ear disease using telehealth at primary health care level. *J Telemed Telecare*, 20, 300-306.

Binol H., Moberly A.C., Niazi M.K.K., Essig G., Shah J., et al. 2020a. SelectStitch: Automated Frame Segmentation and Stitching to Create Composite Images from Otoscope Video Clips. *Applied Sciences*, 10, 5894.

Binol H., Niazi M.K.K., Essig G., Shah J., Mattingly J.K., et al. 2020b. Digital Otoscopy Videos Versus Composite Images: A Reader Study to Compare the Accuracy of ENT Physicians. *The Laryngoscope*.

Brennan-Jones C.G., Whitehouse A.J.O., Calder S.D., Costa C.D., Eikelboom R.H., et al. 2020. Does Otitis Media Affect Later Language Ability? A Prospective Birth Cohort Study. *Journal of Speech, Language, and Hearing research*, 63, 2441-2452.

Da Costa C., Eikelboom R.H., Jacques A., Swanepoel D.W., Whitehouse A.J.O., et al. 2018. Does otitis media in early childhood affect later behavioural development? Results from the Western Australian Pregnancy Cohort (Raine) Study. *Clin Otolaryngol*.

Eikelboom R.H., Mbao M.N., Coates H.L., Atlas M.D. & Gallop M.A. 2005. Validation of tele-otology to diagnose ear disease in children. *Int J Pediatr Otorhinolaryngol*, 69, 739-744.

Gunasekera H., Miller H.M., Burgess L., Chando S., Sheriff S.L., et al. 2018. Agreement between diagnoses of otitis media by audiologists and otolaryngologists in Aboriginal Australian children. *Med J Aust*, 209, 29-35.

Hancock K.J., Brennan-Jones C.G., Vithiatharan R., Payne D., Runions K., et al. 2017. Mental health problems among 4-17-year-olds with hearing problems: results from a nationally representative study. *Hearing, Balance and Communication*, 15, 145-155.

Jerger J.F. 1970. Clinical expeience with impedence audiometry. *Arch Otolaryng.*, 92, 311-324.

Jervis-Bardy J., Sanchez L. & Carney A.S. 2014. Otitis media in Indigenous Australian children: review of epidemiology and risk factors. *The Journal of Laryngology & Otology*, 128, S16-S27.

Jones W.S. 2006. Video otoscopy: bringing otoscopy out of the "black box". *Int J Pediatr Otorhinolaryngol*, 70, 1875-1883.
Kokesh J., Ferguson A.S., Patricoski C., Koller K., Zwack G., et al. 2008. Digital images for postsurgical follow-up of tympanostomy tubes in remote Alaska. *Otolaryngol Head Neck Surg*, 139, 87-93.
Kong K. & Coates H.L.C. 2009. Natural history, definitions, risk factors and burden of otitis media. *Medical Journal of Australia*, 191, S39-S43.
Landis J.R. & Koch G.G. 1977. The Measurement of Observer Agreement for Categorical Data. *Biometrics*, 33, 159-174.
Lundberg T., Biagio d.J.L., Swanepoel W. & Laurent C. 2017. Diagnostic accuracy of a general practitioner with video-otoscopy collected by a health care facilitator compared to traditional otoscopy. *Int J Pediatr Otorhinolaryngol*, 99, 49-53.
Lundberg T., Biagio L., Laurent C., Sandstrom H. & Swanepoel d.W. 2014. Remote evaluation of video-otoscopy recordings in an unselected pediatric population with an otitis media scale. *Int J Pediatr Otorhinolaryngol*, 78, 1489-1495.
Lundberg T., Westman G., Hellstrom S. & Sandstrom H. 2008. Digital imaging and telemedicine as a tool for studying inflammatory conditions in the middle ear--evaluation of image quality and agreement between examiners. *Int J Pediatr Otorhinolaryngol*, 72, 73-79.
Mandavia R., Lapa T., Smith M. & Bhutta M.F. 2018. A cross-sectional evaluation of the validity of a smartphone otoscopy device in screening for ear disease in Nepal. *Clinical Otolaryngology*, 43, 31-38.
Metcalfe C., Muzaffar J., Orr L. & Coulson C. 2021. A systematic review of remote otological assessment using video-otoscopy over the past 10 years: reliability and applications. *Eur Arch Otorhinolaryngol.*, 1–9.
O'Connor T.E., Perry C.F. & Lannigan F.J. 2009. Complications of otitis media in Indigenous and non-Indigenous children. *The Medical Journal of Australia*, 191, S60-S64.
Patricoski C., Kokesh J., Ferguson A.S., Koller K., Zwack G., et al. 2003. A Comparison of In-person Examination and Video Otoscope Imaging for Tympanostomy Tube Follow-Up. *Telemedicine Journal and e-health : the official journal of the American Telemedicine Association*, 9.
Payten C.L., Eakin J., Smith T., Stewart V., Madill C.J., et al. 2020. Outcomes of a multidisciplinary Ear, Nose and Throat Allied Health Primary Contact outpatient assessment service. *Clinical otolaryngology*, 45, 904-913.
Peer S., Vial I., Numanoglu A. & Fagan J.J. 2018. What is the availability of services for paediatric ENT surgery and paediatric surgery in Africa? *European annals of otorhinolaryngology, head and neck diseases*, 135, S79-S83.
Pokorny M.A., Thorne P.R., Whitfield B.C.S., Lee A.C. & Wilson W.J. 2021. Can an advanced audiology-led service reduce waiting times for paediatric ear nose and throat outpatient services? *Journal of paediatrics and child health*, 57, 268-272.
Pokorny M.A., Wilson W.J., Thorne P.R. & Whitfield B.C.S. 2019. Is an advanced audiology-led service the solution to the paediatric ENT outpatient waiting list problem? *Speech, Language and Hearing*, 22, 137-141.
Pokorny M.A., Wilson W.J., Whitfield B.C.S. & Thorne P.R. 2020. Effectiveness and Safety of Advanced Audiology-Led Triage in Pediatric Otolaryngology Services. *Ear and hearing*, 41, 1103-1110.
Richards J.R.M.D. 2015. Comparison of traditional otoscope to iPhone otoscope in the pediatric ED. *American Journal of Emergency Medicine*, 33, 1089-1092.
Rimon O., Avraham Y., Sharabi-Nov A., Luder A., Krupik D., et al. 2015. Video-otoscopy in children and patient-centered care: A randomized, controlled study. *Int J Pediatr Otorhinolaryngol*, 79, 2286-2289.

Sebothoma B. & Khoza-Shangase K. 2018. A comparison between video otoscopy and standard tympanometry findings in adults living with human immunodeficiency virus (HIV) in South Africa. *S Afr J Commun Disord*, 65, e1-e7.

Smith A.C., Armfield N.R., Wu W.I., Brown C.A. & Perry C. 2012. A mobile telemedicine-enabled ear screening service for Indigenous children in Queensland: activity and outcomes in the first three years. *J Telemed Telecare*, 18, 485-489.

Smith A.C., Perry C., Agnew J. & Wootton R. 2006. Accuracy of pre-recorded video images for the assessment of rural indigenous children with ear, nose and throat conditions. *Journal of Telemedicine and Telecare*, 12, 76-80.

Swanepoel D.W., Clark J.L., Koekemoer D., Hall J.W., Krumm M., et al. 2010. Telehealth in audiology: The need and potential to reach underserved communities. *International Journal of Audiology*, 49, 195-202.

Swanepoel D.W. & Hall J.W. 2010. A Systematic Review of Telehealth Applications in Audiology. *Telemedicine Journal and e-health*, 16, 181-200.