AMPLITUDE OF ACCOMMODATION IN 9 TO 13 YEAR OLD SCHOOL CHILDREN OF MANKWENG CIRCUIT, LIMPOPO PROVINCE

Full Dissertation submitted in fulfilment of the requirements in respect of the Master's degree of Optometry (M.Optom)

in the
School for Allied Health Professions,
Faculty of Health Sciences at the University of the Free State

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September 2020

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DECLARATION

I hereby declare that the work submitted here is the result of my own independent investigation. Where help was sought, it is acknowledged. I further declare that this work is submitted for the first time at the University of the Free State / Faculty of Health Sciences towards a Magister degree in Optometry and that it has never been submitted to any other University / Faculty for the purpose of obtaining a degree.

Mrs M.E. Mafeo 18 September 2020
Date

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DEDICATION

This study is dedicated to my sons, Nyakallo and Therisano, their sister, Lehakwe and my beloved husband, Tieho Paulus Mafeo. Their love, encouragement, support and faith in me has made my dream come true.

ACKNOWLEDGEMENTS

I would like to extend my sincere gratefulness towards the following:

- The assistance and guidance from my supervisor, Dr M. Oberholzer (Department of Optometry, Faculty of Health Sciences in University of the Free State) is appreciated.
- The biostatistician, Ms R. Nel, for assisting with statistical analysis of data.
- University of the Free State for financial support in paying tuition fees.
- Department of Health, as an employee, for granting study leave to complete the study.
- Department of Education for granting permission to conduct the study at the chosen sites. The support from teachers and parents of learners is appreciated. Most appreciation to the learners who participated in the study. This study wouldn't be possible without you.
- The optometrist, Mr L.M.J. Makgoba, and Ms M.J. Ntahane for their assistance during data collection. I really thank you for your time and support.
- Ms I. Mathabathe and Ms M.D. Mashuba, for assisting with translation of Appendices from English into Sepedi language. I wouldn't make it without you colleagues.
- My mother, siblings and my family in law whom provided support and encouragement throughout my studies.
- Our family friends, Mr T.E. Mosikidi and Mrs L.A. Mosikidi, for always providing warm welcome and hospitality in their home, when I come to the university for consultation sessions.
- My loving husband for his unconditional love, support, encouragement and patience. Thank you for believing in me, you are a star. I am blessed to have you in my life.
- The Lord Almighty for HIS abundant mercy, grace and the provision of good life.

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ABSTRACT

Background

Amplitude of accommodation (AA) is the function of accommodation referred to as the dioptric difference between the far point (the eye is at rest) and near point (when the eye is fully accommodated) and is known to reduce with increase in age. To determine if an individual has low, normal or high amplitude of accommodation (AA) for his / her age, norms calculated from Hofstetter's formulae are still used as reference all over the world. However, these norms were found to be irrelevant to Ghanaian and Swedish children. Out of the few accommodation studies conducted in South Africa, none of the studies documented the AA of learners from the Mankweng circuit, Limpopo province in South Africa.

Aim of the study

The aim of this study was to investigate the AA in 9 to 13 year old school children of Mankweng circuit, Limpopo province.

Method

A cross - sectional, analytical, descriptive study was conducted on 291 learners aged 9 to 13 years of age (median age = 11.3 years). Learners were conveniently selected but schools were randomised. Learners who passed visual screening tests consisting of habitual visual acuity at 6 m and 40 cm right eye and left eye (RE and LE), +2.50 D lens test at 6 m (RE and LE), prism cover test at 40 cm and direct ophthalmoscopy (RE and LE), were included in this study. One hundred and eighty - five (185) learners met the inclusion criteria and proceeded to the measurements of AA which were determined subjectively using the push - up (PU) to - blur (first data set) and pull - away (PA) to - clear (second data set) techniques, and objectively using the dynamic retinoscopy (DR) (fourth data set). The PU and the PA results were thereafter used to determine the average AA for each participant, which were regarded as the third AA measurement data set for the current participants.

Results

The subjective and objective techniques of measuring AA yielded different results among the same participants aged 9 to 13 years. Dynamic retinoscopy (DR) technique measured the highest AA (median = 19.7 D), with PU (median = 14.3 D), PA (median = 13.4 D) and the average results of PU / PA techniques (median = 13.8 D) measuring lower. The median AA were reducing from 21.2 D to 18.3 D as age increased in 9 to 13 year old participants when measured with DR; from 15.5 D to 12.9 D with PU; from 14.4 D to 12.2 D with PA and from 15.0 D to 12.5 D when using the average results of PU / PA measurements. The rate at which AA changed between different age groups was found to be inconsistent. Furthermore, a significant difference existed between the AA of groups of 2 years or more apart. There was no statistical significant difference between the AA in female and male participants. The results further showed that the type of technique used to collect AA measurements, may have influenced the prevalence rate of a **LOW** AA. The results showed a high prevalence of **LOW** AA with PA technique 18.4% (CI of [13.5% to 24.6%]), followed by the average results of PU / PA techniques 12.4% (CI of [8.4% to 18.0%]) and lastly PU technique 7.6% (CI of [4.6% to 12.3%]). For the same participants, the DR technique did not measure **LOW** AA amongst any of the age groups. In each technique, there were outliers reported, with the majority in the 9 - year - old age group.

Conclusion

The measured AA decreased with increasing age with all the techniques used, although the rate of reduction was not constant between the age groups. Furthermore, the AA between the age groups 12 and 13 years was statistically significantly different and also between the age groups of two or more years apart (e.g. 9 and 11 years). The AA in female and male participants showed no statistical significant difference. The prevalence of **LOW** AA determined, was higher with the PA technique as compared to the PU technique. The objective measurements were statistically significantly higher to the subjective measurements.

Keywords: Push - up technique, Pull - away technique, Dynamic retinoscopy technique, PU / PA techniques, subjective technique, objective technique, Hofstetter's formulae, prevalence, low AA.

CHAPTER 1: INTRODUCTION

1.1 **Background**

Accommodation was defined by Rabbetts and Mallen (2007) as the ability of an eye to increase its refractive power by altering the shape of the crystalline lens. The maximum ability of the crystalline lens to accommodate in response to a near stimulus is called the amplitude of accommodation (AA). This AA is known to reduce with an increase in age (Ovenseri - Ogbomo *et al*., 2012), which is due to the anatomical changes occurring in the crystalline lens with age (Rabbetts and Mallen, 2007). It forms one aspect of three, necessary to assess accommodation. The other two aspects include accommodative facility and accommodative response (Scheiman and Wick, 2008). The measurements of accommodative amplitude are clinically valuable for the diagnosis of accommodation dysfunction such as accommodative insufficiency (AI), and also for the determination of a reading add.

There are various techniques to determine the AA of a patient. The most commonly used subjective method is the push - up (PU) technique. This method has, however, been found to overestimate the true measurements of the AA (Anderson and Stuebing, 2014; Momeni - Moghaddam *et al*., 2014), as compared to Dynamic retinoscopy (an objective technique) which was found to be more reliable and consistent (León *et al*., 2012). The AA norms computed from Hofstetter's formulae are still used today as reference when assessing the AA of a subject of a particular age. Hofstetter (1950) derived three formulae based on data from Donders (1864) and Duane (1912), to determine minimum, maximum and average AA for a subject of a certain age. According to Hofstetter's formulae, an individual is considered to have **NORMAL** AA if the measured AA is within the reference values of his / her calculated minimum and maximum AA (Hofstetter, 1950).

When the measured AA is below the minimum age expected norm, a participant is said to have **LOW** AA, which according to Scheiman and Wick (1994), is an indication of accommodative insufficiency in a pre - presbyope. In this case, other related tests requiring the stimulation of accommodation are necessary to confirm the diagnosis. Patients with **LOW** AA may experience blurry vision and headaches when performing close work. Sterner *et al*. (2006) has reported impaired AA on learners with subjective symptoms when performing near work. Furthermore, the results of the study of Oberholzer *et al*. (2014) has showed that amongst three parameters namely: visual acuity (VA), AA and near point of convergence (NPC) and their relation to academic performance investigated, insufficient AA was a major parameter associated with academic achievement in school children. According to the American Optometric Association (Cooper *et al*., 2011), AI can be treated with vision therapy and / or plus lenses and the prognosis was reported to be excellent if the patient is compliant with the prescribed treatment schedule (Cooper *et al*., 2011).

Most research studies that have focused on AA have been conducted elsewhere with only one study in Limpopo province, South Africa, on university students (Mathebula *et al*., 2018). According to my knowledge, this is the first study documenting the AA measurements of learners aged 9 to 13 years of Mankweng circuit (Limpopo province, South Africa).

1.2 **Research problem statement**

Vision is regarded as the primary sensory input during the process of learning thus, a well - functioning accommodative system must be ensured (Sucher and Stewart, 1993). Insufficient AA was found to be associated with subjective symptoms such as headaches, eyestrain, floating text and the inability to change focus from distance to near with ease (facility problems) among school children doing school work (Sterner *et al*., 2006). These subjective symptoms were reported to be more prevalent in children older than 8 years compared to that found in younger children (Sterner *et al*., 2006). A possible reason could be that the engagement of activities requir0ing near vision increases as a child grows older and progresses into higher grades of their school career. Accommodative insufficiency (AI), a condition in which AA is less than the minimum expected age amplitude as calculated by Hofstetter’s formulae, has received minor attention in South Africa, despite it being common among school aged children in other parts of the world (Borsting *et al.*, 2003).

The AA has been investigated in depth globally and continentally. Sterner *et al*. (2004) investigated the AA in Swedish school children aged 6 to 10 years old with the aim to compare the measured results with the age expected norm values. In addition, Castagno *et al*. (2017) evaluated the association between AA and age, gender, economic status, time of day, in addition to prevalence of AI among the Brazilian school children aged 6 to 16 years. The study of Ovenseri - Ogbomo *et al*. (2012) compared the measured AA of the Ghananian school children aged 8 to 14 years with the calculated age expected norms predicted by Hofstetter’s formulae.

In South Africa, three studies on AA have been conducted among school children and one on university students. Moodley (2008) investigated the prevalence of low amplitude of accommodation among primary school children (6 - 13 years) screened in Durban. Metsing and Ferreira (2012) investigated the prevalence of low amplitude of accommodation among grade 3 and 4 school children in Johannesburg. Oberholzer *et al.* (2014) investigated the association between amplitude of accommodation and academic achievement among grade 4 and 5 school children in Bloemfontein. Mathebula *et al*. (2018) compared the AA determined subjectively and objectively on South African university students. To my knowledge, there is no published data available on how AA is distributed by age and gender among South African Limpopo province school children. A search of the relevant literature has shown that, currently there are no norms for South African children, and clinicians still rely on the available norms set by Hofstetter. It is crucial to establish regional norms as Ovenseri - Ogbomo *et al*. (2012) has found that regional norms differ from the norms calculated using Hofstetter's formulae and also found males to have a higher AA compared to females. Establishing norms for South African children will assist optometrists when diagnosing and managing school children presenting with AA related problems. Furthermore, this will be the first study conducted to determine the AA among school children in the Limpopo province, Mankweng circuit.

1.3 **Aim of study**

The aim of this study is to investigate the AA in 9 to 13 year old school children of Mankweng circuit, Limpopo province. This age range was selected because children of this age understand instructions and give better responses as compared to lower ages. Children in this age range are usually in grades 3 to 8 where they use reading as a learning tool and do intensive near work. Thus, children at this age range read for longer periods on smaller font types and thus accommodation plays a critical role in enabling them to read with ease (Scheiman and Rouse, 2006).

The results of this study may contribute to improving the current assessment practice of accommodative function in school children of the Mankweng circuit. The results are expected to provide information that may assist in understanding the function of the accommodative system in relation to AA better. This study will further aid in understanding the pattern in which accommodation changes with regard to the AA found in school children of different ages or give a clear trend of AA within this age range. This information will in addition assist in planning ideal management strategies for these school children.

1.4 **Research objectives**

1.4.1 To compare the AA results for 9 to 13 year old participants.

1.4.2 To compare the AA measurements in gender of 9 to 13 year old participants.

1.4.3 To determine the prevalence of low AA at different age intervals in 9 to 13 year old participants.

1.4.4 To compare the objective and subjective AA results of 9 to 13 year old participants.

1.5 **Outline of the dissertation**

This dissertation is organised into six chapters and the details of each chapter are presented below:

- Chapter 1 comprises of an introduction, research problem statement, aim of the study, objectives of the study and the format of dissertation.

- Chapter 2 consists of the literature review done on the topic and is sub - divided into the following sections namely:
    - Factors affecting measurements of AA
    - AA and gender
    - Comparison of the techniques for measuring AA
    - The prevalence and impact of Low AA

- Chapter 3 presents the methodology and data analyses of the study.

- Chapter 4 presents the findings of the study according to the objectives investigated in the study and the techniques used for data collection:
    I. Comparisons of the AA results for 9 to 13 year old participants.
        - The AA results as measured with the push - up (PU) technique.
        - The AA results as measured with the pull - away (PA) technique.
        - The AA results as determined with the calculated average of the PU / PA techniques.
        - The AA results as measured with the Dynamic retinoscopy (DR) technique.

    II. Comparisons of the AA measurements in gender of 9 to 13 year old participants
        - The AA results according to gender, for each technique used.
        - Comparisons of the median AA in females and males for subjective and objective technique.
        - Comparisons of gender using categorical classification for each technique used.

    III. To determine the prevalence of **LOW** AA at different age intervals in 9 to 13 year old participants.

    IV. To compare the subjective and objective AA results of 9 to 13 year old participants.

  - Comparison of the subjective and objective AA results among 185 participants using numerical data.
  - Comparison of the subjective and objective AA results among 185 participants using categorical classification.

- Chapter 5 presents a general discussion on the findings of the study.

- Chapter 6 presents the conclusion chapter, where the main findings are summarised, and the suggestions for future study and limitations of the study are listed.

CHAPTER 2: LITERATURE REVIEW

2.1 **Introduction**

Good vision is important for a child to be able to perform well. According to James *et al*. (2014), eyes become fully developed by age 6 years and by 7 years, visual skills such as visual acuity, ocular muscle control, peripheral vision and color discrimination are fully developed. The brain uses visual processing skills to interpret things we perceive from our surroundings. Well - developed visual skills are essential for this process to occur smoothly and accurately, such that even learners benefit during their daily class activities. The most important visual problems affecting school - aged children are caused by impairments in visual information input, pattern processing or output for action. According to Eide and Eide (2006), visual information input problems include visual acuity problems, eye movement control problems and visual field deficits. Problems with pattern processing include trouble recognizing visual objects, face blindness and impaired visual attention. In addition, Christenson and Borsting (2012) suggest that visual efficiency skills such as eye alignment (binocularity), eye movement and accommodation may cause trouble in reading to learn, which according to Flax (1970), starts from grade 4 upwards. The proper functionality of the following visual skills is important for learning at school which may improve their academic performance.

2.1.1 **Visual acuity (VA)**

Visual acuity is a measure of the clarity of the central vision or how well a person sees (Boyer and Tabandeh, 2012). It is a visual skill that evaluates the capability of the eye in focusing light on the retina at the back of the eye. The problems of reduced visual acuity such as “difficulty to see on the chalkboard or objects that are far” are common. Impaired acuity may result from light images that are not focused on the retina which may be caused by the crystalline lens or irregularities in the ocular surface. The visual acuity may differ between the eyes, however; if the difference is extreme, the brain may start to ignore the weak eye as the image is blurrier. Twenty - twenty (20/20) vision is regarded as good vision and a normal VA, however; it is not sufficient for a child to perform efficiently in class. It only permits a child to see small print on the chalkboard, but does not evaluate the near vision which a child requires for efficient reading and writing. Other visual skills such as eye movement, binocularity and focusing are often omitted during vision screenings and are essential for providing efficient and comfortable near vision (Metsing and Ferreira, 2012).

2.1.2 **Eye movement**

Learners are expected to look steadily at the chalkboard (fixation) and move their eyes from one object to another (tracking) e.g. one word to another. During reading, learners' eyes are expected to follow a line from word to word, keeping track on the same line of print and shifting focus to the next line or word accurately. Each eye has six extra ocular muscles which assist in looking in any direction, fixating in one place, following a moving object and changing focus from a close object to a distant object (Eide and Eide, 2006). According to Patestas and Gartner (2016), extraocular muscles that control eye movements are innervated by three cranial nerves namely, cranial nerve 3 (Oculomotor), cranial nerve 4 (Trochlear) and cranial nerve 6 (Abducens). During the involvement of head movement, the vestibulo - ocular reflex mechanism (mediated by the connection of the vestibular system with the cranial nerves innervating the responsible extraocular muscles), is activated to compensate for the shifting of head position and maintaining visual fixation on an object (Patestas and Gartner, 2016). The visual processing and fusion may be attained easily when both eyes are aligned and working together as a team. According to Brodal (2004), all natural ocular movements are coupled or conjugated. Two eyes move together to make sure that the image falls on matching points of the retinas. For example; the lateral and medial rectus muscles produce horizontal movement, whereas the superior and inferior rectus muscles produce vertical movements (Brodal, 2004). Furthermore, during bilateral adduction or convergence when focusing on near objects, the action depends primarily on the medial rectus muscles receiving assistance from superior and inferior recti muscles. This requires an extra effort for a child whose eyes have a tendency to turn outwards (exophoria), in order to keep the eyes fixated at near (± 40 cm).

The ocular movements that do not occur in conjugation result in double vision, which is a common symptom of the partial paralysis of extraocular muscles (Brodal, 2004). One eye may turn either in or out, constantly or intermittently. The images from the misdirected or turned eye may end up being suppressed and eventually, the eye will become amblyopic. Amblyopia may affect the child's ability to judge distances and / or depth when in class. A child with poor eye movements or binocularity may experience loss of place when reading, moving prints or jumping of letters or words, headache or eyestrain, problems with eye - hand activities or closing of one eye in order to maintain single vision.

2.1.3 **Eye focusing / Accommodation**

As children are changing focus from one object to another, ideally it is expected to immediately see the object of interest clearly, even when changing focus from the chalkboard to a book at near (40 cm). Vision is expected to adjust quickly and clearly with minimal effort to continue smoothly with school work. The ability of an eye to change focus from distance to near and still maintain clear vision is called accommodation. It is through this mechanism that we are able to see clearly at various distances closer than 6 m. This function is achieved as a result of the ability of the ciliary muscles, together with the lens zonules to adjust the refractive power of the lens (Bye *et al*., 2013). During the mechanism of accommodation, ciliary muscles contract, the ciliary body moves anteriorly and inward releasing the tension on the zonules. This will lead to an increase in both anterior and posterior lens curvatures, increasing the refractive power of the lens (Bye *et al*., 2013) to enable focusing at a close distance for tasks such as reading. According to Nilsson *et al*. (2011) the lens surface curvatures increases greatly anteriorly and to a lesser extend posteriorly.

The act of accommodation causes three physiological reactions which are known to form the accommodative triad or near reflex. Eyes converge, pupils constrict through the contraction of the iris sphincter muscles and the refractive power of the lens increases (accommodation) by increasing the curvatures of the lens. The intraocular muscles such as ciliary muscles and sphincter muscles are innervated by postganglionic innervation (Bye *et al*., 2013). The innervation of the ciliary body and the iris sphincter muscle arises from the Edinger - Westphal nucleus, which contains preganglionic parasympathetic neurons, whose axons travel through the oculomotor nerve (cranial nerve 3) to the ciliary ganglion where it synapses with postganglionic fibres (Frazier and Jaanus, 2007). From the ciliary ganglion, the nerve runs via the short ciliary nerves and signals are sent to the ciliary muscle, medial rectus muscle and the sphincter muscle causing them to contract.

Accommodation relaxes when an emmetropic eye is focused on a distant object (Nilsson *et al*., 2011) and stimulated by objects closer than 6 m or the use of minus lenses (Grosvenor, 2007), and these are referred to as stimulus to accommodation. The light rays coming from these stimuli diverge and if accommodation does not take place, rays would focus at an imaginary point behind the eye (Grosvenor, 2007) and, as a result the object will appear blurred. The response of accommodation is primarily stimulated by a blurred retinal image. According to Nilsson *et al*. (2011), the response produced by the accommodative system is usually less than the magnitude of the stimulus provided, and the difference is called lag of accommodation. If stimulus amplitude is increased further, lag of accommodation will increase as the accommodative response is reaching its maximum amplitude (Nilsson *et al*., 2011). The lag of accommodation depends on the depth of focus or depth of field, which differs according to the size of the pupil and the size of the object of regard (Grosvenor, 2007). In study by Bernal - Molina *et al*. (2014), the visual system showed that the amount of lag increased with accommodative demand when measuring the accommodative response for all stimuli provided at eight different accommodative demands (from -1 to 6 D in steps of 1 D), using an optical visual simulator. Furthermore, DOFi showed to increase with a decrease in pupil diameter. The effect of this factor may be lessened by containing the level of illumination so as to avoid the excessive constriction of the pupil or by use of letters that are consistent with patient's visual acuity. In addition, pupil constriction contributes to the accommodative effort (e.g. reading) by decreasing the size of blur, or the diffusion circle on the retina and thereby, extending the depth of field (Millodot, 1982[a]). Therefore, it is clear that as lag of accommodation increases with increasing stimulus, pupils constrict and depth of focus increases as well. The important alteration of an increase in the lens curvatures increases the refractive power of the lens and clears up focused images.

Poor accommodation may lead to blurred vision, visual fatigue, headaches when reading, and subsequently difficulty copying from the chalkboard or viewing a distant object, or blurry distance vision after reading. When the eyes' accommodative system does not function properly, this is termed accommodative dysfunction. There are various classifications of accommodative dysfunction, which include: accommodative insufficiency (AI), ill - sustained accommodation, paralysis of accommodation, unequal accommodation, accommodative excess or accommodative infacility (Scheiman and Wick, 2008). Some authors have found AI to be more prevalent when compared to other accommodative and / or vergence dysfunction (Abdul - Kabir *et al*., 2014; Davis *et al*., 2016). Accommodative insufficiency may be caused by medical conditions such as whooping cough, mumps, anaemia, measles, tonsillitis, scarlet fever; use of certain drugs such as alcohol, antihistamine, cycloplegic; or neuro - ophthalmic disorders such as lesions in Edinger - Westphal syndrome, Horner's syndrome or Herpes zoster (Scheiman and Wick, 1994). It is interesting to note that Abdul - Kabir *et al*. (2014) and Davis *et al*. (2016), in their studies, were diagnosing AI based on the measurements of amplitude of accommodation (AA) only, which was not the intention of the current study.

i. ***Amplitude of accommodation***

Barrett and Elliot (2007) define amplitude of accommodation (AA) as the maximum ability of the crystalline lens to accommodate in response to a near stimulus or target. It is referred to as the distance, in diopters, between a point conjugate with the retina when accommodation is fully relaxed (far point) and a point conjugate with the retina when accommodation is fully exerted (near point) (Rosenfield, 2009). The far point of the eye is defined as the furthest point at which the human eye can see an object clearly when accommodation is at rest. In turn, the near point of an eye refers to the closest point at which an object can be seen clearly with accommodation at its best or maximum. The measurements of AA require distance correction prior to the assessment. In addition, the measurements of this parameter should not be confused with accommodative response, as it is only concerned with the maximum potential accommodative response, rather than the actual response to stimulus.

Clear, single and comfortable vision is essential for school children since most of the learning that takes place, is through the sense of vision and visual problems may lead to children disliking school work. Several studies have been conducted all over the world to document the prevalence of visual skill deficiencies in children. Vision screenings that include the assessment of visual acuity only, have been shown to omit many visual problems in school children (Metsing and Ferreira, 2012). A study by Davis *et al*. (2016) documented the rate of accommodation and vergence anomalies among American learners who were in grades 3 to 8 during the time of the study and these could have been missed if the focus was on visual acuity screening only. The study was aimed at determining the prevalence of convergence insufficiency (CI) and accommodative insufficiency (AI), and in turn, assess the correlation between the CI, AI, visual symptoms and astigmatism. The results of their study showed that, in 484 students; the prevalence of students with symptomatic CI was 6.2% and of symptomatic AI, was 18.2%. These authors defined symptomatic CI as participants who met the set clinical criteria of three clinical signs which included: exodeviation of at least 4 prism diopter greater at near (40 cm) than at distance (6 m), near point of convergence (NPC) break point of 6 cm or greater - (receded NPC) and insufficient positive fusional vergence (PFV) at near (40 cm) and in addition to a score of greater than or equal to 16 with the convergence insufficiency symptom survey (CISS) (Davis *et al*., 2016).

In the same study of Davis *et al*. (2016), participants were classified as symptomatic AI if they had a minimum measured AA of 2 D below the minimum age - based norms described by Hofstetter and CISS score of ≥ 16. It is interesting to note a greater prevalence of AI in the students with CI (55.6%) when compared to those without CI (29.5%). In the same way, 56.7% of participants classified with symptomatic AI were also classified with symptomatic CI. These results further indicated that, participants classified as clinical AI only (meaning they had a minimum measured AA of 2 D below the minimum age - based norms and did not meet CI criteria) and those classified as both clinical CI (meaning they met the set three clinical criteria) and AI, showed a significant higher average CISS score compared to participants with neither CI nor AI clinical signs. This was different with participants classified as CI only, as they observed no significant high average CISS score.

Abdul - Kabir *et al*. (2014) conducted a study on 204 Ghanaian learners aged 13 to 17 years (who were in grades 7 to 9). According to the results of their study, 65 learners were found to have AI and 54 had accommodative infacility. Out of 80 learners who had at least one of the named dysfunctions, 26 learners had AI only, 15 had accommodative infacility while 39 had both AI and accommodative infacility. Important notes from these studies (Davis *et al*., 2016; Abdul - Kabir *et al*., 2014) include that: a higher prevalence of AI was noted amongst the students with CI and elevated symptoms on participants with AI only, compared to participants with or without CI. Furthermore, the results raises awareness of the need to assess AI among the learners of various ages in different locations e.g. Polokwane, Johannesburg, Bloemfontein, etc.

Metsing and Ferreira (2012) assessed the following visual skills: visual acuity, refractive error, accommodation, vergence and ocular motilities on 112 learners from mainstream and learning disabled schools in Johannesburg. Only the results of 73 learners aged 8 to 13 years from a mainstream school were reported on. According to the results of the study, the prevalence of the following visual deficiencies was reported on: poor accommodation facility (12.3%), poor accommodation amplitude (10%), poor convergence amplitude (17%) and poor vergence facility (21.9%). There was no co - existence of the accommodative and vergence dysfunctions in any of the participants investigated. The lack of standardised criteria to diagnose AI is still a challenge. However, according to Scheiman and Wick (2008), amongst the components that are essential for diagnosing AI, reduced AA was regarded as the primary indication for AI. Since the main aim of the current study was to investigate the AA of 9 - 13 year old learners, more attention was given to this visual skill.

2.2 **Factors affecting the measurements of AA**

The magnitude of the AA is affected by underlying refractive error, age, monocular / binocular testing (evaluation), gaze angle, target size (Rosenfield, 2009), illumination and depth of focus (Burns *et al*., 2014). These factors are discussed in the following sections.

2.2.1 **Uncorrected refractive error**

In an emmetropic eye, the parallel rays of light coming from a distant object are focused on the retina of an unaccommodated eye to create a clear image that is transmitted to the brain for interpretation via the optic nerve (afferent pathway). This process represents a normal refraction of light and it is aided by the cornea and lens (Dhaliwal, 2018). The far point in the case of an emmetropic eye, is at infinity (Wilkinson, 2006), while the near point varies with age, being shorter at childhood e.g. 7 cm at 10 years and greater in adulthood, e.g. 33 cm at 45 years (Khurana, 2008). According to Wilkinson (2006), the near point of an eye is found when uncorrected refractive power of the eye is added to the accommodative ability of the eye. An emmetropic state is necessary, but not sufficient for clear vision (Millodot, 1982[a]). Due to various factors such as the length of the eye (longer or shorter axial length), shape of the cornea or stiffness of the lens, the eye may fail to focus the image of a distant object on the retina, resulting in a blurred image which is referred to as the refractive error. A state where refractive error is present in a resting eye is called ametropia (Grosvenor, 2007). The far point of an ametropic eye does not lie at infinity and may occur in one of three forms, namely: myopia, hyperopia and / or astigmatism.

2.2.1.1 ***Myopia***

Myopia is a refractive state in which the parallel rays of a distant object focuses in front of the retina of a resting eye. The refractive state of myopia may occur as a result of steeper corneal curvature or higher lenticular powers (called refractive myopia) or may occur due to a longer axial length of the eye (axial myopia) (Wilkinson, 2006). The infinity or far point of a relaxed myopic eye is imaged in front of the retina. The stimulus found on the retina of a myopic eye is thus a blur circle and not a clearly focused image point (Wilkinson, 2006). According to Grosvenor (2007), the far point and near point of accommodation for a myopic eye are always located in front of the eye. By moving the object of interest closer to the myopic eye, helps the image point to focus on the retina, establishing a focal point of the eye (Wilkinson, 2006). Thus, during accommodation, the near point of the uncorrected myope becomes closer to the retina increasing the ability to see at near.

2.2.1.2 ***Hyperopia***

In a hyperopic eye, the parallel rays of light from a distant object are focused behind the retina of a resting eye. Thus, a far point is formed behind the retina. The state of hyperopia may occur due to a flatter corneal curvature, or when the power of the eye at the corneal surface is less than +60.0 D (called refractive hyperopia), or as a result of a shorter axial length of the eye (Wilkinson, 2006). During accommodation, the focus point of a distant object on an uncorrected hyperopic eye shifts onto the retina allowing clear vision of distance objects (Goldstein, 2009). More efforts of accommodation or constant accommodation is expected in order to see clearly at distance and near, although higher accommodative demands are necessary for near tasks. This constant accommodation may result in fatigue when reading or performing near work (Goldstein, 2009).

2.2.1.3 ***Astigmatism***

Astigmatism occurs when the cornea has an asymmetric curvature (corneal astigmatism). In this case, the front surface of the cornea is more curved in one meridian than in another and results in distorted vision for both distance and near objects. Astigmatism may also occur as a result of the crystalline lens surface being toroidal or distorted in shape (lenticular astigmatism) or as a combination of the corneal and lenticular astigmatism (Keirl and Christie, 2007). Uncorrected astigmatism may cause eyestrain and headaches, especially after reading. According to Scheiman and Wick (1994), low degrees of astigmatism may cause accommodative fatigue if the level of accommodation swings back and forth as the patient is trying to obtain clarity. Furthermore, eyestrain symptoms caused by these small astigmatic errors, were reported to be severe amongst hyperopes with astigmatism (Khurana, 2008). Davis *et al.* (2016) suggest that management of refractive error and an adaptation period of spectacle wear may yield the accurate assessment of vergence disorders. In addition, authors in this study were convinced that, irrespective of high prevalence of astigmatism within the participants, the results of high prevalence of CI and AI were not related to the prevalence of astigmatism, since the participants were wearing spectacle correction to correct astigmatism.

The correction of significant refractive errors such as hyperopia ≥ +1.50 D, myopia ≥ -1.00 D and astigmatism ≥ -1.00 D (Scheiman and Wick, 1994) was regarded as the first consideration to management of accommodative and binocular disorders, as this may alleviate secondary accommodative and vergence anomalies (Scheiman and Wick, 1994). According to Scheiman and Wick (1994), the presence of uncorrected refractive errors during the assessment of accommodative, ocular motor and non - strabismic binocular anomalies, may:

1) result in either under or over accommodation and in turn, secondary accommodative dysfunction,

2) result in high phoria,

3) cause an imbalance between the two eyes leading to sensory fusion disturbances, and

4) may create reduced fusional ability due to blurred retinal images.

Therefore, the optical correction of the ametropic conditions, minimizes the underlying causative factors of accommodative and vergence anomalies. Davis *et al*. (2016) followed the same approach in their study of 484 Grade 3 to 8 participants. Each participant had a cycloplegic examination. Refraction was conducted 30 minutes after instilling 3 drops of 0.5% proparacaine, 1% tropicamide and 1% cyclopentolate and participants with significant refractive errors were prescribed spectacles. Binocular vision assessments were conducted on the following day and those wearing spectacles were given an adaptation period of two weeks before the assessment of binocular vision was done wearing spectacles.

According to Scheiman and Wick (1994), little consensus has been reached on the management of low degrees of refractive error. The corrections of small refractive errors are considered significant if it gives a clear retinal image that improves fusion and aids in binocular vision management. Furthermore, accommodative, ocular - motor or binocular vision anomalies often occur in the presence of low refractive errors. However, there are special cases that need to be treated with caution, similar to low refractive errors that present with all accommodative and binocular testing within normal values. Thorough investigation has to be done to check if there is a relationship between the symptoms experienced and the eye use or activities engaged in, and whether a low prescription may be helpful.

When ametropia is fully corrected as in the case of an emmetropic eye, the patient will accommodate only at near and the AA will be expected to be similar for any myope or hyperope of any given age. The AA will be recorded as the reciprocal of the near point of accommodation. The natural dynamics of accommodation with its relation to refractive error has been evaluated. Abraham *et al*. (2005) evaluated the relationship between AA and refractive errors in 316 patients in the age group 35 - 50 years. In the results, the authors reported a statistical significant difference in AA between myopes and hyperopes and between myopes and emmetropes in the participants aged between 35 - 44 years. Similar findings were reported between emmetropes and hyperopes in the age group 40 - 44 years. Maheshwari *et al*. (2011) studied the relationship between accommodation and different refractive errors, amblyopia and biometric parameters such as the anterior chamber depth, axial length and lens thickness. The results of this study showed that the AA was significantly higher in the corrected myopes (12.30 ± 2.01), followed by emmetropes (10.11 ± 1.66) and then corrected hyperopes (8.21 ± 2.61). Furthermore, when AA was compared between different categories of myopia; corrected low myopes of < 2 D, corrected myopes of between 2 - 4 D and corrected myopes of above 4 D; AA was found to be significantly higher in the corrected low myopes (< 2 D). There was no significant difference found between myopes of 2 - 4 D and myopes of > 4 D, although myopes of > 4 D showed a tendency of a lower AA compared to the myopic group of between 2 - 4 D. In addition, McBrien and Millodot (1986) conducted a study on university students aged 18 - 22 years and the AA was found to be high in the following sequence: highest AA in the latest onset of myopia (students who have recent myopia), followed by early onset of myopia (students who have long - term myopia), then emmetropes and lastly hyperopes. Hashemi *et al*. (2018) found somewhat similar results to Maheshwari *et al*. (2011) and McBrien and Millodot (1986) when considering the myopic group, as they all found high AA in this group. Furthermore, contrasting results were seen when considering hyperopic and emmetropic groups as Hashemi *et al*. (2018) found the higher mean AA in the hyperopes (mean AA= 14.87 D) and then emmetropes (mean AA= 14.31 D). Nonetheless, the parameter of AA has also been reported to change according to age.

2.2.2 **Age: The change of AA with age**

A decrease in AA occurs throughout life, measuring 13 - 14 D at the age of 10 years to approximately 6 D at 40 years (Dai and Boulton, 2009). Furthermore, by the age of 60 years, the AA is almost 0 D. Patients who have sufficient accommodation and the ability to focus on close objects to their satisfaction, are classified as pre - presbyopes. Such patients do not require near correction to see adequately at near. Presbyopia causes a reduced AA in older patients and that causes the AA to be too low to allow clear or comfortable vision at near. This is believed to be attributed to the anatomical changes occurring as a result of the aging crystalline lens (Rabbetts and Mallen, 2007). It commonly starts between ages 40 and 45 years. In such cases, only additional plus lenses can correct symptoms resulting from the eyes' inability to accommodate sufficiently. This is different from AI in that, in AI, the reduced AA is not normal relative to the patient's age and affects pre - presbyopes.

It is well known that the crystalline lens grows throughout life and changes continuously with age, which may in turn have a great impact in its functionality. The refractive index of the crystalline lens is important for accommodation and presbyopia (Uhlhorn *et al*., 2008). This refractive index of the lens is distributed non - uniformly, increasing from the periphery to the central region of the lens (Uhlhorn *et al*., 2008; Augusteyn *et al*., 2008). The gradient refractive index contributes to the total optical lens power (Uhlhorn *et al*., 2008) and aids in reducing spherical aberration (Augusteyn *et al*., 2008). As new layers of protein cells are continuing to form in the peripheral (cortex) region of the lens, old cells become compacted and concentrated in the central region causing the refractive index to increase in this region (Augusteyn *et al*., 2008). The changes of the refractive index in the central region are very slow and the gradient gradually decreases with increasing age as the central plateau of the refractive index is formed (Augusteyn *et al*., 2008). In addition, the plateau develops from early ages and increases with age. According to Borja *et al*. (2008), the decrease in the contribution of the gradient refractive index distribution leads mainly to the decrease in the lens optical power with age. Glasser and Campbell (1998) concluded that the age changes that affect the human lens does not only cause presbyopia but may also lead to the substantial changes of the lens optical and physical properties. The study of Uhlhorn *et al*. (2008) indicated that the gradient refractive index may contribute to the amplitude of accommodation although its relation with age is still not understood.

The relationship between AA and age was first determined by Donders (1864) and thereafter by Duane (1912), as they both strived to elicit a trend of change in AA with a change in age. Numerous studies (Castagno *et al*., 2017; León *et al*., 2016; Ovenseri - Ogbomo *et al.*, 2012; Heron and Schor, 1995), despite the different techniques used for data collection, are in agreement that AA reduces with an increase in age. The trend and rate at which this AA changes with age, especially on children of less than 10 years of age, is still unclear and contrasting results have been found in different studies. This may be due to the impression created by Donders (1864) and Duane's (1912) data on their classic studies; although Duane (1908) in the end justified that the rate of reduction is not constant and does not occur each year.

In 1944, Hofstetter studied the data of Donders (1864) and Duane (1912) and concluded that the relationship between AA and age was misrepresented. During the analysis, Hofstetter suggested that there is a linear relation between AA and age. He then concluded that AA reduces at a rate of 0.3 D each year until it reaches 0.5 D magnitude at the age of 60 years. Amplitude of accommodation is rarely measured on participants' older than 55 years. At this age of 55 years, AA has reduced greatly and what is remaining, is depth of focus and not accommodation (Keirl and Christie, 2007). This factor has a tendency to increase as a result of the increasing pupillary constriction associated with ageing (senile miosis). In 1950, Hofstetter derived three formulae to determine the minimum, maximum and average AA for a subject of a certain age. For instance, to determine the minimum AA, in diopters, of a subject of a given age, Hofstetter suggested the formula: [15 - (0.25 x subject's age in years)]. Furthermore, Hofstetter in his longitudinal study has found the rate of reduction to be slightly more than 0.4 D per year (Hofstetter, 1965). The three formulae resulting from Hofstetter's research are as follows:

- Minimum AA = [15 - (0.25 x subject's age in years)] (1)
- Average AA = [18.5 - (0.30 x subject's age in years)] (2)
- Maximum AA = [25 - (0.40 x subject's age in years)] (3)

León *et al*. (2016) observed a significant negative correlation between age and the AA when measured objectively using the dynamic retinoscopy. The trend of AA change between the age groups 5 and 19 years as well as 45 and 60 years, was stable with no significant change even though there was a minimal increase in AA between ages 5 and 10 years. Amplitude of accommodation appeared to reduce yearly by 0.25 D from age 20 to 44 years. Sterner *et al*. (2004) studied AA as a function of age on Swedish children aged 6 to 10 years and did not find any significant relationship between age and the observed AA. The pattern between age and the AA for this age range, 6 to 10 years, seemed stable and unchanged. The results of the study by Benzoni and Rosenfield (2012), showed a two - phase change in AA while using subjective the push - up (PU) and pull - away (PA) techniques. The results suggest a significant decrease in AA between age groups 5 and 7 years with a slight increase in AA between the age groups 8 and 10 years. The objective AA results of Anderson and Stuebing

(2014) showed an increase in AA between ages 3 to 5 years and 6 to 10 years. Thereafter, a sudden drop in AA was noted in the age group 11 to 64 years. Numerous authors (León *et al*., 2016; Benzoni and Rosenfield, 2012; Duane, 1908) have tried to show that even though AA reduces with an increase in age, the rate of change is not constant throughout life as described earlier on by Hofstetter. Furthermore, monocular AA was found to be different to binocular AA as explained in the next section.

2.2.3 **Monocular / binocular evaluation**

Amplitude of accommodation (AA) can be measured monocularly and binocularly. Monocular measurement of AA represents the maximal dioptric power produced by the accommodative system, whereas the binocular measurement represents the maximal dioptric power produced in the presence of convergence (Duckman, 2006). Monocular values are taken first and should be approximately the same for both eyes respectively (Keirl and Christie, 2007). Ovenseri - Ogbomo *et al*. (2012) have found a positive correlation between the findings of right and left eyes of the same individuals. These monocular measurements are essential for screening the defects associated with the oculomotor nerve.

The study of Bharadwaj *et al*. (2011) found that the mean change in pupillary diameter, change in accommodation and change in vergence with viewing distances (80 and 33 cm), were significantly smaller with monocular than binocular viewing conditions. Monocular findings were always found lower compared to binocular findings. According to the study of Duane (1922), binocular measurements of AA exceed monocular AA with 0.2 D to 0.6 D for all age groups. For the ages 10 to 17 years specifically, related to the age groups in this study, monocular AA should be increased by 0.6 D to get binocular measurements. This difference may be attributed to the additional accommodation induced during convergence. Sterner *et al.* (2004) have found the median monocular AA to be 12.00 D for the right eye, 12.70 D for the left eye and the binocular measurement, 15.00 D which is higher than both the monocular measurements, respectively. This is possibly a result of binocular summation.

2.2.4 **Gaze angle**

The manner in which a target is held when performing the AA procedure, differs according to the type of technique used. During the push - up (PU) procedure for measuring AA, the royal air force (RAF) ruler is placed in a slightly depressed position (Esmail and Arblaster, 2016). The eye level of the participant in this case will be slightly below primary gaze, unlike when performing dynamic retinoscopy (DR), where the eye level is at primary gaze. The position of the RAF ruler during a procedure may have an effect on the measurements of AA. The tilted or depressed position may exaggerate the true AA (Burns *et al*., 2014). The classroom set -

up also requires learners to read and write with a steeply downward gaze. Several studies have been conducted to assess the effects of visual gaze on AA. Majumder (2015) compared AA in four different vertical viewing angles on 31 Malaysian subjects aged 18 - 26 years. The results of this study showed AA to increase with a declining vertical gaze. At 20˚ upward gaze, AA was 9.37 D, primary gaze showed an AA of 9.72 D, 20˚ downward gaze resulted in 11.26 D and 40˚ downward, 11.89 D.

Amplitude of accommodation was further compared between the different reading postures (Chiranjib *et al*., 2018). The results of this study showed that the change in reading posture increases AA significantly when changing position from sitting to standing. The mean difference found was 1.29 D more when standing.

2.2.5 **Target size**

The use of large targets or optotype when measuring AA may cause a delay in the patient to recognize the presence of blur and may result in overestimation of AA (Rosenfield, 2009). A 6/6 line on a near chart will not subtend the same angle when viewed at 40 cm or 10 cm during the PU technique. Furthermore, the study of Chen and O'Leary (1998) has found that the difference between the AA measured using modified PU technique and the conventional PU technique, may be as a result of the choice of target and criterion used. LEA symbol targets were found to measure higher AA values as compared to letter targets. However, no statistical significant difference was found on the AA measured using the LEA symbol target sizes of N5 and N8 (Chen and O'Leary, 1998).

2.2.6 **Illumination**

The quality of illumination used when measuring AA may affect the AA measurements. Lara *et al.* (2014) studied the effect of pupil diameter on objective amplitude of accommodation and found that AA depends on the pupil size. The authors (Lara *et al*., 2014) took measurements under different room lighting conditions (low and high) with a fixed luminance on the fixation target. The results of their study (mean monocular pupil size value at low room light: 6.26 mm (relaxed) and 4.15 mm (maximum accommodation), and at high room light: 4.74 and 3.04 mm) found a greater change in pupil size (monocular) under low ambient room lighting conditions with the smallest pupil size measured under high room light level. However, the effects of both light levels (low and high) on accommodation were reported to be statistically significant. Furthermore, a higher AA was most of the time found in bright lighting as compared to low lighting, in which there was a smaller pupil size found due to pupil constriction. On the other hand, insufficient illumination may lead to an increase in pupil size and thus, less accommodation. The reduced accommodation would result in a poorer quality of the retinal image.

2.2.7 **Depth of focus**

Depth of focus (DOF) is a variant of the placement of the image in front or behind the retinal shell which retains a clear image. According to Yi *et al*. (2011), the human eye will continue to perceive the image as being clear as long as the target image remains within the DOF of the image space. Depth of focus may arise as a result of the limitations to the recognition of blur, which depends on acuity and awareness of blur (Burns *et al*., 2014). The DOF of the human eye is dependent on the pupil diameter (which depends on the illumination), for instance; the smaller the pupil size, the greater the DOF. It helps bring the near objects of interest into better focus. Depth of focus negatively affects all the measuring techniques of AA that require detection of blur, for example the push - up technique (Burns *et al*., 2014). Furthermore, the magnitude of error varies according to the measuring techniques. When an object is accurately focused monocularly, the eye often allows objects slightly closer and slightly further to be seen clearly without a change in accommodation. A similar concept known as depth of field (DOFi), is defined as the distance range in which the objects are seen clearly without a change in accommodation (Khurana, 2008). According to Bernal - Molina *et al*. (2014), DOFi can be used interchangeably with DOF. DOFi is inversely proportional to pupil size and the size of the blur circle on the retina is directly proportional to pupil diameter. The latter refers that, the smaller the pupil size, the smaller the blur circle (Millodot, 1982[b]). The size of the pupil during constriction with the near response test (accommodation) should be similar to that measured with the light response (Bergenske, 2012). The excessive illumination may lead to a greater pupil constriction which results in better DOF and consequently higher AA measurements.

2.3 **Amplitude of accommodation and gender**

The effects of gender on AA were investigated as one of the objectives in the study of Majumder (2015). The results showed no statistical significant difference of AA in males and females investigated in four different vertical gaze directions tested. In addition, Wold (1967) has found no difference between AA in males and females by accepting the null hypothesis at p - value of 0.01 (1% level of significance). However, Ovenseri - Ogbomo *et al*. (2012) have found a statistical significant gender difference in their study. Male participants were found to have higher AA (17.49 D) as compared to female participants (16.44 D).

2.4 **Comparison of the techniques for measuring AA**

Measurements of AA are components of a routine clinical eye examination. The subjective measurements of AA can be taken using push - up (PU), pull - away (PA) or push - down, or minus lens - to - blur techniques. Objectively, AA can be measured using dynamic retinoscopy (DR) or an auto - refractor. Optometry has long used psychophysical testing to evaluate the ability of a participant to detect and identify a stimulus, differentiate between it and another stimulus, and further describe the magnitude or nature of this difference. With the PU procedure, the near reading chart is moved towards the participant until first sustained blur is detected and the reciprocal of the measured distance from the eye to the near reading chart is suggested to represent the AA. At this point, the test object is said to be at the eye's near point. The PA or push - down procedure involves placing a target closer to the participant and slowly pulling it away until the target can be identified. This procedure was reported to be more accurate when compared to the PU procedure (Rosenfield, 2009).

A study by Koslowe *et al*. (2010) compared the measurement of AA using the PU and PA techniques on 79 participants aged 7 to 35 years. Their results showed a statistical significant difference between the two techniques, with the PA consistently giving lower AA measurements as compared to the PU technique. Amongst other factors that might have contributed towards the significant difference found between the two techniques, authors believed that the difference may be due to psychophysical error of perseveration or error of habituation that exist in opposite directions for the two testing procedures (PU and PA). All the subjective procedures involving the movement of a target are influenced by the error of reaction time occurring between the participant and a clinician (Burns *et al*., 2014). These errors occur during the time that the participant has to register the precise end point (blur), vocalise it and the time the clinician takes to register the participant's message and respond to this message (Burns *et al*., 2014).

To minimize the effects of such errors, the PU and PA techniques may be combined. The target is first pushed up until first sustained blur. Then, a clinician moves the target to the spectacle plane and pulls it away until the participant reports when it first becomes clear, then note the average measurement of the two techniques. Another subjective technique is the minus lens - to - blur technique. In this procedure, the target or Snellen chart is kept at a fixed position of 40 cm and the participant is asked to fixate on the 20/20 row of letters on the chart, while minus lens powers are added in 0.25 D steps. The minus lenses are added to the distance refractive correction until letters become and remain blurred. The AA is taken as 2.50 D plus the amount of minus lens power added. This technique is performed only monocularly because it results in an excess accommodative convergence, and binocularly will be assessing positive relative accommodation. Both the PU and minus lens - to - blur techniques rely on the patients' correct identification of the blur point (a point at which the target reaches sustained blur and not total blur - out of the target). This end - point of first sustained blur can be difficult for some patients to recognise. The DR technique determines the end - point by observing the retinoscopic reflex.

Different authors have used various end - points during the DR procedure of measuring AA. In the study of Rutstein *et al*. (1993), the examiner observed the vertical streak showing with motion. After that, the examiner moved the retinoscope inward, until the retinoscope reflex became narrowed, dimmer and slower in speed. Rutstein *et al*. (1993) used a similar procedure described by Eskridge (1989), although authors performed the technique monocularly while the eye not used, was occluded. Eskridge (1989) performed the technique with both eyes open. León *et al*. (2016) and León *et al*. (2012) used the Pascal heterodynamic retinoscope technique. In this procedure, the fixation target is initially placed close to the trial frame (participant's face) and the participant will push the target away until letters become clear. With the target kept at this position of clarity, the examiner will position the retinoscope at a distance twice the distance between the target and participant. The examiner will observe the retinoscope reflex and its movement. If the movement of the reflex is 'against' (meaning that the vertical streak of the retinoscope is moving in the opposite direction with the movement of the retinoscope), the examiner will move towards the participant until a neutral reflex is observed. Once the neutral reflex is observed, the distance between the spectacle plane and retinoscope will be measured with a meter rule. The objective AA will be taken as the reciprocal of the distance in meters. This procedure of DR was reported to give lower findings of AA compared to the procedure used by Rutstein *et al*. (1993).

Ideally, both the subjective and objective techniques of measuring AA are supposed to give similar results for AA on the same individual. However, several studies have shown that different results on the same person are found using different measuring techniques (León *et al*., 2016; León *et al*., 2012; Rutstein *et al*., 1993). Some literature (León *et al*., 2016; León *et al*., 2012) suggests that subjective techniques are not measuring the actual increase in refractive power of the eye, similar to objective techniques. Instead, subjective techniques quantify the closest point at which the participant can see clearly (León *et al*., 2012). The difference between the subjective (modified push - down and minus lens) and objective techniques could be explained better by accommodative lag (León *et al*., 2012). The study of Hokoda and Ciuffreda (1982) has found the difference between the AA measured with the PU and DR procedures to be 1.5 D higher for PU in the control participants and 2.4 D in amblyopes. Amongst the subjective techniques for measuring AA, PU is a common, easy and fast procedure used clinically in optometry practices and the research field. However, several studies have confirmed that the PU technique is often not as reliable, as it depends on the participant's response and was proven to be affected by the depth of focus or field resulting from pupillary constriction (Wold, 1967).

Furthermore, Anderson and Stuebing (2014) believe that the AA measurements taken using the PU technique do not reflect true measurements of accommodative response. However, according to Atchison *et al*. (1994), the PU technique provides realistic measurements as it involves the normal direct stimulus of accommodation compared to other techniques such as the Badal optometer assisted PU technique, or the concave lens (minus lens - to - blur) technique. The PU procedure was used by Donders and Duane to collect data which is still in use as reference for normal values of AA for a certain age. As indicated earlier on, Donders and Duane's data were further used to derive three formulae which are also still used to calculate AA for an individual of a certain age. Several studies have proven that it may be inappropriate to use the standardized norms on different ethnic groups of the same age. This was agreed by, amongst other studies, in the results of Ovenseri - Ogbomo *et al*. (2012) and Sterner *et al*. (2004) who measured the AA on Ghananian and Swedish school children, respectively. The Ghananian study results showed to be higher compared to the calculated results, whereas the Swedish study results were lower than the calculated results, using Hofstetter's formulae. According to Scheiman and Wick (1994), the PU technique results in an overestimation of AA because of the relative distance magnification. As the target is moved towards the eye, the proximal stimulation to accommodation increases, the retinal image subtends a larger angle which may delay the participant's ability to detect the end - point (blur). This delay to detect blur will obviously exceed the near point of accommodation resulting in an overestimation of AA. Other than depth of field, there are other factors contributing towards the delay of the detection of blur during the PU technique. For instance, target size, pupil size, illumination and end - point criteria.

Ovenseri - Ogbomo *et al*. (2012) measured the AA in 435 junior secondary school children aged 8 to 14 years with the purpose of comparing results of the PU technique to that of the calculated age expected values as estimated by Hofstetter's formulae. The researchers, Ovenseri - Ogbomo *et al*. (2012), used Donders' PU technique with a fixed target of N5 print, which according to Atchison *et al*. (1994), was confirmed to give high AA. Furthermore, Ovenseri - Ogbomo *et al*. (2012), failed to exclude the effects of depth of focus in their study which were reported to inflate the subjective, PU AA measurements results by 1.75 D (Atchison *et al.*, 1994; Hamasaki *et al*., 1956). Several techniques such as the Badal optometer assisted PU technique or the concave lens (minus lens - to - blur) technique were suggested by Atchison *et al*. (1994) to overcome the effects of the angular size of the target. Atchison *et al*. (1994) found the suggested techniques to be practically unreasonable as they opposed the natural interaction of accommodation - convergence. In addition, a near vision chart with sentences reducing in size of letters was invented; wherein for every half diopter movement of the target towards the participant, the participant was instructed to focus on a line of smaller letters (Atchison *et al*., 1994).

Rosenfield (2009) also suggested the combination of the PU and push - down or PA techniques during the measurement of AA, thereby taking the averaged value of the PU and PA measurements. This combination was thought to offset the overestimation caused by the PU technique when detecting blur and the underestimation caused by the PA or push - down technique when detecting clarity. Benzoni and Rosenfield (2012) investigated AA in children aged between 5 and 10 years with the aim to compare their measured results with age - defined norms. In this study, the PU technique was found to measure higher AA as compared to the push - down technique. After researchers have observed the trend, the average results of the PU and push - down techniques was used for the analyses in response to set objectives.

Sterner *et al*. (2004) conducted a similar study to that of Ovenseri - Ogbomo *et al*. (2012). The study involved a non - cycloplegic static retinoscopic refraction, refined by a subjective refraction that was performed prior to the assessment of AA. The best distance correction was worn and a fixed target was used during the procedure of the AA measurement. The researchers introduced minus lenses (-3.00 D or -6.00 D) when the dioptric value of 20.00 D was shown on the RAF ruler. This was done to push the near point away from the participant's eye to avoid an increase in angular size. Despite correcting the flaws found in the Ovenseri - Ogbomo *et al*. (2012) study, their results were much lower than the calculated age expected values using Hofstetter's formulae (1950). The researchers believed that the lower values could possibly be due to accommodative lag. The necessity of the objective AA measurements was suggested to confirm the subjective AA measurements (Ovenseri - Ogbomo *et al.*, 2012), since they are less affected by the effects of DOF. Objective techniques have been reported to be reliable as they are not affected by the participants' subjective responses (Otake *et al*., 1993).

A study by Rutstein *et al*. (1993), compared the findings of the PU and DR techniques. The participants were clinical patients aged 6 to 39 years. The modified DR technique was performed on 57 patients and the PU technique was performed on 48 patients. The AA procedures were performed with refractive correction worn and were done by two examiners, each performing the same procedure until the study was complete. This was to ensure accuracy of the results. The results showed that the measurements of the modified DR technique were higher compared to that found with the PU technique. The average AA measurements when measured with the modified DR and the PU techniques, were 11.99 D and 9.32 D respectively for the right eyes and 12.79 D and 10.03 D respectively for the left eyes. The average difference in the AA measurements measured with modified DR and that measured with the PU technique for children 12 years or below, was found to be 1.73 D. The initial subjective PU letter target results of Wold (1967), were far higher than that for the DR technique results. Wold (1967) decided to consider the effects of DOF by re - assessing the subjective measurements on five participants. From these measurements taken, the DOF values were calculated and subtracted from the initial values. At the end, the DR results of three participants were higher compared to the subjective PU letter target results and for the other two participants, the subjective PU letter target results remained higher compared to the DR results.

León *et al*. (2012) found contradicting results compared to the study of Rutstein *et al*. (1993) and Wold (1967), which showed that the results of the objective DR technique are lower compared to the subjective results even though the modified push - down and minus lens techniques were used as subjective techniques. The end - point criterion appears to have an influence on the measurements when using the DR technique. In the study by Rutstein *et al*. (1993), researchers regarded the changes occurring in the retinoscopic reflex as the end - point. The examiner stopped the assessment when the retinoscopic reflex changed to a narrower, dimmer in colour reflex and when the speed became slower. León *et al*. (2012) used the Pascal DR procedure when comparing the reliability of the DR and subjective measurements of AA on 79 participants aged between 18 and 30 years. The criterion used during the DR procedure was a point of neutrality (neutral reflex). The end - point criteria used by León *et al*. (2012) gave lower readings of AA compared to that of Rutstein *et al*. (1993) and Wold (1967). Furthermore, DR also showed the best repeatability and reproducibility when compared to subjective techniques. The criterion used by Wold (1967) and Rutstein *et al*. (1993) showed a tendency of overestimating AA measurements.

2.5 **The Prevalence and Impact of Low Amplitude of accommodation**

The measurements of AA in children are very important for the diagnosis of accommodative dysfunction such as accommodative insufficiency. Accommodative Insufficiency (AI) is a condition in which patients' eyes are not able to focus clearly or sustain focus on near objects. It is a condition in which the accommodative system of the patient has difficulty stimulating accommodation (Scheiman and Wick, 1994). Accommodative insufficiency is characterised by the AA measuring below the lower limit of the patient's age expected value. According to Marran *et al*. (2006), AI is present when the minimum AA is 2 D below Hofstetter's age - related norms using Donders' PU technique. The study of Cacho *et al.* (2002) investigated the most sensitive test, in addition to AA, in order to classify AI. The study was conducted on the participants with or without reduced AA. The four techniques tested included the monocular estimated method (MEM) DR, monocular and binocular accommodative facility (MAF and BAF) and positive relative accommodation (PRA). The sensitivity results of their study suggested the failure of the ± 2 D MAF test to be a sign associated with AI. Beside the primary characteristic known as low AA, Scheiman and Wick (1994) recommended the use of these other characteristics when diagnosing AI: low positive relative accommodation (PRA), difficulty clearing minus lenses during the test of accommodative facility, high MEM retinoscopy results, and high fused crossed - cylinder findings.

As technological developments are continuing to unfold, this poses a great demand for prolonged near vision in all ages. On the other hand, school work demands a child to have the ability to comfortably read and write for a long period of time. Accommodative insufficiency was found to be common in school aged children and this was associated with increased subjective symptoms (Borsting *et al*., 2003). Consequently, the symptoms of AI are related to reading or near work. Common symptoms include blur, headaches, eyestrain, diplopia, reading problems, fatigue, difficulty changing focus from one distance to another (facility problem) and / or words moving on the page (floating text). Sterner *et al*. (2004) conducted a cohort study in which two evaluations were done 1.8 years apart on the same participants. The aim of the study was to assess the association between accommodation and the subjective symptoms experienced by young school children with close work. The symptoms investigated were headache, asthenopia, floating text and facility problems. Headache and asthenopia were the most common and both symptoms showed to occur with at least one or more other symptom. The symptoms were reported to be common among the participants aged 8 years and above.

The interesting finding of this study (Sterner *et al*., 2004) was that, children showed no symptoms during the first occasion of examination, however, symptoms were reported during the second examination. Furthermore, the AAs of those participants, when compared to the previous examination, were significantly reduced with 3.4 D and 3.3 D in the right eyes (REs) and left eyes (LEs), respectively (Sterner *et al*., 2004). Most children showed symptoms in the second examination and as indicated, this could be due to an increase in near work leading to near vision demands as children progress to higher grades. Another contributing factor could be that the participants' level of understanding had improved and they could understand instructions much better.

Any deficits of the accommodative function in school children may result in reading difficulties and may have effects on a child's learning or progress in school. Insufficient accommodation has also been shown to have an effect on a learner's academic performance. Oberholzer *et al*. (2014) investigated the following three parameters namely visual acuity (VA), AA and near point of convergence (NPC) and their relation to academic performance. The results of their study showed that an insufficient AA was a major parameter negatively associated with academic achievement in school children. The results of this study by Oberholzer *et al*. (2014) agree with the study of Moodley (2008) who has concluded that a comprehensive vision screening is vital during the early ages of schooling.

The clinical practice guidelines of the American Optometric Association (AOA) on accommodative and vergence dysfunction support the findings of these studies by Oberholzer *et al*. (2014) and Moodley (2008). The guidelines encourage early examination in children in order to detect and eliminate accommodative and vergence anomalies as they may have a negative effect on school performance as the near work demand increases. However, it is known that school screenings are difficult to implement, especially those that incorporate accommodation and vergence screening tests. Sterner *et al*. (2006) recommend that eye examinations be offered to learners experiencing near vision symptoms. The treatment of AI has shown to improve the AA and relief the subjective symptoms. Scheiman and Wick (1994) recommend the following sequential management as the treatment strategies for accommodative dysfunction: correction of refractive error (ametropia), near added plus lenses and optometric vision therapy.

Uncorrected ametropia such as hyperopia, astigmatism, anisometropia, may cause accommodative fatigue. The muscular fatigue resulting from the uncorrected hyperopia when accommodating, may cause subjective symptoms associated with accommodative disorders (Scheiman and Wick, 1994). According to Scheiman and Wick (1994), providing lenses for a small prescription of hyperopia, astigmatism and anisometropia (difference in refractive error between two eyes), may give immediate relief of subjective symptoms. When the refractive error is fully corrected, the clinician may proceed with the assessment of accommodative and binocular vision status.

The second step of the treatment plan for AI is the use of the near added plus lenses. The role of the near added lenses is to minimize blur such that the remaining blur is within a patient's accommodative capability (Wahlberg *et al*., 2010). These lenses assist the accommodative system to get a clear, focused retinal image. The added plus lenses benefit participants experiencing difficulty stimulating accommodation compared to participants with other accommodation disorders like accommodative excess or infacility. The appropriate lens needed to reduce blur is determined by analysing the findings of the participant. The added lenses may be prescribed for temporary or permanent use depending on the cause of

AI. Bartuccio *et al.* (2008) has found that added plus lenses are mostly used as treatment of AI over other lens options such as progressive addition lenses (PAL).

The final step of the treatment of AI, visual therapy, restores the normal function of the accommodative system. Scheiman and Wick (1994) recommend three phases of vision therapy, each with various objectives. The main objective of the first phase of the therapy is to improve the ability of the participant to stimulate accommodation and normalize the accommodative amplitude. The magnitude of the accommodative response is a major concern in this phase compared to the speed of the accommodative response. The objective of the second phase is to normalize the patient's ability to relax and stimulate accommodation as fast as possible. In the third phase, the accommodation and binocular therapy are integrated. The aim of this phase is for participants to develop the ability to change eye focus from convergence to divergence.

Wahlberg *et al*. (2010) used two forms of vision therapy namely plus lens reading addition (PLRA) and spherical flippers (orthoptic exercise). The main aim of their study was to evaluate the type of reading addition lens between +1.00 D and +2.00 D, which is more efficient in the treatment of AI. A group of 11 participants were given +1.00 D and another group was given +2.00 D lenses to use frequently when conducting all near vision work. After eight weeks of treatment, the binocular AA for the group using +1.00 D treatment lenses was found to have improved significantly with an increased average of 3.28 D in the AA. The improvement in the group treated with the +2.00 D lenses was 1.36 D, which was not significant. Although both treatment lenses showed a significant reduction in asthenopia symptoms, the greater reduction was found in the group using +2.00 D lenses. However, Wahlberg *et al*. (2010) concluded that the +1.00 D lens is more efficient in treating AI, based on the success rate of improving accommodative amplitude since with +2.00 D, there is no guarantee if symptoms will reappear once +2.00 D treatment is stopped.

2.6 **Gaps identified**

To my knowledge, the literature study done on this topic shows that much work on AA in school children has been done in other countries (Ovenseri - Ogbomo *et al*., 2012; Sterner *et al*., 2004; Rutstein *et al*., 1993). Furthermore, none of the available studies from South Africa were conducted in the Limpopo province, Mankweng circuit, for data collection (Oberholzer *et al*., 2014; Moodley, 2008). Of these few studies, none compared the objective and subjective results of AA in school children nor investigated the distribution of AA by gender in school children.

2.7 **Closing the identified gaps**

The researcher intends to investigate the AA in 9 to 13 year old school children of Mankweng circuit, Limpopo province. During the investigation, the results of AA between the different age groups included will be compared. A comparison of the subjective and objective results of AA will be done as well as determining the prevalence of **LOW** AA at each age group of the participants. Age expected norms calculated from Hofstetter's formulae will be used as reference for classifying the AA of the participants. The researcher will further investigate the relation between AA and the gender of the participants.

The subsequent section presents the methodology used in this study to achieve the set objectives.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 **Introduction**

This chapter details the methodology used to address the set objectives of the study. The descriptions of the study design, population, sampling and sample size are given. Inclusion and exclusion criteria are outlined. Measuring instruments are described and the reliability of the instruments and procedures used during data collection are discussed. The section entails the sequence followed during data collection and describes the personnel involved in the study. In conclusion, ethical considerations and data analysis are explained.

3.2 **Study design**

The study followed a quantitative, analytical, descriptive design that investigated the AA in 9 to 13 year old school children of Mankweng circuit, Limpopo province. The study further determined the prevalence of **LOW** Amplitude of Accommodation (AA) at different age intervals between 9 and 13 years of age and compared the AA measurements according to gender in 9 to 13 year old school going participants. No intervention (other than referrals) was implemented during the study and it is thus of an observational nature (Clark - Carter, 1997). A cross - sectional design was applied as collection of data was done by taking the required measurements at one occasion on a certain number (representative sample) of participants in the Mankweng circuit and thereafter generalising the results to the entire population of the sub - district, Mankweng circuit (Omair, 2015).

3.3 **Study population / Sampling / Sample size**

3.3.1 **Study population**

The population of the study included learners of Mankweng circuit, Limpopo province, aged 9 to 13 years. Limpopo is one of the nine provinces found in South Africa and has five districts that include Capricorn. Mankweng circuit is in the Capricorn district and is one of the 134 circuit offices of the Department of Education found in the Limpopo province. The Mankweng circuit includes 17 public primary schools with a total of 7 946 learners, aged 9 to 13 years during the time of the study. The total study population included 4 075 boys and 3 871 girls with the majority being Sepedi speaking learners. The target group was selected based on the report that the subjective symptoms such as headaches, eyestrain, floating text and the inability to change focus from distance to near with ease (facility problems), were more prevalent in children older than 8 years compared to younger children (Sterner *et al*., 2006).

3.3.2 **Sampling and sample size**

3.3.2.1 ***Schools***

The process of selecting participants for a sample that is representative of the target population for analysis, is called sampling (Trochim, 2006). For the purpose of this study, probability sampling was used. According to Gomm (2008), probability sampling, random with replacement, gives each individual from the study population an equal opportunity to be selected for the sample. This method guarantees a bias free sampling and was used to select the name of schools via a fishbowl technique (Brink *et al*., 2012). The school rolls of Mankweng circuit (consisting of 17 primary schools) were used as sampling frames (Gomm, 2008; Trochim, 2006) and were requested from the Limpopo Provincial Department of Education. The researcher wrote the name of each school appearing on the school rolls of Mankweng circuit, on a piece of paper. Thereafter, the pieces of paper were rolled up and shuffled in the bowl. The researcher removed one rolled paper from the bowl and noted the name of the school written on it. The piece of paper was then put back into the bowl and the bowl was again shuffled until another piece of paper was removed. In the cases where a school name was selected more than once, the name was only noted once. From this, four schools comprising of quintiles 2 (1 school) and 3 (3 schools) were selected to participate in the study.

3.3.2.2 ***Participants***

For every study to warrant statistical analysis, the sample must be representative of the total population. The calculated sample size of the study included a total number of 366 participants from a total population of 7 946 pupils in this sub - district / circuit, Mankweng. The sample size was calculated as follows (Krejcie and Morgan, 1970):

$S=X^2NP\ (1 - P) \div d^2\ (N - 1) + X^2P\ (1 - P)$

= [3.841 x 7 946 x 0.50 (1- 0.50)] ÷ [(0.05)2 (7946-1)] + 3.841 x 0.50 (1-0.50)

= 7 630.1465 ÷ 20.82275

= 366.43318………………………………………………………………………………….. (1)

Where S is the required sample size, N the given population size, P population proportion (assumed to be 0.50), d the degree of accuracy expressed as a proportion (0.05) and X^2 the table value (3.841) of chi - square for 1 degree of freedom at the desired (0.95) confidence level.

The sample was thereafter divided into five groups of 73 participants for the following age groups: 9 years to 9 years - 11 months; 10 years to 10 years - 11 months; 11 years to 11 years - 11 months; 12 years to 12 years - 11 months and 13 years to 13 years - 11 months. The learners aged 9 to 13 years from all selected schools were invited to participate in the study by receiving consent forms (Appendix A and B) and information sheets (Appendix C and D). All four schools that were approached to take part in the study, gave permission. Of the four schools, two hundred and fifty consent forms and information sheets (50 per age group) were given out to two schools (quintile 3) as these schools allowed sufficient time for the data collection to be done. One of the four schools (quintile 3) permitted only one day for screening and as a result, 40 consent forms and information sheets were given out at this school in all the age groups (8 per age group). The last of the four schools (a quintile 2 school), had space restriction according to that requested by the researcher, and only 150 forms were given out to learners within the included age groups.

The aim was to hold meetings with the parents or guardians of all four schools. Unfortunately, the meetings could only take place at one school during which the information regarding the study, as well as the explanation of consent and assent forms were discussed. Meetings at the other three schools could not take place, as the quarterly meetings with parents had already been held and the principals of these schools agreed to distribute the consent forms and information sheets to the parents via the class teachers.

The aim was to select participants via a random with replacement method using the fishbowl technique. As a result of poor returning of consent forms by the majority of learners, the screening for the sample was conducted on all those who had both the consent and assent forms signed. Therefore, a convenience non - probability sampling method was used. The screening of the learners for the required inclusion criteria was conducted by a team of two Optometrists including the researcher. The consent forms (Appendix A and B) had the following four questions that the parents / guardians had to complete:

- Is your child’s eyes crossed / squint?
- Does your child have a problem seeing on the chalkboard or reading a book?
- Is your child on any medication?
- When last did your child see an eye doctor?

The feedback or history given by the parents / guardians also assisted in screening the learners for the inclusion criteria. In the event that the parent / guardian did not answer the health questions as stated on the consent form, the learner was included in the study, unless any pathology or medical history could be picked up during case history, after which the learner was excluded if relevant.

3.3.3 **Inclusion criteria**

The following learners were included in the study:

- Age range: 9 - 13 years, 11 months of age.
- Learners with binocular functional vision.
- All genders.
- All races.
- Habitual (with / without spectacles or contact lenses) minimum distance VA of 6/6 in each eye at 3 m calibrated for 6 m testing distance and habitual near VA of 6/6 at 40 cm (Carlson, 2004). This is to ensure that learners with significant refractive errors were excluded.
- Passed the +2.50 D test, thus VA reduced to less than 6/9 through +2.50 D lenses monocularly to exclude latent hyperopia.
- Phoria at near as tested with a horizontal prism bar showed values within the norms as stated by Scheiman and Wick (2008) for the included age group, thus: 0 to 6 exophoria at 40 cm.
- Must have completed and passed all screening procedures.

3.3.4 **Exclusion criteria**

- The learner with apparent ocular abnormalities or pathology (such as severe vernal keratoconjunctivitis (VKC) with / without limbitis, corneal opacities, pupillary defects such as poor reaction, anisokoria or irregularity in shape and lens opacities) that could impact the measurements of AA.
- The learner with strabismus or amblyopia as screened for with the cover test and VA chart.
- The learner with medical conditions such as whooping cough, tonsillitis, mumps, anaemia, measles [most information was obtained from parents / guardians and learners through questions on the consent forms and case history taken during screening].
- The learner who had taken any medication that may have effects on accommodation (such as Antihistamine).

3.4 **Measuring instruments or data collection tools**

- Snellen Alphabet charts calibrated for 40 cm and 6 m were used to measure the distance and near VAs as part of the screening before enrolment into the study.
- The Illiterate Tumbling E Snellen charts calibrated for 40 cm and 6 m were used to measure the distance and near VAs in learners who were not familiar with the alphabets.
- +2.50 D lenses were used to screen for the presence of latent hyperopia.
- A Welch Allyn portable monocular direct ophthalmoscope was used to assess the ocular health status of the anterior and posterior segments of the eye, including the assessment of the pupillary reflexes (direct and consensual) as part of the screening before enrolment into the study. The batteries of the ophthalmoscopes were charged after the assessment of every 20 learners.
- A prism bar was used to measure the magnitude of a phoria during evaluation with the cover test at near before enrolment into the study.
- An eye patch was used throughout the study to cover the eye that was not being evaluated.
- Alcohol swabs were used to clean the eye patch after each learner was evaluated.
- A Welch Allyn portable retinoscope with MEM card(s) were used to measure the AA objectively during the dynamic retinoscopy technique.
- A measuring tape was used to measure the distance from the end point of the AA to the spectacle plane of the participant during the study.
- A lux meter (smart phone application) was used to measure the amount of illumination present at the working station. This was to ensure that the illumination used was within the recommended levels of between 150 and 300 lux (lx) and was consistent throughout the data collection of the study.

3.5 **Reliability**

According to Gomm (2008), reliability refers to the consistency of the instruments that measurements are being taken with. The test - retest reliability was used in this study to ensure reliability of the measurements. During the assessment of each participant, five measurements for each technique were taken, of which the average result was then converted into diopters and used for data analysis of AA.

3.6 **Clinical procedures**

Each one of the four schools included, provided a room were all the tests were performed. The allocated rooms were illuminated by natural light that measured between 150 and 300 lx with the Lux (illumination) measuring application on a smartphone. In the event that light was insufficient due to cloudy weather conditions, electric room lights were used additionally to ensure the reading was still between 150 and 300 lx. In some schools, the allocated rooms had curtains and in some, windows were covered with newspapers to reduce the amount of natural light at the ophthalmoscopy station. The learners who took medication for influenza or allergies (even eye drops) were not included in the study.

The pre - enrolment or vision screening tests were performed on all learners who had signed and submitted their assent forms (Appendix E or F), and their parents had also submitted signed consent forms. Only the learners who passed the VA test at 6 m and 40 cm, the +2.50 D lens test, the cover test at near and ophthalmoscopy according to the stated criteria, proceeded to the amplitude of accommodation evaluation station.

3.6.1 **Vision screening tests and procedures**

3.6.1.1 ***Distance habitual Visual Acuity (VA)***

The distance VA test was performed to measure the ability of the learner to see clearly at distance and was done according to the method described by Carlson (2004). The Alphabet Snellen chart was placed at 3 m calibrated for a 6 m testing distance in a room with 150 - 300 lx intensity. The learners were seated comfortably and the examiner covered the learner’s left eye (LE) with the eye patch. The learners were asked to read the letters on the chart with the right eye (RE), starting at the top line until they could not identify more than half of the letters on the smallest line anymore. Thereafter, the examiner uncovered the LE and covered the RE and the above procedure was repeated. The vision of each eye was noted on the vision screening sheet (Appendix G, Section 2). In the case that a learner was not familiar with the alphabet, the same procedure was followed with an Illiterate Tumbling E Snellen chart. The expected findings for this test were 6/6 in each eye. The learners whose visual acuities were worse than 6/6, were referred for a full eye examination and excluded from the study. They did not proceed to the next vision screening tests.

3.6.1.2 ***Near habitual Visual Acuity (VA)***

The near VA test was performed to measure the ability of the learner to see at near (40 cm), and was done according to the method described by Carlson (2004). The procedure was the same as that noted above in paragraph 3.6.1.1 for distance at 6 m. The only difference was in the set - up. With this test, the near chart was placed at 40 cm. A distance of 40 cm was ensured by measuring the distance from the target to the learner’s spectacle plane with a measuring tape. The VA obtained was noted on the vision screening sheet (Appendix G, Section 2). The expected findings for this test were 6/6 in each eye. The learners whose visual acuities were worse than 6/6, were referred for a full eye examination and excluded from the study. They did not proceed to the next vision screening tests.

3.6.1.3 ***Plus lens test (+2.50 D)***

The +2.50 D lens test was performed to evaluate the presence of latent hyperopia and was done according to the procedure described by the Colorado Department of Education (2006). The test was done immediately after the distance VA test. The examiner covered the learner's LE with an eye patch and put a +2.50 D lens in front of the learner's RE. The learner was asked to read the 6/9 VA line through the plus lens. The expected findings were failure or inability to read the 6/9 VA line through the plus lens (this was regarded as a pass). After failing to read the 6/9 VA line, to be able to record the exact VA with plus lens for reference purposes, the participant was asked to read the letters on the chart starting from the top line until where he / she could not identify more than half of the letters on the smallest line. The procedure was repeated on the LE. The results were recorded on the vision screening sheet (Appendix G, Section 2). If the vision improved with the lens (which was not found during this study), the learner would have been excluded from the study. Failure of the test may be indicative of latent hyperopia, and the learner would have been referred for further assessment and intervention using the referral letter (Appendix H). The same learner would not have proceeded to the next vision screening tests.

3.6.1.4 ***Cover test with habitual prescription***

The researcher performed the cover test at 40 cm, to check for the presence of heterotropia and heterophoria. The method followed, was as described by Barrett and Elliott (2007). The procedure was performed on the learners with habitual correction (if any), in a room with 150 - 300 lx intensity for the examiner to easily pick up any eye movement that might be present during the conduction of the test. The target was a 6/9 letter "V" on a tongue depressor stick, which is a line larger than a learner's best VA. To check for the presence of either heterotropia or heterophoria, the unilateral cover test was performed. The examiner firstly covered the LE with an occluder while observing the response of the RE that was uncovered. The procedure was repeated three times. In the same way, the examiner covered the RE while observing the response of the LE. The procedure was also repeated three times. If any eye movement was observed on the eye that was uncovered while the fellow eye was covered, it would be indicative of a heterotropia and the learner would have been referred for a full eye examination using the referral letter (Appendix H) and would also be excluded from the study. If no movement was observed on the eye that was uncovered while the fellow eye was covered, there was a possibility of the presence of the heterophoria. Then, the examiner further used the alternating cover test to check for the presence of heterophoria. The examiner placed the occluder in front of the LE for about two to three seconds, then quickly transferred the occluder to the RE, observed the response of the just uncovered eye and kept the occluder on the RE for about two to three seconds while allowing the LE to take up fixation. The occluder was moved along a horizontal line between eyes to ensure that the learner would not view the target binocularly. The examiner repeated the cycle three times. To measure the magnitude of a deviation, a prism bar was placed in front of any eye according to the direction of the eye movement observed. To neutralize a movement, a prism bar was placed before one eye, increasing the prism diopters until no movement was observed with the alternating cover test. The expected findings were a heterophoria at near ranging between orthophoria to 6 exophoria, no esophoria was expected at near according to the standardised norms (Scheiman and Wick, 2008). The results were recorded on the vision screening sheet (Appendix G, Section 3). The learners whose phorias were outside the expected norms as stated by Scheiman and Wick (2008), were referred for a full eye examination using referral letter (Appendix H) and did not proceed to the other screening tests and were thus excluded from the study.

3.6.1.5 ***Direct Ophthalmoscopy***

The direct ophthalmoscopy test evaluates the health status of the eye and was performed according to the procedure described by Carlson (2004). The test was used to assess the anterior segment first, which included the evaluation of the pupillary reflexes and also assessment of the posterior segment of the eye. The assessment of the anterior segment of the eye was performed in a room with 150 - 300 lx intensity to allow a better view of the structures of the anterior segment. The learners were asked to sit comfortably, removed spectacles (if any) and look straight ahead. The examiner used a wide aperture on the ophthalmoscope to view the structures of the anterior segment such as the eyelids, conjunctiva, sclera, cornea and pupil. The learners whose anterior segment structures were showing some abnormalities such as vernal keratoconjunctivitis (VKC) with / without limbitis, conjunctival hyperemia, corneal opacities, pupillary defects such as irregular shape, dilated or constricted pupils or pupils of different sizes (anisocoria) were referred for a comprehensive eye examination and the learners did not proceed to the other tests. These learners were thus excluded from the study.

The examiner reduced the amount of natural light coming through windows by covering a window facing directly to the station performing ophthalmoscopy. This was done to prevent light from interfering with the pupillary reaction. The room light was reduced to 50 - 70 lx as measured with Lux meter application on smartphone, in order to assess the pupillary reflexes of the learners through direct and consensual and also to assess the posterior segment of the eye. The learners were asked to look at a distant target (6/60) while the examiner was shining a light on the visual axis of the RE to observe the speed of pupil constriction in the RE (this method tested the direct response of the pupils). This test was repeated twice. Thereafter, light was shone in the RE and the speed of pupil constriction in the LE was observed, namely the consensual response of the pupil. The test was repeated twice. Both tests (direct and consensual) were performed on both pupils. The learners whose pupils differed in sizes or had irregular shapes, or would not have responded as expected when you shone the light into the eye, were referred for a comprehensive eye examination and the learner did not proceed to the other tests and were thus excluded from the study.

The examiner assessed the crystalline lens as well as the posterior segment of the eye by holding the ophthalmoscope handle with the right hand and braced the ophthalmoscope head against the examiner's RE to examine the learner's RE. With a zero diopter lens in the ophthalmoscope, the examiner located the orange reflex of the fundus within a learner's pupil. The examiner continued to reduce the lenses to more minus, and moved the head more closely to the learner's head until the right hand touched the learner's face and the ocular fundus was well focused. If fundus abnormalities were noted, e.g. optic disc defects such as atrophy or retinal defects such as retinitis pigmentosa, the learner was referred for a comprehensive eye examination and excluded from the study. The results for ophthalmoscopy were recorded on the vision screening sheet (Appendix G, Section 4).

3.6.2 **Amplitude of Accommodation techniques and procedures**

The following techniques were performed in a room with 150 - 300 lx intensity and only on the participants who have passed all the screening tests as discussed above. The results were recorded on the data collection sheet (Appendix I). The pilot study (as discussed in paragraph 3.6.3.1), showed that the RE and LE eyes were not statistically significantly different. Therefore, only the REs of all participants were included in the study. It is preferable that RE and LE of the same individual not be pooled in the same sample when data is collected or analysed (Karakosta *et al*., 2012), as there may be possible symmetry between eyes of the same individual.

Measurements of AA were taken using subjective and objective procedures for evaluating AA. These techniques are briefly described below:

3.6.2.1 ***Push - up / Pull - away technique***

Subjective measurements of AA were taken using the Push - Up / Pull - Away (PU / PA) technique as described by Barrett and Elliott (2007). The procedure was performed only in the RE as discussed above, in a room with 150 - 300 lx intensity. The participants were firstly seated comfortably and wore an eye patch on the LE, as the techniques used should be performed monocularly. The researcher commenced by carrying out a demonstration to each participant to ensure that they understood the instructions prior to the AA measurements. They were encouraged to read out letters (N, H, or E) on the target to ensure that accommodation is effective throughout the procedure. The letters used for reading by the participants, were the letters N, H, or E from 6/9 prints of the near reading chart. The target was firstly held close to the participant's nose while the participant's RE was closed. The participant was asked to open his / her RE, and the researcher slowly moved the target away until the participant could identify the letter on the target. This was regarded as the end point for the PA measurement. The distance from the end point to the participant's spectacle plane was recorded as the measurement in centimetres (cm). Thereafter, the target was moved backwards until about 40 cm. The researcher then moved the target slowly towards the participant instructing the participant to keep the letter clear and read the letter out as the target was moved closer. The participant was asked to blink in order to clear the target and eliminate blur when he / she was calling out the wrong letter. The end point of this PU technique was noted when the participant could not clear the target even after blinking or trying to clear it (first sustained blur). The researcher then measured the distance from the end point to the spectacle plane in centimetres (cm). Five measurements were taken for each technique (PU and PA) and the average of each five measurements were converted into diopters and were recorded as the average AA for each technique. The average AA result of the PU / PA techniques was calculated by summing the PU and PA results and divided the sum by two. This value was labeled as the "Average subjective". The average results of the PU / PA techniques as described are referred to as the "**Average subjective**" in the dissertation.

3.6.2.2 ***Objective measurements of AA: Dynamic Retinoscopy***

The objective measurements of AA were taken using the dynamic retinoscopy (DR) technique as described by Eskridge (1989). This procedure was performed immediately after the subjective AA. With the eye patch worn on the LE, the researcher attached an MEM card (for Grade 6) to the front of the retinoscope. The MEM card for Grade 6 was selected based on the small size of letters it contained and small letters are essential to keep accommodation active or stimulate accommodation more than big letters. The participants were continuously asked to spell out the letters appearing in each word on the target card (MEM) as the researcher was busy examining. In the case were the participant was not familiar with the letters, an MEM card with various figures of similar size to letters on the MEM card for Grade 6, was used. The researcher began by scoping the horizontal meridian of the RE at 40 cm using the vertical streak and then observed the movement of the vertical streak. At first, the streak was seen as broad and fast in speed. The researcher proceeded by moving slowly towards the participant while scoping until a thin / narrow, dim and slower ''with'' movement streak was observed. This was regarded as the end point for objective amplitude and the distance in centimetres was measured from the participant's spectacle plane to the position or distance where a narrow slower streak was observed. Five measurements were taken in the RE and the average distance was converted into diopters and this was recorded as the average objective AA. These average results are referred to as "**Objective AA**" in the dissertation.

3.6.3 **Data collection procedure**

3.6.3.1 ***Pilot study***

The pilot study was conducted on ten participants with the purpose of assessing the feasibility of the procedures, the vision screening and data collection sheets to be used in the main study. The inclusion criteria for the pilot study were the same as that for the main study. However, the data of these pilot study participants (n= 10) was not included in the main study following a few adjustments made, like targets previously used, were modified. All researchers (principal investigator, research assistant and administrator) that participated in the main study, also participated in the pilot study. During the pilot study, the AA measurements (subjective and objective) were taken in both eyes and the time spent per participant was roughly 21 minutes. The participants were tired after all the tests were completed and thus, the possibility of only including one eye in the main study was considered. This would ensure better attention span of the participants and better turn - around time. The results of the pilot study were analysed by a Biostatistician from the Department of Biostatistics (UFS) with the aim to test the correlations between REs and LEs. The results showed a very strong correlation between RE and LE data and thus, only REs were included in the main study. Literature has also shown, that the two eyes of the same individual cannot be pooled in the same data set, and should a researcher aim to investigate both the RE and LE of the same individuals, REs and LEs should be analysed separately (Karakosta *et al*., 2012).

3.6.3.2 ***Main study***

The vision screening tests were only performed on the learners who had submitted signed consent and assent forms. The screening took place in a room allocated by the school officials. During the vision screening procedure, three stations were created. The first group of learners was collected from their respective classrooms by the researcher and was taken to the testing room in group of three. Prior to the screening procedures, the learners were tasked to sit down in the testing room (or classroom) and were addressed about what to expect during the screening. The assent form was also explained to the learners and they were asked to sign or write their names to voluntarily give assent to take part in the study.

All the stations were visibly labelled and the following tests were performed at each station:

- Station 1: Learner's registration. The demographic details taken at this station were recorded on Appendix G, Section 1. The registration was done by an administrator. Each participant spent approximately 2 minutes at the station.
- Station 2: This station included case history taking, the assessment of distance (6 m) and near (40 cm) VAs, the evaluation of the presence of latent hyperopia with the use of the +2.50 D lens test and direct ophthalmoscopy. The results were recorded on Appendix G, Sections 1, 2 and 4. The ophthalmoscope batteries were charged after the assessment of every 20 learners to ensure the same intensity throughout the screening especially during the assessment of pupillary reflexes. The tests at this station were performed by a registered optometrist. Each learner spent approximately 7 minutes at this station.
- Station 3: This station included the cover test at 40 cm and the main techniques of the study which were DR and the PU / PA techniques to test the AA of each participant. The cover test was performed first to complete the visual screening procedures and if the learner met the inclusion criteria, he/she then proceeded to the measurements of the AA. The PU and PA techniques were always performed before the DR and with the PU and PA techniques; the order was maintained per participant. For instance; if started with the PA technique, the sequence for the first measurements will be PA then PU, second measurements PA then PU, etc. until five measurements per technique were collected. The order was sometimes alternating between the participants. Sometimes the examiner would start with the PU and then PA. In this case, the sequence of the PU then PA would be adhered to until five measurements were collected per technique. The last procedure performed was DR and five measurements were taken.

The results for cover test were recorded on Appendix G, Section 3, and the results of DR and the PU / PA tests, on Appendix I. These tests were performed by the principal investigator (registered optometrist). The retinoscope batteries were also charged after the assessment of every 20 participants, to ensure the same intensity throughout the screening. Each participant spent approximately 13 minutes at the station. The principal investigator checked the room intensity after every 30 minutes during the assessment of participants to ensure that the light intensity has not dropped below 150 lx. Participants were managed in groups of three and the next group was called by one of the participants of the previous examined group after completion of the assessment.

3.6.4 **Personnel involved in the study**

Data collection for this study was conducted by two registered optometrists (this included the principal investigator) and the administrator. Each of the personnel was allocated to a station and remained at the same station for the remainder of the data collection to ensure accuracy and consistency of the procedures during data collection. This was maintained to ensure standardization of the data collection. The administrator manned station 1; the first registered optometrist (research assistant) manned station 2 and the researcher (principal investigator), manned station 3. The researcher conducted training to the research assistant and administrator prior to the conduction of the pilot study. Emphasis was put on the procedures, targets to be used, illumination and time in general. On the days that the research assistant was not available, the researcher performed all the screening procedures and AA measurements herself.

3.7 **Ethical considerations**

The research protocol was approved by the Health Sciences Research Ethics Committee of the University of the Free State (HSREC NR: UFS – HSD2017/0130) (Appendix J). The approval to conduct the investigation at the identified schools was also granted by the Limpopo Provincial Department of Education (Appendix K), Mankweng Circuit (Appendix L) as well as by the individual School Principals. Learners were only seen when they were in possession of the signed assent form (Appendix E or F) and informed consent form (Appendix A or B) completed either by the parent or guardian. Learners were informed that they had a choice not to participate or to withdraw at any time during the study. Voluntary participation was encouraged.

The study involved vision screening and assessment of AA. No harmful techniques and / or medication / drops were instilled into the learners' eyes. The vision screening and assessment of AA were rendered at no cost to both the participants and learners who were excluded from the study due to the inclusion criteria. Learners who were found to have eye problems, were referred using a referral letter (Appendix H) for further assessment and management at the nearest institution providing eye care services. Learners were not given any form of reward or payment after participation. The participant's vision screening and data collection sheets (Appendix G and I) are kept confidential and are not accessible to anyone outside the study except the parents who consented their children to participate in the study. The temporary identification numbers (ID number) were created mainly for the study (different from the real personal ID numbers, which were not required in the study) and each participant was identified with this temporary ID number throughout the study. Each participant's name was replaced with this temporary ID number during the registration on the vision screening sheet (Appendix G). The list (hard copy) that contains the names of the participants with their temporary allocated study ID numbers and the original copies of the vision screening and data collection sheets (Appendix G and I) are kept inside the principal researcher's personal safe whose password is known only by her. The electronic version consisting of temporary ID numbers, vision screening results and data results is saved in a folder on the principal researcher's computer with a password known by the principal researcher only.

3.8 **Data analysis**

Data was analysed using the SAS statistical software with the assistance of a biostatistician from the Department of Biostatistics (UFS). The data was analysed for normal distribution, however; the data showed to be not normally distributed. Non - parametric statistics were thus used for the analysis of the data. The results were summarised with frequencies and percentages (categorical variables) and medians and percentiles (numerical variables), hence; the averages / means were not used for statistical analysis. The difference between the AA results measured with subjective and objective techniques per age group and thereafter, compared to the calculated age amplitude, were calculated and described by means of 95% confidence intervals for the median or percentage difference. The difference between the AA in gender of 9 to 13 years were calculated and described by means of 95% confidence intervals for the median or percentage differences. The prevalence of **LOW** AA was determined and described by means of 95% confidence intervals for the prevalence. The association between the subjective and objective techniques according to Hofstetter's norms was also determined through the use of Bhapkar and McNemar tests.

McNemar test is a non - parametric test, which is applied to 2 x 2 tables with a dichotomous response from the matched pairs of subjects (Sun and Yang, 2008). It determines the equality between the marginal frequencies in a row and column. This test was used for the age groups 11 and 13 years because they had matching data (cf. 4.5.2.4, p. 79). For example: for subjective techniques (variable) the participants had two classifications which are **LOW** and **NORMAL** AA and for the objective technique (variable), they also had two classifications - **NORMAL** and **HIGH** AA. The Bhapkar test was used for the age groups 9, 10 and 12 years as they had missing data. For the subjective techniques, the participants had three classifications which are **LOW**, **NORMAL** and **HIGH** whereas for the objective technique they had only two, which are **NORMAL** and **HIGH.** Therefore, the appropriate test to be used for these age groups was the Bhapkar test (cf. 4.5.2.4, p. 79). The data analysis excluded non - respondents and dropouts.

3.9 **Conclusion**

Chapter 3 outlined the methodology, population, sample size, criteria as well as the measurement procedures and data collection of the study.

The subsequent chapter explains the results obtained in this section.

CHAPTER 4: RESULTS

This analytical descriptive, cross - sectional study was conducted on participants aged 9 to 13 years, schooling in Mankweng circuit, Limpopo province. The participating schools were randomly selected and a sample size of 366 was calculated using formula 1 (cf. 3.3.2.2, p. 30) (Krejcie and Morgan, 1970). A total of 690 consent forms were issued to three quintiles 3 schools and one quintile 2 school selected via random sampling with replacement method (cf. 3.3.2, pp. 30 - 32). Two hundred and ninety - one (291) signed consent forms were received from learners which were all screened (both eyes) for participation in the study.

The screening tests (cf. 3.6.1, pp. 34 - 37) included the following:

- Habitual Visual Acuity at 6 m and 40 cm (RE and LE)
- +2.50 D lens test at 6m (RE and LE)
- Prism cover test at 40 cm
- Direct ophthalmoscopy (RE and LE)

One hundred and six (106) of the screened learners were excluded from the study as they did not meet the inclusion criteria. All of these excluded learners were referred for a full eye exam by the researcher (registered optometrist), to the nearest facility offering eye care services.

One hundred and eighty - five (185) learners met the inclusion criteria and proceeded to the last station for the AA measurements.

The data was found to be not normally distributed and therefore, non - parametric statistical methods (cf. 3.8, pp. 42 - 43) were used for the data analysis. The results are thus described using medians, and not means or averages.

The ages of the participants were categorized into five groups as follows:

- 9 years to 9 years - 11 months (Age group 9);
- 10 years to 10 years - 11 months (Age group 10);
- 11 years to 11 years - 11 months (Age group 11);
- 12 years to 12 years - 11 months (Age group 12) and
- 13 years to 13 years - 11 months (Age group 13).

Hofstetter's norms (1950) were used as the reference for the minimum and maximum values as standardised for each age group (cf. Table 4.1, p. 45). Even though Hofstetter's norms have been standardised elsewhere in United State of America (USA), these norms are internationally recognised and used globally as reference for the evaluation of AA.

Table 4.1 The minimum and maximum values of Hofstetter's norms as standardised for each age group.

Age (years)	Minimum values (D)	Maximum values (D)
9	12.8	21.4
10	12.5	21.0
11	12.3	20.6
12	12.0	20.2
13	11.8	19.8

The AA results of all participants were grouped as **LOW, NORMAL** or **HIGH,** based on the minimum and maximum values of Hofstetter's norms (categorical classification, cf. Table 4.1, p. 45). **LOW** refers to the measured average AA of participants less than the minimum value as per the standardised norms described by Hofstetter for each age group. **NORMAL** refers to the AA results of participants measured within the reference values (between minimum and maximum) of Hofstetter per age group, and **HIGH** was used for measurements exceeding the maximum value as recommended by Hofstetter. For example, a 9 - year - old participant:

- If the average AA of a 9 - year - old participant was measured to be less than 12.8 D (minimum value as calculated per Hofstetter's formula, cf. p. 16), this participant was classified as having a **LOW** AA.

- If the average AA of a 9 - year - old participant was greater than 12.8 D (minimum value as calculated per Hofstetter's formula, cf. p. 16), but less than 21.4 D (maximum value as calculated per Hofstetter's formula, cf. p. 16), this participant was classified as having **NORMAL** AA.

- If the average AA of a 9 - year - old participant was greater than 21.4 D (maximum value as calculated per Hofstetter's formula, cf. p. 16), the participant was classified as having a **HIGH** AA.

The following four objectives were investigated in this current study and the results will be explained in the subsequent paragraphs:

Objectives:

- To compare the AA results for 9 to 13 year old participants.
- To compare the AA measurements in gender of 9 to 13 year old participants.
- To determine the prevalence of low AA at different age intervals in 9 to 13 year old participants.
- To compare the subjective and objective AA results of 9 to 13 year old participants.

4.1 **Demographic data**

Five different age groups were included in the study.

In Table 4.2, it can be seen that the total sample of participants was 185. The results of the sample of 185 participants comprising 103 (55.7%) females and 82 (44.3%) males are presented in Table 4.2. The median age for all 185 participants was 11.3 years (with the ages range between 9 and 13.8 years of age).

Table 4.2 The demographic details of the participants (n= 185) by age group and gender.

Age Group	**Gender**		**Total**
	Female	**Male**	
9	19	16	18.9%
10	17	28	24.3%
11	22	14	19.5%
12	37	17	29.2%
13	08	07	8.1%
Median age= 11.3	**Total= 103**	**Total= 82**	**Total= 100 %**

The participants included Grade 3 to Grade 7 learners, with the most participants from Grade 4 (47) and Grade 6 (46). Figure 4.1 (cf. p. 47) presents the number of participants according to the grades that they resided in at the time of data collection.

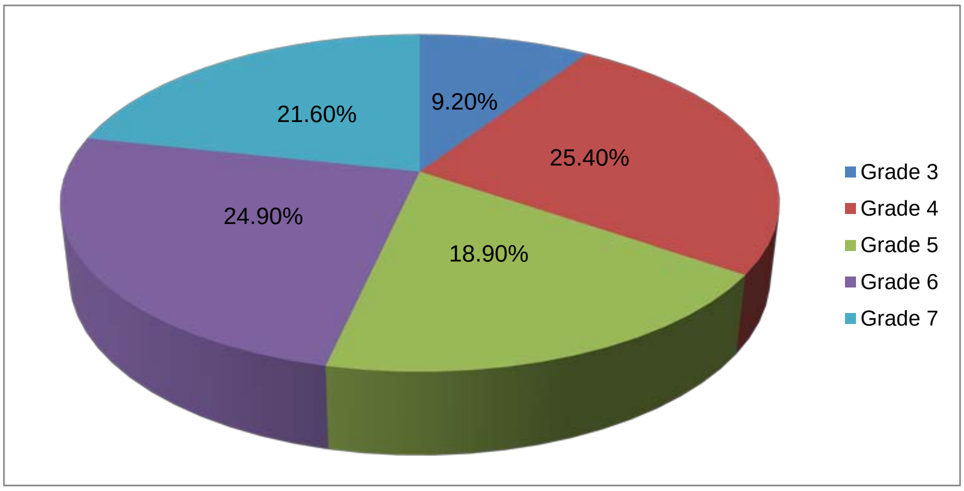


Figure 4.1 A pie chart showing the distribution of learners according to grades. The higher number of the participants were from Grades 4 and 6.

The screening results of the participants according to the prescribed inclusion criteria for the current study are shown in Table 4.3.

Table 4.3 The screening profile of all the participants (n= 185).

	Right Eye		**Left Eye**	
Procedure	**Frequency**	**Results**	**Frequency**	**Results**
VA @ 40 cm	185	6/6	185	6/6
VA @ 6 m	185	6/6	185	6/6
+2.50 D Test	185	6/120 - 6/24^{-1}	185	6/120 - 6/15^{-2}
Ophthalmoscopy	185	NAD*	185	NAD*

*where NAD is no abnormality detected

In Table 4.4 (cf. p. 48), it can be seen that the cover test was performed at 40 cm and the results were between orthophoria and 6 exophoria for all participants, that is within the stated heterophoria norms for near (3^{Δ} exophoria ± 3^{Δ}) by Scheiman and Wick (2008).

Table 4.4 The Cover test results for all the participants (n= 185).

Procedure	Frequency	Results
Cover Test @ 40 cm	20	4 XOP*
	14	6 XOP*
	151	Orthophoria

*where XOP is exophoria

The current study included 185 (female and male) participants aged 9 to 13 years. The participants had VA's of 6/6 in each eye (RE and LE) both at 40 cm and 6 m to exclude a possible refractive error. Latent hyperopia was ruled out by performing the + 2.50 D lens test. No participant was found to have obvious ocular pathology. Cover test was performed to ensure that all participants had a phoria that falls within the norms of near phorias (40 cm), which is between orthophoria and 6 exophoria.

The data of the main study was collected on the REs of participants only, as a strong correlation was found in the AA results between RE and LE of the same individual during the pilot study. Thus, it may be assumed, due to the strong correlation found, that RE and LE of the same individual may give very similar results. To lower the chance of closely related data and the possibility of eyes being symmetrical as a result of this high correlation, only REs were included. The same methodology of including only one eye was previously used in other literature (Ovenseri - Ogbomo *et al.*, 2012; Benzoni and Rosenfield, 2012). Therefore, only RE results are explained in the subsequent sections.

4.2 **Objective 1: Comparison of the AA results for 9 to 13 year old participants**

The measurement of AA for all participants included the measurements taken from the three techniques namely: Push - up (PU), Pull - away (PA) and Dynamic retinoscopy (DR). In each technique, five measurements were taken and the average reading was used in the presentation of the data within this results section. The results of each technique are described in the following sections: the push - up (PU) technique (cf. 4.2.1, pp. 49 - 52), the pull - away (PA) technique (cf. 4.2.2, pp. 52 - 56) and the dynamic retinoscopy (DR) technique (cf. 4.2.4, pp. 60 - 64). The measurements of AA were also determined by summing the PU and PA results and divided the sum by two. Then, the calculated results were labeled as the average results of the PU / PA techniques. These results are described in section 4.2.3 (cf. pp. 56 - 60).

4.2.1 **The AA results as measured with the Push - up (PU) technique**

For an overview of how the technique was performed, refer to (cf. 3.6.2.1, pp. 37 - 38).

In Table 4.5 below, it can be seen that the interquartile range (25% to 75%) of the AA measurements for the 9 - year - old group is between 14.3 D and 16.8 D with a median AA of 15.5 D. For the oldest age group, the median AA is 12.9 D with an interquartile range (25% to 75%) of 11.9 D to 13.5 D. The median results of the complete sample of 185 participants showed to be 14.3 D, with an interquartile range (25% to 75%) of between 13.3 D and 15.9 D. Table 4.5 presents the median AA, lower (25%) and upper (75%) quartile AA results of 185 participants grouped according to age.

Table 4.5 The distribution of AA according to age for the PU technique of measuring AA. An average of five readings was used for the data analysis, (n= 185).

Age group	Median AA (D)	Lower Quartile (D) 25%	Upper Quartile (D) 75%
9	15.5	14.3	16.8
10	14.9	13.9	16.2
11	14.3	13.6	15.6
12	13.8	12.7	15.2
13	12.9	11.9	13.5
Total=185	**14.3**	**13.3**	**15.9**

The median AA between the different age groups in the current study showed a pattern of reducing as age increases (cf. Figure 4.2, p. 50). The box and whisker plot further showed that amongst the participants aged 9 years, the minimum AA measured was found to be 11.3 D with a maximum AA of 17.3 D. The oldest participants aged 13 years, showed a normal range of 10.3 D to 14.4 D. In each age group, except 13 years, there were a few outliers shown and appeared to be the most in the age group 9 years as compared to other age groups. For the age group 9 years, the outliers identified were the following AA values greater than the maximum AA value for this age group: 21.4 D, 22.5 D and 27.9 D. These outliers normally influence the distribution of the data, as can be seen in Figure 4.2 (cf. p. 50). The median AA, lower (25%) and upper (75%) quartiles, range of the data (minimum and maximum values of AA) and outliers in each age group involved are shown in Figure 4.2 (cf. p. 50).

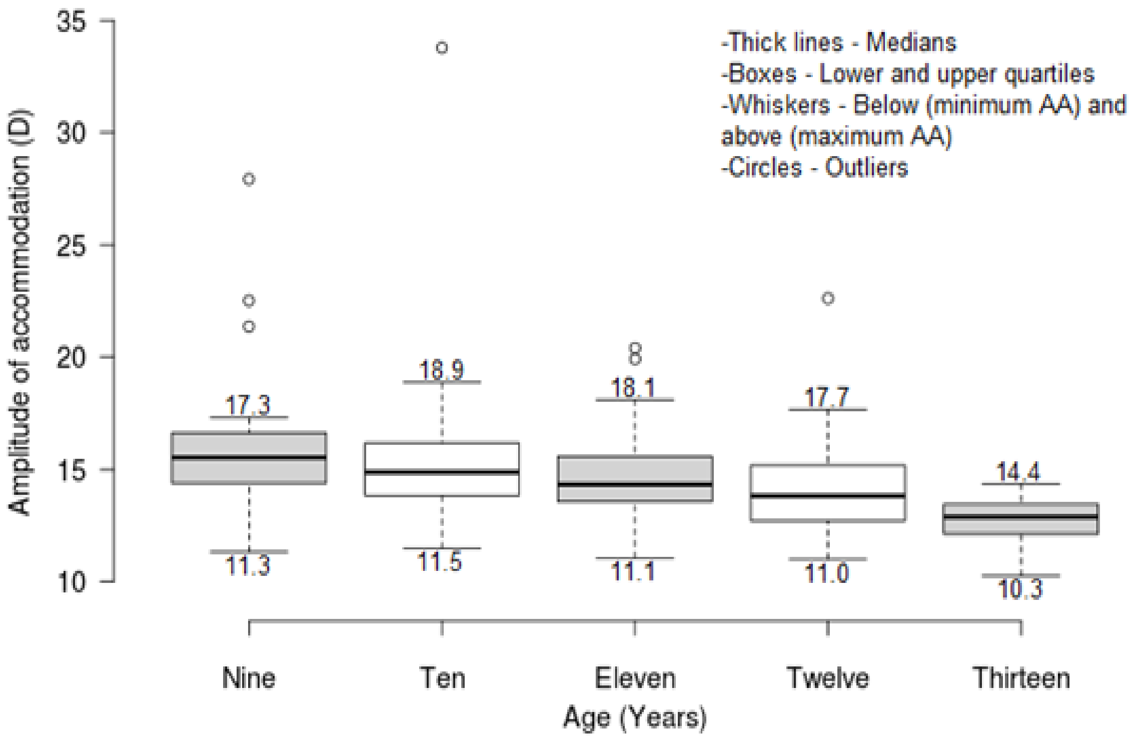


Figure 4.2 Box and whisker plot of the AA for the participants aged 9 to 13 years as measured with the PU technique. In this plot, the thick lines represent the medians, the boxes represent the lower (25%) and upper (75%) quartiles, and whiskers below and above the box indicate the minimum and maximum values excluding outliers, thus the range. The circles above the whiskers represent outliers. It can be seen that the median lowers as the age increases.

In Figure 4.3 (cf. p. 51), the median AA of the participants showed a reduction from 15.5 D in the age group 9 years to 12.9 D in the age group 13 years when investigated with the PU technique. The rate at which the median AA changes between the different age groups relative to each other, was not constant. As an example, the AA changed with 0.6 D from ages 9 to 10 years and from 10 to 11 years. However, from 11 to 12 years, the AA changed with 0.5 D and from 12 to 13 years, with 0.9 D. Furthermore, the median AA results for all age groups in the current study, if compared to the age expected norms as calculated from Hofstetter's formulae, were found to be higher than the minimum values but lower than the maximum values (cf. Figure 4.3, p. 51).

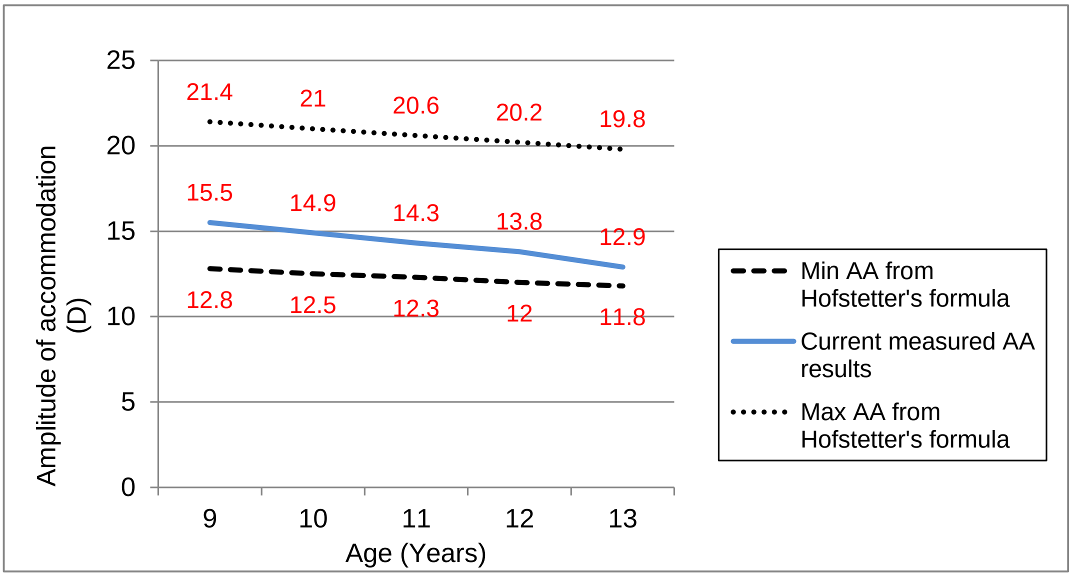


Figure 4.3 The median AA as measured with the PU technique on 9 to 13 year old participants. The AA clearly reduces with an increasing age and the rate of change was not constant between the different age groups. The measured results (median AA) were found to be between the minimum and maximum AA results as calculated with Hofstetter's formulae.

The AA results of the participants measured using the PU technique, were further described and compared according to categorical classification for each age group. Amongst 185 participants aged 9 to 13 years, 4.4% to 13.3% were classified as **LOW** with the most participants in the age group 13 years included in this group. Eighty - six point seven percent (86.7%) to ninety - three point three percent (93.3%) were classified as **NORMAL** with the highest number of participants in age group 10 years being included in this group. Only 5.7% in age group 9 years, 2.2% in 10 years' group and 1.9% in age group 12 years were classified as **HIGH**. No participant presented with a high AA in the age groups 11 and 13 years, for any of the subjective techniques used in the current study. Figure 4.4 (cf. p. 52), shows the categorical distribution of AA per age group.

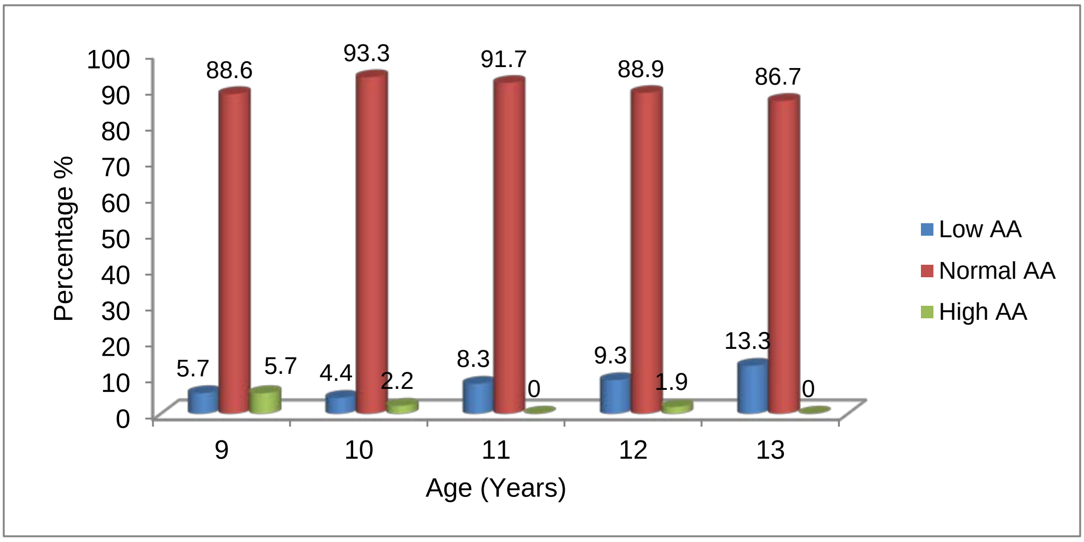


Figure 4.4 The categorical distribution of AA per age group for the PU technique shows that **LOW** AA was highest amongst 13 year old group and lowest amongst 10 year old group.

4.2.2 **The AA results as measured with the Pull - away (PA) technique**

The procedure of the pull - away (PA) technique is outlined in section 3.6.2.1 (cf. pp. 37 - 38).

The PA technique was used to measure the AA in the different age groups. An average of five readings was used for the presentation of the results.

The results showed that, the majority of the participants in the age group 9 years (youngest age group) showed an AA of between 13.4 D (lower 25% quartile) and 15.3 D (upper 75% quartile) with a median AA of 14.4 D. For the oldest age group (age 13 years), the median AA was found to be 12.2 D with an interquartile range (25% to 75%) of 11.3 D to 12.8 D. The median AA for the complete sample was found to be 13.4 D, with an interquartile range (25% to 75%) of between 12.5 D and 14.8 D. Table 4.6 (cf. p. 53), shows the median AA, lower (25%) and upper (75%) quartile AA results of 185 participants grouped according to ages included in the study.

Table 4.6 The distribution of AA according to age for the measurements taken by the PA technique. An average of five measurements was used for the data analysis, (n= 185).

Age group	Median AA (D)	Lower Quartile (D) 25%	Upper Quartile (D) 75%
9	14.4	13.4	15.3
10	13.7	13.0	15.1
11	13.3	12.5	14.7
12	13.0	12.0	14.2
13	12.2	11.3	12.8
Total=185	**13.4**	**12.5**	**14.8**

Similar to the results obtained with the PU technique, the median AA results measured with the PA technique in the current study showed a pattern of decreasing with increasing age. The box and whisker plot in Figure 4.5 (cf. p. 54) presents various ranges of AA data for participants aged 9 to 13 years. For example, the participants aged 9 years showed a range of 11.7 D (minimum AA) to 15.8 D (maximum AA). Possible outliers in the age group 9 years were found below 11.7 D (one data point identified was 10.7 D) and also above 15.8 D (three data points were identified: 20.1 D, 20.2 D and 24.0 D). Outliers were noted in each age group, except for the group 13 years and are known to influence the distribution of the data, as can be seen in Figure 4.5 (cf. p. 54). The oldest group aged 13 years, showed a normal range of 9.9 D to 13.7 D. When this group was compared to other age groups included in the study, it was found to have the smallest distribution of values (3.8 D between 9.9 D and 13.7 D) and also the smallest interquartile range (25% to 75%) of AA values between the lower (25%) and upper (75%) quartiles (11.3 D to 12.8 D). The median AA, lower (25%) and upper (75%) quartiles, range of the data (minimum and maximum AA) and outliers found in each age group are presented in Figure 4.5 (cf. p. 54).

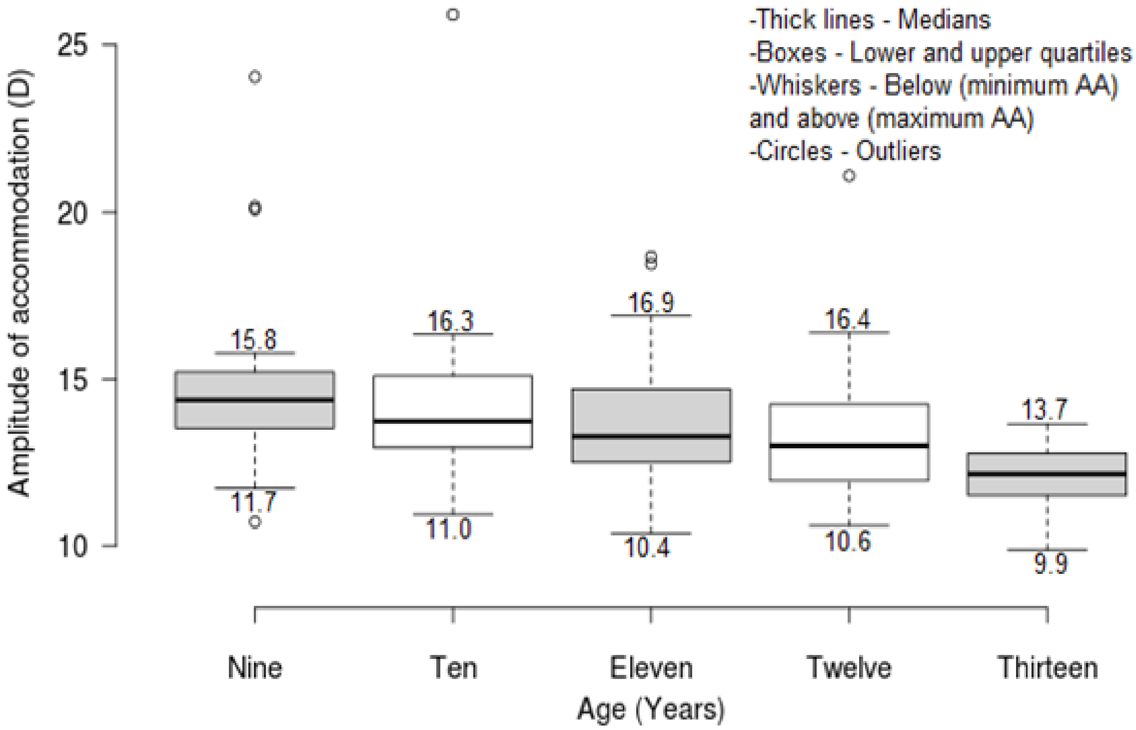


Figure 4.5 Box and whisker plot of the AA for the participants aged 9 to 13 years. As can be seen from the plot, the distributions of the PA measurements are similar to that found with the PU, where the median reduces as the age increases.

In Figure 4.6 (cf. p. 55), it can be seen that for the PA technique, the median AA reduced from 14.4 D in the 9 - year - old group, to 12.2 D in the 13 - year - old group. The rate at which the median AA changes within the age groups was again not constant, as was also seen in the comparisons made with the PU technique measurements. The AA changed with 0.7 D from 9 to 10 years, 0.4 D from 10 to 11 years, 0.3 D from 11 to 12 years and lastly 0.8 D from 12 to 13 years. When the measured results of the PA technique were compared to the age expected norms calculated from Hofstetter’s formulae, the median results showed a minimal difference to the minimum age expected norms as compared to the PU results (Figure 4.6, p. 55).

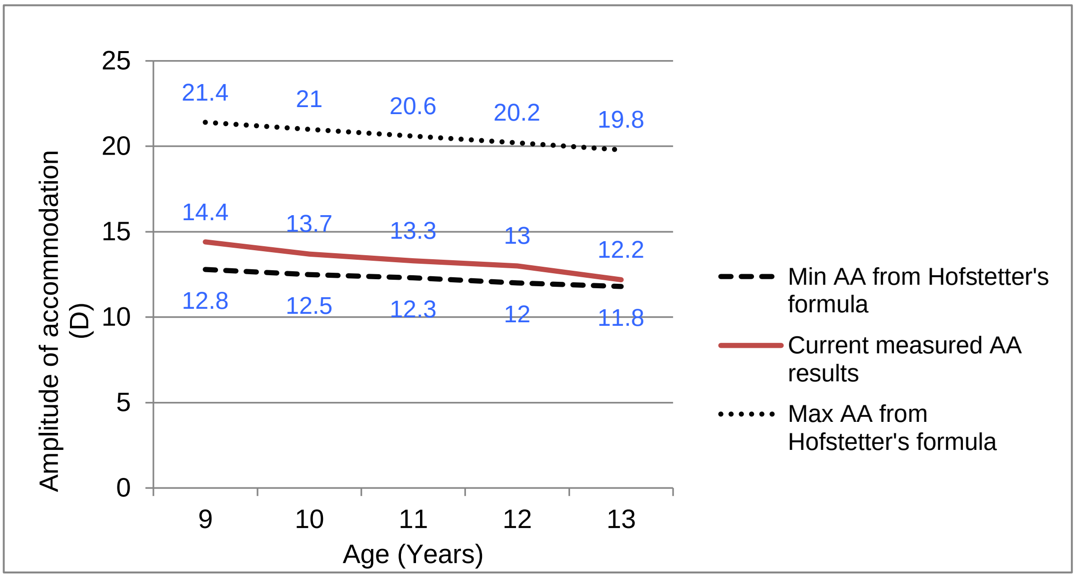


Figure 4.6 The median AA of the 9 to 13 year old participants measured with the PA technique reduces with an increasing age. The rate of change is different between the age groups. Furthermore, it may be seen that a line graph of the median AA results measured with the PA technique is very close to the minimum age expected norms, especially with regard to age group 13 years.

The categorical distribution of the AA results of the 9 to 13 year old participants, measured using the PA technique, is shown in Figure 4.7 (cf. p. 56). The results showed that 11.4% to 33.3% of the participants were classified as **LOW** with a higher percentage of participants in the 13 year age group. However, these results of **LOW** classification were higher if compared to the results of the PU technique. Sixty - six point seven percent (66.7%) to eighty - six point one percent (86.1%) of participants were classified as **NORMAL** and the age groups, 9, 10 and 12 years, showed a few participants classified as **HIGH**.

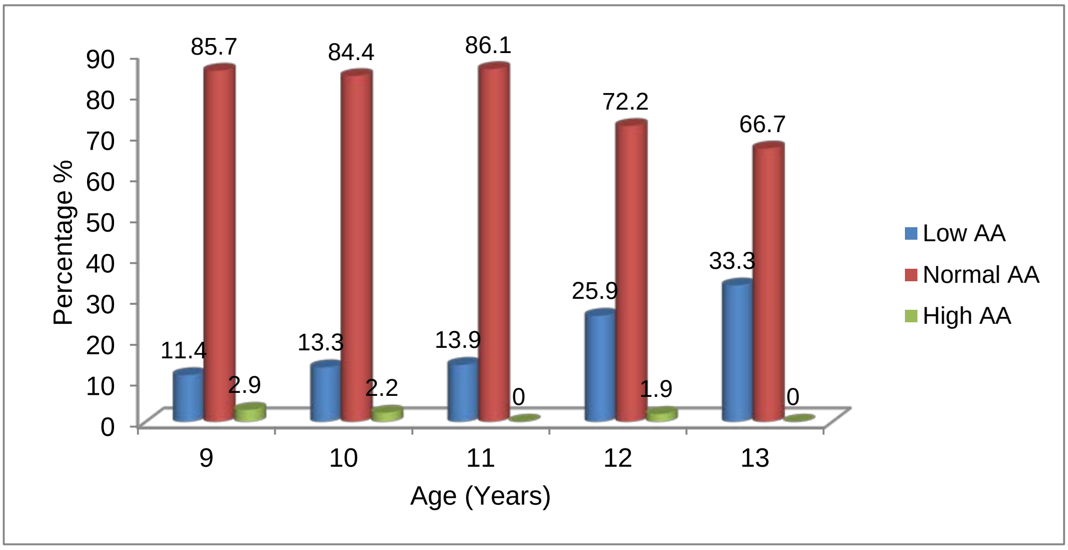


Figure 4.7 The categorical distribution of AA per age group for the PA technique. It may be noted from this figure that most of the participants in each age group are classified within the **NORMAL** range of AA.

4.2.3 **The AA results as determined with the calculated average of the Push - up (PU) / Pull - away (PA) techniques**

Refer to section 3.6.2.1 (cf. pp. 37 - 38) for the procedure of the Push - up (PU) and Pull - away (PA) techniques.

The PU as well as the PA techniques were used to measure the AA in the different age groups. The averages of each five measurements (in centimeters) were converted into diopters and recorded as the average AA for each technique (PU or PA), also referred to as the PU results or the PA results. The average AA result of the PU / PA techniques was calculated by summing the PU and PA results and divided the sum by two. The result value was referred to as the average result of the PU / PA techniques, PU / PA average result or as Average subjective in the dissertation.

Even though the measurements in this section were determined by calculating the average of the PU and PA results, the data was not normally distributed. Therefore, non - parametric statistical methods were implemented for the analysis of this data. The data is thus presented by means of medians and quartiles, not means or averages.

The mathematical calculated average results were used for the presentation of the results in this current section.

Table 4.7 (cf. p. 57), shows that the median result of the AA for the youngest age group (9 years) is 15.0 D, with an interquartile range (25% to 75%) of 13.9 D to 16.1 D. For the age group 13 years, the interquartile range (25% to 75%) for the AA measurements is between

11.6 D and 13.1 D. The complete sample of 185 participants showed to have a median AA of 13.8 D, with an interquartile range (25% to 75%) of 12.9 D to 15.4 D. These current median results were lower for all age groups as compared to the PU results but higher if compared to the results of the PA technique.

Table 4.7 The distribution of AA according to age for the measurements determined with the calculated average of the PU / PA techniques. An average of two measurements was used for the data analysis, (n= 185).

Age group	Median AA (D)	Lower Quartile (D) 25%	Upper Quartile (D) 75%
9	15.0	13.9	16.1
10	14.3	13.4	15.7
11	13.8	13.0	15.2
12	13.5	12.3	14.7
13	12.5	11.6	13.1
Total=185	**13.8**	**12.9**	**15.4**

Just as seen with the PU and PA techniques respectively, the median results determined from the average results of the PU / PA techniques, showed a pattern of reducing AA with increasing age (Figure 4.8, p. 58). The participants in the age group 11 years showed a wider distribution of the AA range values (from 10.7 to 17.5 D) compared to the other participants in the age groups 9 to 13 years. However, it must be noted that the wider distribution observed in the age group 11 years was also seen with the PA results, whereas with the PU results this was seen in the age group 10 years. Furthermore, when the AA results of the current method (PU / PA average results) was considered, the age group 9 years showed a wider spread of AA values seen in the lower (25%) quartile with a very small spread on the upper (75%) quartile range. A few data points that are too far from other data points (outliers) were identified in each age group except that of 13 years. This has also influenced the data distribution, hence the skewed data. The age group 13 years has again showed the smallest distribution of the range of AA values of 3.9 D (from 10.1 to 14.0 D) as compared to the spread of AA values in the 11 year old group which has the largest spread of data. Figure 4.8 (cf. p. 58), presents the median AA, lower (25%) and upper (75%) quartiles, range of data (minimum and maximum) and outliers in each age group.

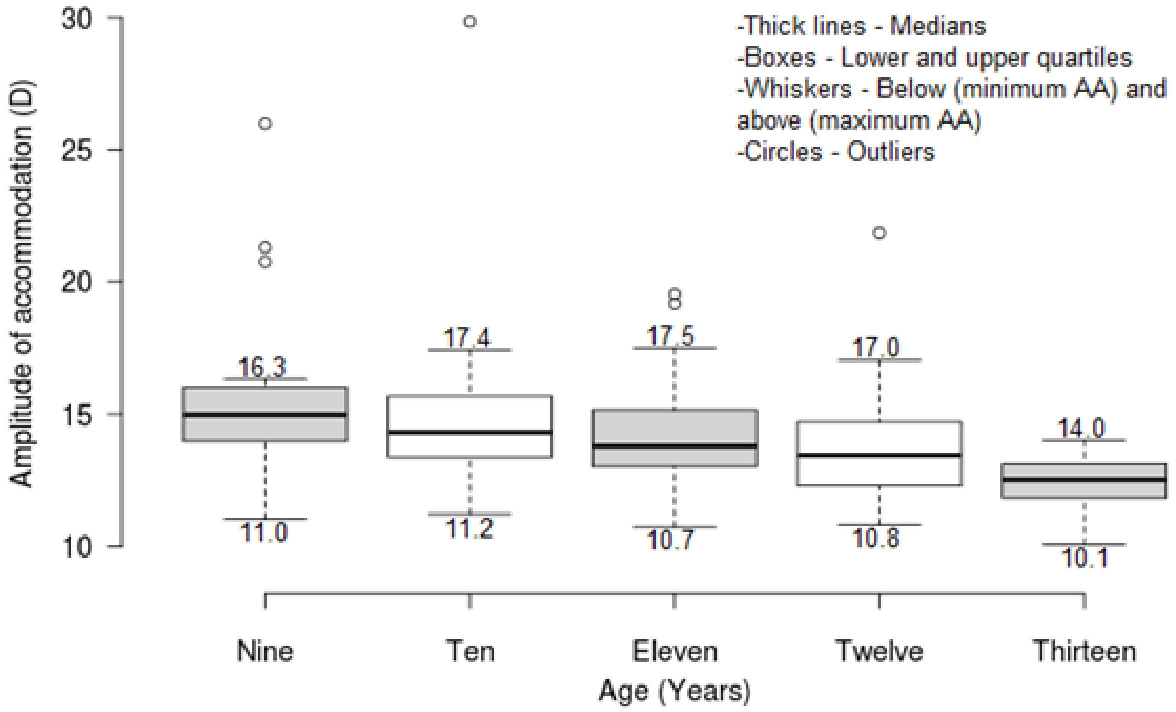


Figure 4.8 Box and whisker plot of the AA measurements for the participants aged 9 to 13 years, as determined with average results of the PU / PA technique. In this plot, it may be seen that the 11 years group have the largest spread and the 13 years have the smallest spread of data points.

The median results generated from the average results of the PU / PA techniques showed a reduction of AA from 15.0 D in the youngest group (9 years) to 12.5 D in the oldest group (13 years). The change in median AA varied as follows between the different age groups (cf. Figure 4.9, p. 59): From age 9 to 10 years with 0.7 D, 10 to 11 years with 0.5 D, 11 to 12 years with 0.3 D and 12 to 13 years with 1.0 D. Again as seen with the PU and PA techniques, the results of the current method, when compared to the age expected norms calculated from Hofstetter's formulae, showed the median results higher than the minimum age expected norms, but lower than the maximum norms. However, the difference between the current median AA results and the age expected minimum norms appear to be higher if compared to the PA results and smaller if compared to the PU results. This could mean that if any over - or underestimations occurred during the procedure, errors could be minimised or overcome by taking the average of the two procedures (cf. Figure 4.9, p. 59).

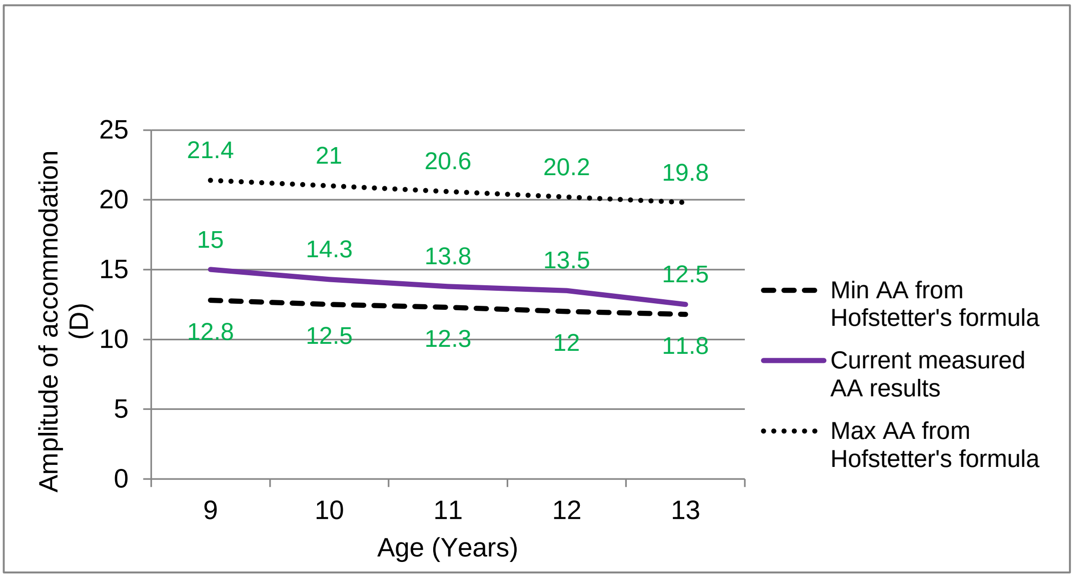


Figure 4.9 The median AA results for the 9 to 13 year old participants, as determined from the calculated average of the PU / PA techniques, reduces with an increasing age. The rate of change of AA between the different age groups is not constant. It may be seen in this figure, that a line of the median AA results is located slightly further from the minimum age expected values if compared to Figure 4.6 (PA results), indicating high values for the average PU / PA results. The opposite is observed if this figure is compared to Figure 4.3 (PU results).

According to the categorical classification, as shown in Figure 4.10 (cf. p. 60), 6.7% to 26.7% of the participants aged 9 to 13 years were classified as **LOW,** and the number compared higher to the results of the PU technique but lower than the PA results. Amongst the 73.3% to 91.1% of participants classified as **NORMAL,** the higher number of participants in this classification was in the age group 10 years as previously seen with the PU results. Only a few participants in age groups 9, 10 and 12 were classified as having a **HIGH** AA.

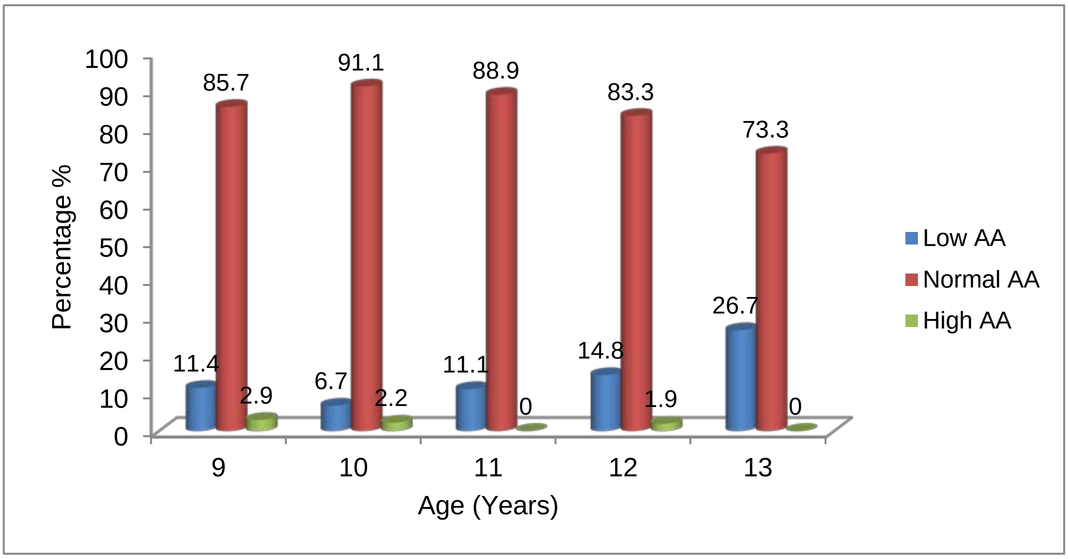


Figure 4.10 The categorical distribution of AA per age group for the average results of the PU / PA techniques. It may be seen in this figure that; the highest percentage of participants was classified as **NORMAL** in age group 10 years.

4.2.4 **The AA results as measured with the Dynamic retinoscopy (DR) technique**

In section 3.6.2.2 (cf. pp. 38 - 39), the procedure of the Dynamic retinoscopy (DR) technique is outlined.

The last technique used to measure the AA of the different groups of participants was the Dynamic Retinoscopy (DR) technique.

The AA median results of the DR technique appeared high for all the age groups as compared to the results of the PU, PA and the average results of the PU / PA techniques. The complete sample of 185 participants showed an interquartile range (25% to 75%) of between 18.3 D and 21.6 D, with a median of 19.7 D. The youngest age group (9 years) still showed a higher median AA of 21.2 D with an interquartile range (25% to 75%) of 19.2 D to 21.8 D, as previously seen with other techniques used in the study. Similarly, the lowest median AA results were still observed in the oldest group (13 years) as 18.3 D. In Table 4.8 (cf. p. 61), the median AA, lower (25%) and upper (75%) quartile AA results of the complete sample of 185 participants according to ages, are presented.

Table 4.8 The distribution of AA results according to age groups for the DR technique. An average of five measurements was used for the data analysis, (n = 185).

Age group	Median AA (D)	Lower Quartile (D) 25%	Upper Quartile (D) 75%
9	21.2	19.2	21.8
10	20.3	19.3	22.2
11	19.6	18.2	21.6
12	19.0	17.7	20.3
13	18.3	17.6	19.3
Total=185	**19.7**	**18.3**	**21.6**

The median results of the current participants aged 9 to 13 years measured from the DR technique gave a similar pattern of reducing with an age increase as shown by the PU, PA and the average results of the PU / PA techniques. In Figure 4.11 (cf. p. 62), a range of AA for the participants aged 9 years is presented as from the minimum 15.5 D to the maximum 23.5 D. These values are very high if compared to the ranges of AA values as measured by other techniques used in the study. In fact, all the AA values measured from the DR technique in this study, are very high if compared with AA values for all the other techniques used. The wider distribution of AA range values (from 14.2 D to 23.8 D) observed in the age group 12 years, was seen in the age group 10 years with the PU technique and in the 11 years age group with the PA and the average PU / PA results. The small distribution of the AA values observed in the oldest age group (13 years) was also seen with the PU, PA and the average PU / PA results, although it is slightly higher with this technique. The participants aged 11 years showed a wider range of AA values between the lower (25%) and upper (75%) quartiles, which is from 18.2 D to 21.6 D. Possible outliers were also identified in each age group included. Furthermore, in age groups 10 and 13 years, these outliers were found both below the minimum AA and above the maximum AA. Figure 4.11 (cf. p. 62), presents the median AA, lower (25%) and upper (75%) quartiles, range of data (minimum and maximum) and outliers in each age group.

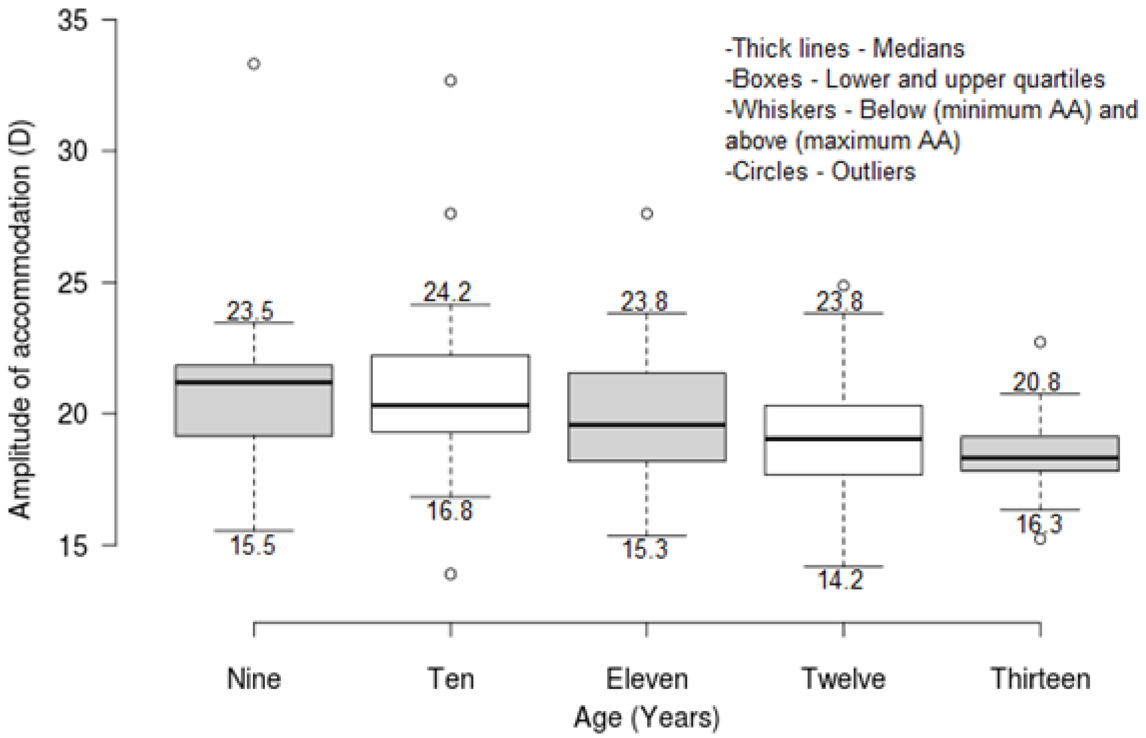


Figure 4.11 Box and whisker plot of the AA for the participants aged 9 to 13 years as measured with the DR. It is clear from this figure that the age group 12 years showed a wider distribution of AA range values, whereas group 11 years showed a wider spread between lower (25%) and upper (75%) quartiles.

The DR findings showed a similar pattern of reducing with an increase in age, from 21.2 D to 18.3 D, for the age group 9 to 13 years, when compared to PU, PA and PU / PA average results. The change in AA median results between the different age groups was also not constant, as seen with other techniques used. Furthermore, the median AA results of the DR technique showed a different pattern to PU, PA and the average results of the PU / PA techniques when compared to the age expected norms calculated from Hofstetter's formulae. As can be seen in Figure 4.12 (cf. p. 63), the current median AA results compared very closely to the maximum age expected norms, which is clearly different to the results of the other techniques used (PU, PA and the average results of PU / PA). These techniques were more comparable to the minimum age expected norms (cf. Figure 4.3, p. 51; Figure 4.6, p. 55; Figure 4.9, p. 59)

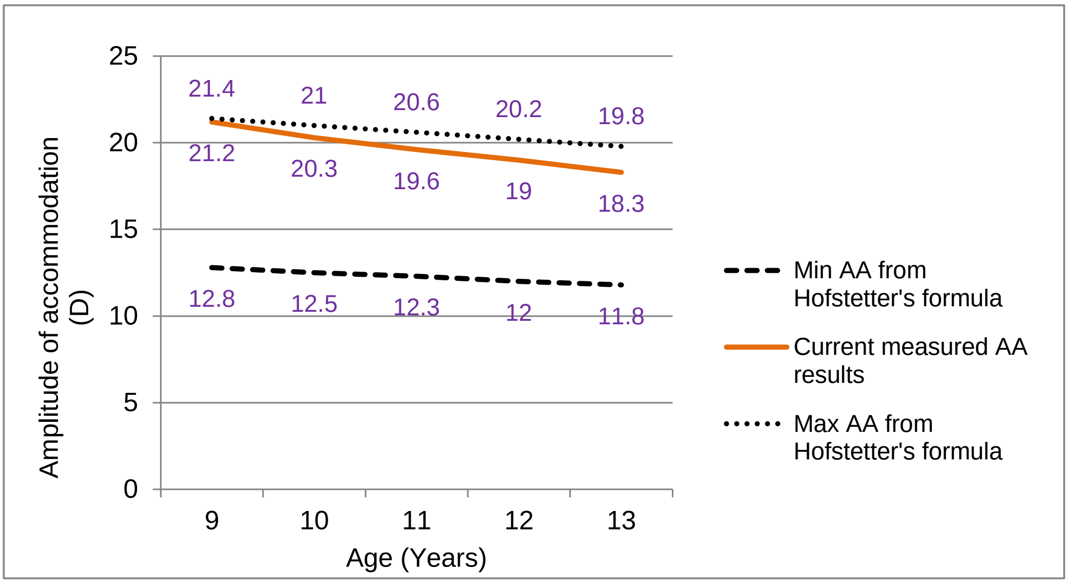


Figure 4.12 In this figure of DR, it may be seen that the median AA results of the participants aged 9 to 13 years are reducing as age is incresing and the change of pattern between the different age groups is not constant. The median results compared very close to the maximum age expected norms rather than the minimum norms.

In Figure 4.13 (cf. p. 64), the categorical classification did not classify any median AA results of any participant measured with DR technique, as **LOW**. This appeared different to other techniques used in the study. Furthermore, the distribution of the participants classified as **NORMAL** for all age groups (55.6% to 86.7%), compared inversely to the **NORMA**L classifications of other techniques such as PU and PA, and also for the average results of the PU / PA measurements. For instance, the number appeared to improve with an increase in age and this was relevant for the age groups 11, 12 and 13 years. With PU, PA and PU / PA average results, the percentage of **NORMAL** classification appeared to reduce with age especially for the age groups stated. Surprisingly, the categorical classification of **HIGH** appeared common in the results of the DR technique, although the percentage of participants showed to reduce with increasing age. This was also found different when compared to the PU, PA and PU / PA average results, as the classification was not made in other age groups such as 11 and 13 years.

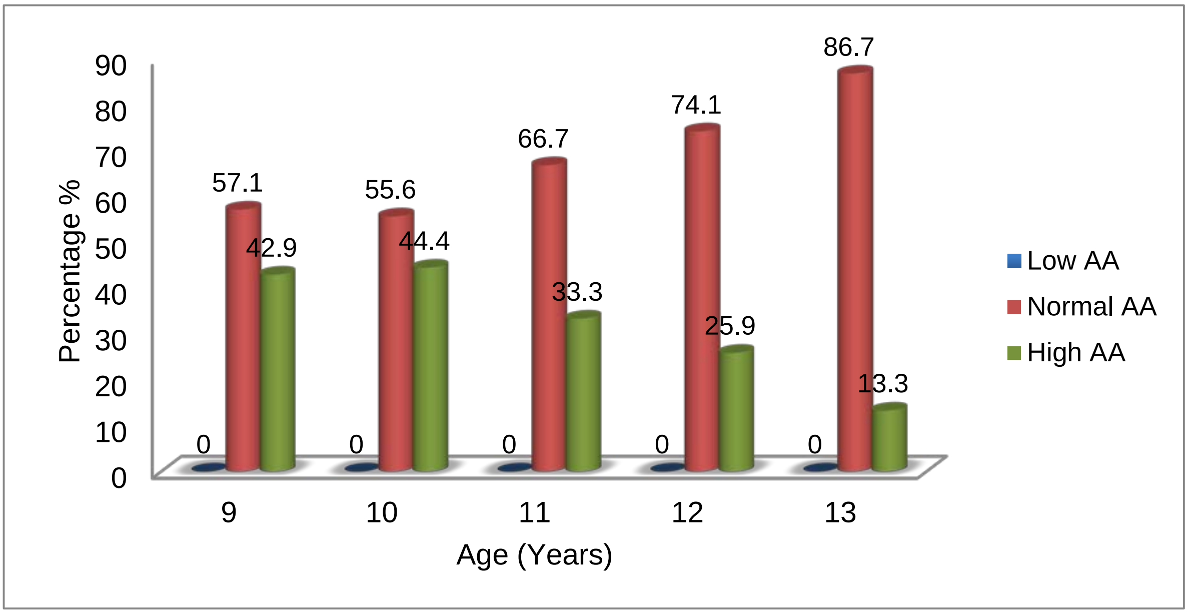


Figure 4.13 The categorical distribution of AA per age group for the DR technique. This figure shows only two classifications (**NORMAL** and **HIGH**). The percentage of participants in the **NORMAL** classification seems proportional to the age (especially for the age groups10 to 13 years) while the participants in the **HIGH** classification seem inversely proportional to the age groups stated.

The data for all three techniques (PU, PA, DR) as well as the average between the PU and PA techniques has been presented. The subjective techniques used were PU and PA, whereas DR was used as an objective technique to measure the AA of the participants. When the AA is compared between different age groups, it is important to consider the confidence intervals to be able to conclude whether these groups were statistically significantly different or not.

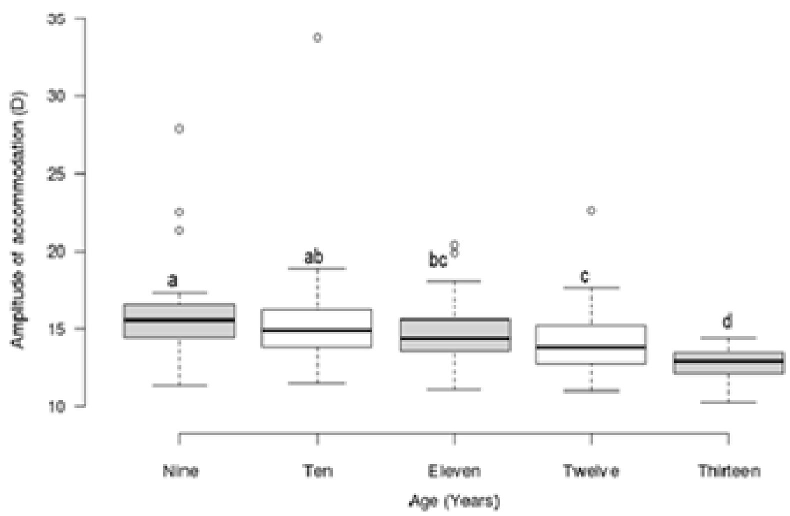
The statistical significant difference confidence interval (CI) data in Table 4.9 (cf. p. 65), will be seen by not including 0 (zero) in the interval and both figures in the interval would be (+) plus or (-) minus (Clarke, 2012). If the interval is + and -, it indicates that the difference is not statistically significant (cf. Table 4.9, p. 65) as a zero is included in this interval. In Figure 4.14 a, b, c and d, the statistical significant difference between the two different age groups compared, is said to be not statistically significant if there are similar alphabets / letters found above both upper whiskers. If alphabets are different, the statistical significant difference exists between the age groups compared.

In Table 4.9 (cf. p. 65) and Figure 4.14 a, b, c and d (cf. pp. 65 - 66), the median AA results for the different age groups were compared to enable interpretation of the results regarding statistical significant differences between the age groups. As can be seen in Table 4.9 and Figure 4.14 a, b, c and d, the results showed that when the AA median results for the subjective (PU and PA), as well as for the average results of the PU / PA techniques and the objective DR techniques, were compared for the following consecutive age groups: 9 and 10 years, 10 and 11 years, 11 and 12 years, no statistically significant differences were found. However, between the age groups, 12 and 13 years, the median difference showed to be statistically significant for both subjective techniques as well as for the average of the techniques, but not for the objective DR technique. Furthermore, when the groups two years or more apart were compared (e.g. 9 - 11 years, 9 - 12 years, 10 - 12 years, 10 - 13 years, etc.) for the PU, PA and the average PU / PA results, it was clear that all the results between these groups were statistically significantly different. This was also true with the DR results for the age groups 9 - 12 years, 9 - 13 years, 10 - 12 years, and 10 - 13 years. Table 4.9 and Figure 4.14 a, b, c and d below, presents the CI results for the different age groups per technique used in the study as well as for the average results of the PU / PA techniques.

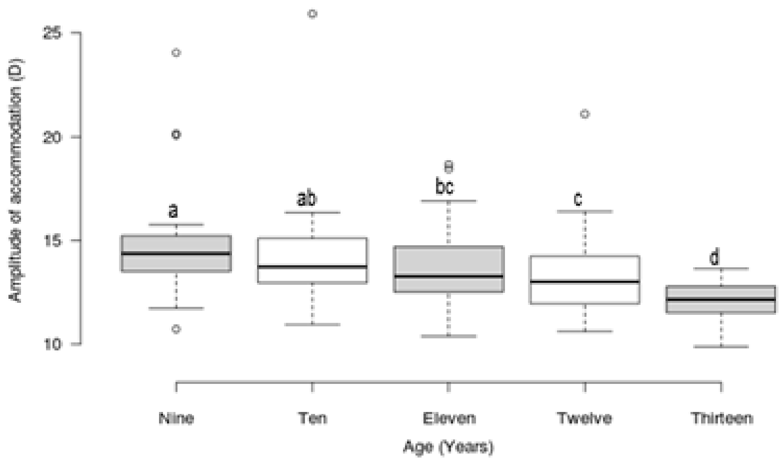
Table 4.9 Comparison of the median AA between age groups for all techniques. Confidence intervals are presented to reveal any statistical significant differences, (n= 185).

Age groups compared	Push-up (PU)	Pull-away (PA)	Average (PU/PA)	Dynamic Retinoscopy (DR)
9-10	[-0.3 ; 1.3]	[-0.4 ; 1.0]	[-0.4 ; 1.2]	[-1.0 ; 0.8]
9-11	[0.1 ; 1.9]*	[0.2 ; 1.6]*	[0.2 ; 1.7]*	[-0.1 ; 1.9]
9-12	[0.8 ; 2.3]*	[0.6 ; 1.9]*	[0.7 ; 2.1]*	[0.6 ; 2.5]*
9-13	[1.9 ; 3.7]*	[1.5 ; 3.1]*	[1.8 ; 3.4]*	[0.9 ; 3.4]*
10-11	[-0.3 ; 1.3]	[-0.2 ; 1.2]	[-0.2 ; 1.2]	[0 ; 1.9]
10-12	[0.4 ; 1.7]*	[0.2 ; 1.5]*	[0.3 ; 1.6]*	[0.7 ; 2.6]*
10-13	[1.4 ; 3.3]*	[1.1 ; 2.8]*	[1.2 ; 3.1]*	[1.0 ; 3.6]*
11-12	[-0.2 ; 1.3]	[-0.3 ; 1.1]	[-0.2 ; 1.2]	[-0.3 ; 1.7]
11-13	[0.8 ; 2.8]*	[0.5 ; 2.3]*	[0.7 ; 2.6]*	[0 ; 2.6]
12-13	[0.3 ; 2.1]*	[0.2 ; 1.9]*	[0.3 ; 1.9]*	[-0.6 ; 1.8]

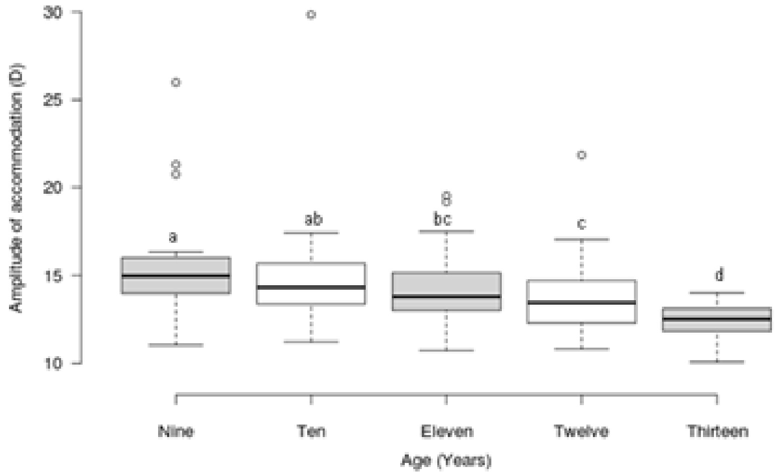
*Statistically significant difference



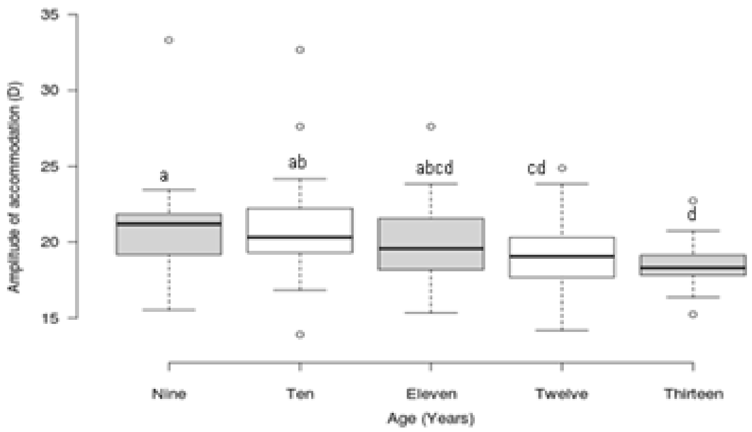
A. PU measurements of AA according to ages



B. PA measurements of AA according to ages



C. PU / PA measurements of AA according to ages



D. DR measurements of AA according to ages

Figures 4.14 Box and whisker plots representing the comparisons of the median AA results for different age groups, to determine the statistically significant difference. The significant difference was determined for each technique used as follows: **A**. for the PU, **B**. for the PA, **C**. for the calculated average results of the PU / PA and **D**. for the DR. The statistical significant difference between the two different age groups compared, is said to be not statistically significant if there is similar alphabets found above both upper whiskers. If alphabets are different, the statistical significant difference exists between the age groups compared.

The different age groups were further compared using the AA results classified as **LOW**, to establish the presence of a significant difference between the numbers of participants with **LOW** AA within the compared age groups. The results in Table 4.10 below, shows that for all age groups compared, the only statistically significant difference was found between the age groups of 10 and 13 years for the PU / PA average results.

Table 4.10 Comparison of the age groups according to **LOW** categorical classification per technique, presented with 95% confidence intervals, (n = 185).

Age groups compared	**Push-up (PU)**	**Pull-away (PA)**	**Average (PU/PA)**	**Dynamic Retinoscopy (DR)**
9-10	[-9.9%; 14.6%]	[-16.5%; 14.3%]	[-8.4%; 19.9%]	[-7.9%; 9.9%]
9-11	[-16.7%; 11.4%]	[-18.8%; 14.0%]	[-15.5%; 16.3%]	[-9.6%; 9.9%]
9-12	[-24.2%; 6.6%]	[-29.2%; 3.0%]	[-17.0%; 12.8%]	[-6.6%; 9.9%]
9-13	[-32.5%; 8.5%]	[-47.8%; 1.3%]	[-41.4%; 6.2%]	[-20.4%; 9.9%]
10-11	[-17.8%; 7.8%]	[-16.9%; 14.5%]	[-19.3%; 8.6%]	[-9.6%; 7.9%]
10-12	[-15.9%; 6.8%]	[-27.4%; 3.6%]	[-20.7%; 5.1%]	[-6.6%; 7.9%]
10-13	[-33.6%; 5.3%]	[-45.9%; 2.2%]	[-45.7%; -0.7%]*	[-20.4%; 7.9%]
11-12	[-12.9%; 13.5%]	[-27.2%; 5.7%]	[-17.3%; 12.2%]	[-6.6%; 9.6%]
11-13	[-30.1%; 11.6%]	[-45.6%; 4.0%]	[-41.7%; 5.7%]	[-20.4%; 9.6%]
12-13	[-29.2%; 10.3%]	[-34.2%; 14.9%]	[-38.1%; 7.8%]	[-20.4%; 6.6%]

*Statistically significant difference

From the investigations of this objective, it may be noted that the numerical data showed that the median results of AA among the participants aged 9 to 13 years reduces with increasing age for all the procedures used. However, the rate of change in AA between the different ages was not constant for any of the techniques used. This is different from the norms predicted by Hofstetter, where his formulae foresee that a constant change is present as the age increases. Statistically significant differences exist between the age groups when the median results of the groups that are more than two years apart were compared, except for the 12 and 13 years age group. Furthermore, the categorical data showed that the only statistically significant difference exist between the age groups 10 and 13 when the different age groups were compared for **LOW** AA. Moreover, the median results for the PU, PA and the average PU / PA results were much closer to the Hofstetter's minimum norms whereas for the DR technique, the medians were closer to the Hofstetter's maximum norms. The AA results will further be compared according to gender among all participants of different age groups.

4.3 **Objective 2: Comparison of the AA measurements in gender of 9 to 13 year old participants**

4.3.1 **The AA results according to gender, for each technique used**

To investigate the AA results according to gender, the complete sample with all age groups was included. For the purpose of investigating possible differences in gender, one subjective and one objective techniques were used for data analysis. The reason for this was that Momeni - Moghaddam *et al*. (2014) encouraged the use of average of the subjective results (PU / PA), as it counteracts the overestimation and underestimation resulting from the PU and PA techniques, respectively. Several authors have reported on AA results according to gender using the AA measurements collected from the PU technique (Hashemi *et al*., 2018; Castagno *et al*., 2017; Ovenseri - Ogbomo *et al*., 2012).

Table 4.11 below shows that the AA results of the female participants aged 9 to 13 years, had a median AA of 13.8 D whereas the male participants showed a median AA of 14.0 D.

Table 4.11 The AA results of the participants (n= 185) according to gender for the PU / PA average results.

Gender	Frequency	Median AA (D)	Lower Quartile (D) 25%	Upper Quartile (D) 75%
Female	103	13.8	12.8	15.1
Male	82	14.0	13.1	15.5

For the DR technique, the results of the female and male participants revealed an equal median AA of 19.7 D as seen in Table 4.12 below. It is interesting to note that the median results for the female and male for the DR was found to be the same.

Table 4.12 The AA results of the participants (n= 185) according to gender for the DR technique.

Gender	Frequency	Median AA (D)	Lower Quartile (D) 25%	Upper Quartile (D) 75%
Female	103	19.7	18.3	21.8
Male	82	19.7	18.3	21.6

There seemed to be thus no difference when the medians of the females and males were compared for both subjective and objective techniques.

4.3.2 **Comparison of the median AA in females and males for both a subjective and objective techniques**

If Table 4.13 below is considered, the results of the median AA are presented for different genders for both objective (DR) and subjective AA (average results of the PU / PA) measuring techniques. It may be noted that, the difference between the median AA for the PU / PA average results and DR technique was 5.8 D in the female and 5.5 D in male participants respectively. No statistically significant difference was found when the median AA between females and males were compared for both the PU / PA average results as well as the DR technique. Confidence Intervals (CI) were not statistically significant because the confidence interval data included 0 (Zero) and the interval is both + and -.

Table 4.13 Comparison of the median AA in female and male participants (n= 185) according to the PU / PA average results and DR technique, as well as the difference in median AA for the two techniques.

Techniques	**Median AA according to Gender**		**95% Confidence Interval for median difference**	
	Female (D)	**Male (D)**		
Average subjective (PU/PA)	13.8	14.0	[-0.7 ; 0.3]	Not Statistically significant
Objective (DR)	19.7	19.7	[-0.4 ; 0.9]	Not Statistically significant
Difference between subjective and objective	-5.8	-5.5	[-0.8 ; 0.3]	Not Statistically significant

There was thus no statistically significant difference between the results of females and males for both subjective (average PU / PA) and objective (DR) AA techniques. A CI would be statistically significant if both "+" or both "-".

4.3.3 **Comparison of gender using categorical classification for each technique used**

For each of the three techniques used (PU, PA, and DR) as well as the PU / PA average results, data is presented according to categorical groups between genders and described by means of percentages. The confidence interval (CI) shows if the difference that exists, was statistically significant or not.

The difference between the median AA in females and males was described by means of 95% confidence intervals for the percentage difference between **LOW**, **NORMAL** and **HIGH** for females and males. This categorical classification of data was described on p. 45. In Table 4.14 (cf. p. 70), it may be seen that, for the PU technique, the percentage of females and males that were found to have an AA within the normal reference values according to Hofstetter's norms, was found to be 91.3% in females and 89.0% in males. For the same technique, a higher number of males showed a tendency of lower AA (11%) whereas only females (3.9%) and no males showed to present with an AA higher than the maximum reference value according to Hofstetter. However, no statistically significant difference was found when the females and males percentages for each category (**LOW**, **NORMAL** or **HIGH**) were compared.

Table 4.14 Comparison of gender for each of the categorical classifications (**LOW, NORMAL** and **HIGH**) for the results of the PU technique, (n= 185).

Gender	**Categorical classification**		
	LOW AA	**NORMAL AA**	**HIGH AA**
Females	4.9%	91.3%	3.9%
Males	11.0%	89.0%	0%
95% CI	[-15.1% ;1.8%] Not statistically significant		

The same analysis was done for the results of the PA technique (cf. Table 4.15), and the results appeared contradictory when compared to that of the PU technique. In this case, the female group (20.4%) showed a higher tendency of **LOW** AA while more males (84.1%) showed to have **NORMAL** AA. However, no statistically significant difference was found with the comparisons of all categories between females and males. Once again, only females showed **HIGH** AA (2.9%).

Table 4.15 Comparison of gender for each of the categorical classifications (**LOW**, **NORMAL** and **HIGH**) for the results of the PA technique, (n= 185).

Gender	**Categorical classification**		
	LOW AA	**NORMAL AA**	**HIGH AA**
Females	20.4%	76.7%	2.9%
Males	15.9%	84.1%	0%
95% CI	[-7.0% ;15.4%] Not statistically significant		

When the calculated results for the average of the PU / PA techniques were considered (cf. Table 4.16, p. 71), it may be seen that similar results to that of the PA technique are presented. More females showed **LOW** AA (13.6%) and more males (89.0%) showed **NORMAL** AA. However, no statistically significant difference was found during the comparisons between females and males for these categories.

Table 4.16 Comparison of gender for each of the categorical classifications (**LOW**, **NORMAL** and **HIGH**) for the calculated results for the average of the PU / PA technique, (n= 185).

Gender	**Categorical classification**		
	LOW AA	**NORMAL AA**	**HIGH AA**
Females	13.6%	83.5%	2.9%
Males	11.0%	89.0%	0%
95% CI	[-7.5%; 12.0%] Not statistically significant		

It is interesting to note that no males presented with a **HIGH** AA in any of the subjective techniques. The complete sample of participants presenting with **HIGH** AA as measured with the subjective techniques consists of females, whereas some males did present with a **HIGH** AA as measured with the objective technique, DR. Furthermore, with DR technique, no females or males showed **LOW** AA as classified according to Hofstetter's norms. The results as stated in Table 4.17 (below) show a high percentage of males (68.3%) presenting with **NORMAL** AA, whereas a high percentage of females (35.9%) presented with a **HIGH** AA. No statistically significant difference was found when gender percentages were compared (cf. Table 4.17).

Table 4.17 Comparison of gender for each of the categorical classifications (**LOW**, **NORMAL** and **HIGH**) for the results of the DR technique, (n= 185).

Gender	**Categorical classification**		
	LOW AA	**NORMAL AA**	**HIGH AA**
Females	-	64.1%	35.9%
Males	-	68.3%	31.7%
95% CI	[-4.5%; 3.6%] Not statistically significant		

The comparison of AA in females and males was determined by the use of numerical and categorical data. Despite the numerical differences that were seen according to gender in the AA measurements of 9 to 13 year old participants, no statistically significant difference was found by comparing the findings of females and males. In the subsequent section, the prevalence results of **LOW** AA are explained per age group.

4.4 **Objective 3: To determine the prevalence of LOW AA at different age intervals in 9 to 13 year old participants**

Amplitude of accommodation (AA) below the minimum expected value for the patient's age was regarded as the primary finding for the diagnosis of accommodative insufficiency

(Scheiman and Wick, 2008). The objective of the current study was to quantify the prevalence of participants with **LOW** AA, not accommodative insufficiency. In order to achieve the set objective, **LOW** AA was classified as the measured average AA results lower than the minimum norm as recommended by Hofstetter. The prevalence of **LOW** AA among 185 participants aged 9 to 13 years are presented for all measuring techniques as well as for the calculated average results of the PU / PA techniques.

In Table 4.18 below, it may be seen that the results of the PU measuring technique are presented. According to the results, 7.6% of the complete sample of all age groups presented with a **LOW** AA, with a CI of [4.6%; 12.3%] which was statistically significant. The prevalence for each age group may be seen in the Table 4.18 and it is clear that the 10 year old age group presented with the lowest prevalence of 4.4% and the oldest group, 13 years of age, presented with the highest prevalence (13.3%). Again, the prevalence appears to increase with increasing age considering the age group 10 to 13.

Table 4.18 The prevalence of **LOW** AA per age group when using the PU technique, (n= 185).

Age group	**Prevalence**	**95% Confidence Interval (CI)**
9	5.7%	[1.6%; 18.6%]*
10	4.4%	[1.2%; 14.8%]*
11	8.3%	[2.9%; 21.8%]*
12	9.3%	[4.0%; 19.9%]*
13	13.3%	[3.7%; 37.9%]*
185 participants	7.6%	[4.6%; 12.3%]*

*Statistically significant

The prevalence of **LOW** AA was thus statistically significant for all age groups.

If the results of the PA technique were considered, (cf. Table 4.19, p. 73), the prevalence of **LOW** AA for the complete sample showed to be 18.4%, with a CI of [13.5%; 24.6%] which was statistically significant. The prevalence rate observed from the PA measurements were comparatively higher than that of the PU, 7.6% (cf. Table 4.18). Furthermore, the prevalence appeared to be lower among the age group 9 years with 11.4% and high in the age group 13 years with a prevalence of 33.3%. A similar pattern of high prevalence of **LOW** AA among the 13 - year - old participants was observed with the PU measurements. The prevalence percentages of **LOW** AA (derived from the PA measurements) appeared to increase with the increasing age from age group 9 to 13 years (cf. Figure 4.15, p. 74). This seems different from the PU and the average PU / PA measurements, as a pattern of increasing prevalence was observed from the age group 10 years. In Table 4.19 below, the prevalence of **LOW** AA for each age group in the study is presented.

Table 4.19 The prevalence of **LOW** AA per age group when using the PA technique, (n= 185).

Age group	Prevalence	95% Confidence Interval (CI)
9	11.4%	[4.5%; 26.0%]*
10	13.3%	[6.3%; 26.2%]*
11	13.9%	[6.1%; 28.7%]*
12	25.9%	[16.1%; 38.9%]*
13	33.3%	[15.2%; 58.3%]*
185 participants	18.4%	[13.5%; 24.6%]*

*Statistically significant

The prevalence of **LOW** AA was thus statistically significant for all age groups.

When the calculated averages of the PU / PA techniques were considered, it may be seen in Table 4.20 that the prevalence of **LOW** AA is 12.4% with a CI of [8.4%; 18.0%] which was statistically significant. These results were higher than the prevalence results of the PU technique and lower than the results of the PA technique. It may be noted that a similar pattern of lower prevalence of **LOW** AA in the age group 10 years (6.7%) and a higher prevalence of **LOW** AA in 13 year age group (26.7%) was observed from the PU measurements (cf. Figure 4.15, p. 74). Again as seen with PU, the prevalence appeared to increase with increasing age considering the age groups 10 to 13 years, whereas with the PA the prevalence appeared to increase from age group 9 years.

Table 4.20 The prevalence of **LOW** AA per age group with the calculated average results of the PU / PA technique, (n= 185).

Age group	Prevalence	95% Confidence Interval (CI)
9	11.4%	[4.5%; 26.0%]*
10	6.7%	[2.3%; 17.9%]*
11	11.1%	[4.4%; 25.3%]*
12	14.8%	[7.7%; 26.6%]*
13	26.7%	[10.9%; 52.0%]*
185 participants	12.4%	[8.4%; 18.0%]*

*Statistically significant

The prevalence of **LOW** AA is thus statistically significant for all age groups.

With the DR technique (cf. Figure 4.15, p. 74), as could also be seen in previous sections of this chapter, there was no prevalence of **LOW** AA (0%; 2.0%).

The differences between the subjective and objective techniques are clearly noted in this data. In all age groups, measured with all subjective techniques including calculated average measurements, the prevalence of **LOW** AA is statistically significant. However, with DR, no **LOW** AA was measured. It is thus evident that DR measures AA higher than the subjective techniques, and comparisons between DR and Hofstetter's norms should be done taking this into account. This issue is further addressed in objective 4.

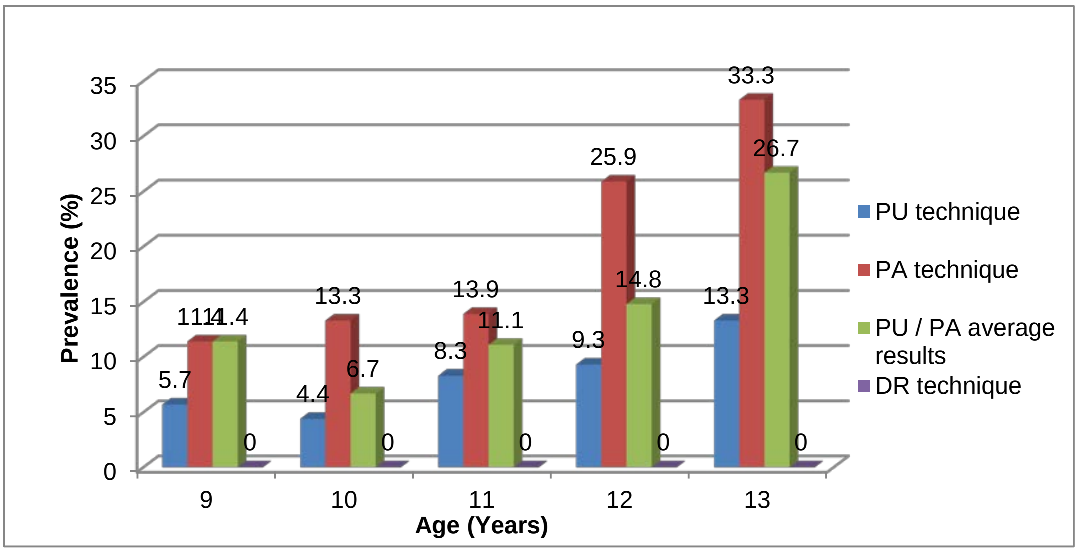


Figure 4.15 The prevalence of **LOW** AA according to age groups per technique used. In this figure, it is clear that the PA technique is showing a high prevalence of **LOW** AA, followed by the PU / PA average results then the PU. It can be seen that the DR did not measure **LOW** AA measurements.

Table 4.21 presents both subjective PU and PA results and the average results of the PU / PA techniques. It is interesting to note that 14 participants (7.6%) were classified as **LOW** by all the subjective (PU and PA) as well as the average results of the PU / PA techniques. However, it is important to note that there are 9 participants who measured **LOW** with PA and the average results of the PU / PA technique but were classified **NORMAL** with PU technique. In addition, 11 participants measured **LOW** with PA but were classified **NORMAL** with PU and average results of the PU / PA technique. Furthermore, it may be noted in Table 4.21 (cf. p. 75) that 147 and 3 participants were also classified **NORMAL** and **HIGH** by the same techniques, respectively. DR technique is not included in the Table 4.21 because it did not measure any AA measurements that were classified as **LOW**. The Table 4.21 (cf. p. 75) presents also the number of participants who were classified differently by the techniques used in the study.

Table 4.21 Comparison of the AA results using participant frequencies and percentages classified categorically **(LOW, NORMAL and HIGH)** per technique PU, PA and PU / PA average results used, (n= 185).

PU	PA	PU / PA average results	Frequencies	Percentage (%)
Low	Low	Low	14	7.6%
Normal	Low	Low	9	4.9%
Normal	Low	Normal	11	6.0%
Normal	Normal	Normal	147	79.5%
High	Normal	Normal	1	0.5%
High	High	High	3	1.6%

From the investigation of this objective, it is clear that the type of technique used to measure AA has an effect on the results of the prevalence of **LOW** AA. The prevalence of **LOW** AA appeares to be high with the PA technique indicating that PA measured lower readings as compared to the other techniques used, followed by the PU / PA average results and lastly the PU technique. For the same sample of participants, the DR technique did not find any prevalence of **LOW** AA. This could possibly indicate that the measurements taken with DR are higher than the measurements taken with the subjective techniques.

4.5 **Objective 4: To compare the subjective and objective AA results of 9 to 13 year old participants**

The data applicable to objective 4 was analysed using both the median results and categorical classification.

4.5.1 **Comparison of the subjective and objective AA results using median results**

The AA results of the objective DR technique were always found to be higher throughout the study as compared to the subjective (PU and PA) techniques used. Furthermore, if the two subjective techniques are compared, it may be seen that the PU results are slightly higher as compared to the PA results. Table 4.22 (cf. p. 76) shows the results of the median AA in 185 participants, distributed according to age groups per technique in diopters.

Table 4.22 The median AA in participants (n= 185) according to age groups per techniques used.

Age group	Subjective techniques			Objective technique
	Push - up (PU) (D)	Pull - away (PA) (D)	Average PU/PA (D)	Dynamic retinoscopy (DR) (D)
9	15.5	14.4	15.0	21.2
10	14.9	13.7	14.3	20.3
11	14.3	13.3	13.8	19.6
12	13.8	13.0	13.5	19.0
13	12.9	12.2	12.5	18.3
Total=185	**Median=14.3**	**Median = 13.4**	**Median= 13.8**	**Median = 19.7**

In Figure 4.16, it may be noted that the subjective techniques (PU and PA, as well as the average results of the PU / PA) showed similar medians, whereas the median for the objective technique, DR, was roughly 5 - 6 D higher for each age group. However, these median results of all the subjective and objective measurements were found within the Hofstetter's minimum and maximum norms.

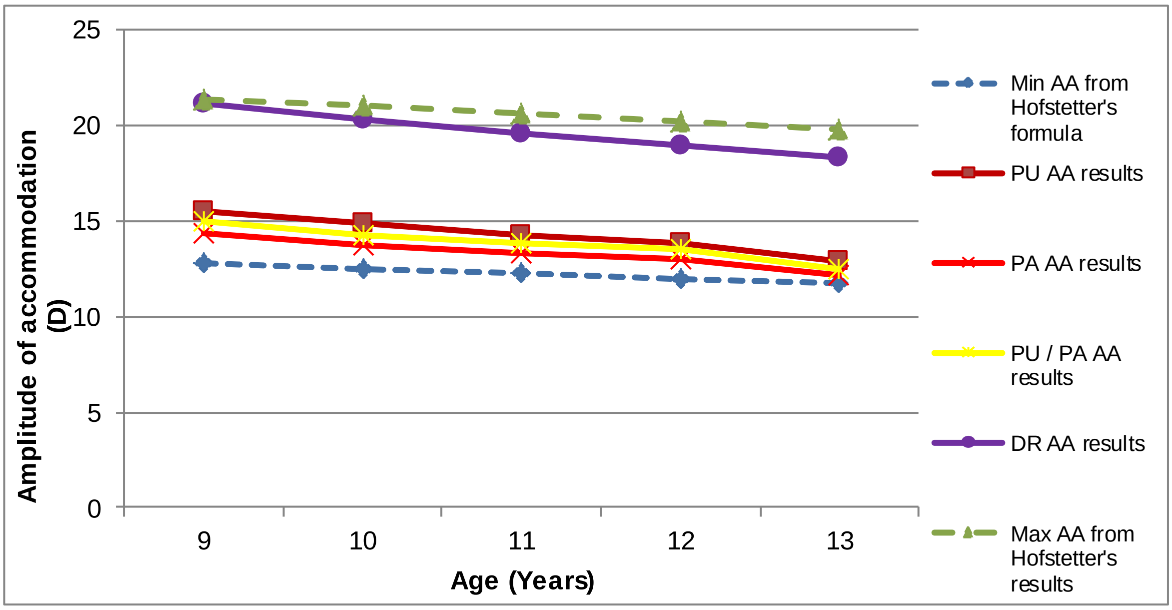


Figure 4.16 The difference in median AA results between the subjective and objective techniques of measuring AA. It may be seen in this figure that the results of the DR are displayed very far from the results of the subjective techniques, indicating high results for the DR technique.

The results as seen in Figure 4.16 are evidenced by the higher median difference found between the DR and subjective techniques as seen in Table 4.22. Once again, Table 4.23 (cf. p. 77) shows the 95% confidence intervals (CI) that indicate statistically significant differences when the median AAs for the subjective and objective techniques are compared. The median results of the subjective in comparison to the objective techniques are thus statistically significantly different. The median differences for the total sample of 185 participants between PU and DR, PA and DR, average PU / PA results and DR were 5.2 D, 6.2 D and 5.7 D, respectively.

Table 4.23 Comparison of median results between subjective and objective techniques, (n= 185).

Techniques	**Median difference**	**95% Confidence Interval for median difference**
Difference between Push-up and objective	5.2 D	(-5.6 ; -4.9)*
Difference between Pull-away and objective	6.2 D	(-6.4 ; -5.9)*
Difference between Average subjective and objective	5.7 D	(-5.9 ; -5.4)*

*Statistically significant difference

It is thus evident that the DR technique measures statistically significant higher AA compared to the subjective PU, PA and average PU / PA results.

4.5.2 **The comparison of the subjective and objective AA results among 185 participants per categorical classification**

4.5.2.1 ***Push - up (PU) and dynamic retinoscopy (DR) techniques***

Table 4.24 shows that the AA measurements of the PU and DR techniques respectively, did not show the same results. Therefore, differences can be seen on the number of participants classified as **LOW, NORMAL** or **HIGH**. For example; 14 participants who showed **LOW** AA with the PU, showed **NORMAL** AA results with the DR technique. The PU and DR coincided on 107 participants who showed **NORMAL** AA and three participants that were found to have a **HIGH** AA. The difference between the PU and DR AA results was found to be statistically significant with the Bhapkar test (cf. 3.8, p. 42) with $p < 0.01$, at a 95% level of confidence.

Table 4.24 The comparison of the individual participant's PU and DR AA results per categorical classification, (n= 185).

PU technique	**DR technique**	
	NORMAL	**HIGH**
LOW	14	0
NORMAL	107	60
HIGH	1	3
Bhapkar test: $p < 0.01$*		

*Statistically significant difference

It is thus evident that the procedure of the DR technique used, measures higher AA compared to the PU technique.

4.5.2.2. ***Pull - away (PA) and dynamic retinoscopy (DR) techniques***

Similar results of the PA and DR techniques are observed as compared to that of the PU and DR techniques. The results of 34 participants showed measurements of **LOW** AA with PA, and with the DR technique, 32 of these participants showed to have a **NORMAL** AA and two presented with a **HIGH** AA. The PA and DR agreed only on 90 participants who showed **NORMAL** AA and three participants that were found to have **HIGH** AA. The Bhapkar test has found the difference between the AA measured with the PA and DR techniques to be statistically significant at a 95% level of confidence, as it can be seen in Table 4.25.

Table 4.25 The comparison of the individual participant's PA and DR AA results per categorical classification, (n= 185).

PA technique	DR technique	
	NORMAL	HIGH
LOW	32	2
NORMAL	90	58
HIGH	0	3
Bhapkar test: $p < 0.01$*		

*Statistically significant difference

It can be seen that the objective measurements of the DR technique, are statistically significantly higher compared to the subjective AA measurements of the PA technique.

4.5.2.3 ***PU / PA average results and DR technique***

In Table 4.26, the calculated results of the average PU / PA techniques present the different results to that of the DR technique as seen with the PU and DR and with the PA and DR techniques. The calculated average results of the PU / PA techniques and DR technique showed the similar results on 99 participants who showed **NORMAL** AA and three participants who showed **HIGH** AA. The difference between the measurement of the AA with the PU / PA average results and DR technique was statistically significant ($p < 0.01$) with the Bhapkar test, at a 95% level of confidence.

Table 4.26 The comparison of the individual participant's PU / PA average results and DR AA results per categorical classification, (n= 185).

PU / PA technique	DR technique	
	NORMAL	HIGH
LOW	23	0
NORMAL	99	60
HIGH	0	3
Bhapkar test: $p < 0.01$*		

*Statistically significant difference

The results of this study have again shown that the procedure of the DR technique used, result in higher AA findings when compared to the measurements of the average results of the PU / PA techniques. The comparison was made between the subjective and objective measurements of the individual participant. Bhapkar test has found the difference between the measurements to be statistically significant. The next section will compare the measurements of the subjective and objective techniques between the participants of the same age group.

4.5.2.4 *The comparison of subjective and objective techniques according to age groups*

Table 4.27 shows the association between the subjective and objective techniques according to age groups. To respond to this objective, two statistical tests namely, Bhapkar and McNemar tests were used to analyse the results. The McNemar test was used for age groups 11 and 13 years as they had matching data between their variables, while the Bhapkar test was used for the age groups 9, 10 and 12 years as they had some data missing (cf. 3.8, p. 42). The results of the Bhapkar test showed statistically significant differences ($p < 0.01$) when the PU, PA and the average results of the PU / PA techniques were compared to the DR (objective) technique for the age groups 9, 10 and 12 years. Similar results of statistical significant difference ($p < 0.01$) were found with McNemar test when the PU, PA and the average results of the PU / PA techniques were compared to DR (objective) technique for the age groups 11 and 13 years.

Table 4.27 Comparison of the subjective and objective techniques within the age groups, (n= 185).

Age groups	PU and DR	PA and DR	Average results of PU / PA and DR	Test used
9	$p < 0.01$*	$p < 0.01$*	$p < 0.01$*	Bhapkar
10	$p < 0.01$*	$p < 0.01$*	$p < 0.01$*	Bhapkar
11	$p < 0.01$*	$p < 0.01$*	$p < 0.01$*	McNemar
12	$p < 0.01$*	$p < 0.01$*	$p < 0.01$*	Bhapkar
13	$p < 0.001$*	$p < 0.0047$*	$p < 0.003$*	McNemar

*Statistically significant difference for all comparisons with DR

During the investigations of this objective, the numerical and categorical data showed that the objective AA results are higher than the subjective results for all the subjective techniques used. The results were found through the comparison made between the measurements of the same individual participant (using the Bhapkar test) and also between the measurements of the participants of the same age group (using both the Bhapkar and McNemar tests). The difference was found to be statistically significant when using both the numerical and categorical data. Therefore, the DR technique was statistically significantly different to all other techniques used in this study and one must take care in comparing these techniques with DR. In the next chapter, the discussion on the results of the current study is presented.

CHAPTER 5: DISCUSSION

5.1 **Introduction**

Vision plays an important role in the learning process of a child. According to a study by Moodley (2008), the accommodative demands required to optimally perform classroom activities are amplitude of accommodation (AA), accommodative facility and accommodative sustainability. Several authors (Moodley, 2008; Metsing and Ferreira, 2012) have encouraged a school vision screening program that include accommodative tests since many visual acuity screening programs have failed to identify other visual problems including accommodative anomalies. The assessment of AA provides a clinical indication of the maximum focusing ability of the eye. These measurements are important for the evaluation and management of the presence of accommodative dysfunction and refractive conditions such as presbyopia and latent hyperopia. To evaluate if the AA of a participant is within the normal range for his / her age, the measured AA readings were compared to the age expected norm values calculated from Hofstetter's formulae (cf. Table 4.1, p. 45). A reduced accommodative amplitude measurement may indicate a pathological condition, use of prescription medication or physiological factors. The current study avoided the stated factors by undertaking a brief case history and performing screening tests as seen in Table 4.3 (cf. p. 47) and Table 4.4 (cf. p. 48), prior to the assessment of AA.

A descriptive, analytical cross - sectional study was conducted to investigate the AA of children, 9 - 13 years of age. Two hundred and ninety-one (291) learners have undergone the screening tests for the inclusion criteria. They were permitted to proceed to the accommodative measurements if (cf. 3.3.3, p. 32) they were within 9 to 13 years, 11 months of age, healthy, had binocular vision (no strabismus or amblyopia), had 6/6 VA in each eye at both 40 cm and 3 m (calibrated for 6 m testing distance), had a reduced VA of less than 6/9 with the + 2.50 D test, near phoria within 0 to 6 exo (as per norms stated by Scheiman and Wick, 2008), no apparent ocular pathology and were able to complete and pass all screening procedures as outlined in 3.6.1 (cf. pp. 34 - 37). As such, only 185 learners met the inclusion criteria to be included in the study and proceeded to the station where the AA was measured.

As indicated in Table 4.2 (cf. p. 46), the sample included 103 female and 82 male learners with a greater participation in the age groups 10 years (24.3%) and 12 years (29.2%). The overall pattern of gender distribution in the current study, female in majority, agrees with that of the Ghanaian children aged 8 to 14 years in a study conducted by Ovenseri - Ogbomo *et al*. (2012). The gender distribution pattern of the current participants and Ghanaian children is also similar between ages 11 and 13 years, although their highest participation was observed in ages 9, 11 and 12 years. This is in contrast to a study by Hashemi *et al*. (2018)

and Moodley (2008) who reported an overall greater participation by males compared to females. Hashemi *et al*. (2018) found greater participation in the age groups 8 and 9 years within participants aged 6 to 12 years as the included ages in his sample. Similar to the current study, Moodley (2008) observed lesser participation by the age group 13 years amongst the participants aged 6 to 13 years. As shown in Figure 4.1 (cf. p. 47), the current participants were attending Grades 3 to 7, with the greatest participation shown by the participants in Grades 4 (25.4%) and 6 (24.9%). The least number of participants were from Grade 3, which was 9.2% (cf. Figure 4.1, p. 47). This could be due to age restriction as only learners of age 9 years were allowed to participate from this grade. The class (Grade 3) was found to include also 8 - year - old learners who were in the majority. The same challenge was found in Grade 7, where it affected the age group 13 years who were found in minority in this grade since most 13 - year - old learners had already progressed to high school (Grade 8).

Three techniques were used for the investigation of AA, namely Push - up (PU), Pull - away (PA) and Dynamic retinoscopy (DR). Five measurements of each technique were taken and the average was used for the data analysis. As indicated in Chapter 4 (cf. p. 44), the participants were divided into five different age groups namely 9, 10, 11, 12 and 13 years, which were also used in the categorical data analysis. The division was done to determine the AA at each age group in order to answer the first objective. Furthermore, the collected results were compared in Table 4.1 (cf. p. 45) according to age groups as discussed in Chapter 4 (cf. p. 45) during the categorical classification.

The current study reports the results of 9 to 13 year old participants of Mankweng circuit, Limpopo. As expected, the AA results of the right and left eye were found to have similar results with no statistically significant difference during a pilot study including 10 participants aged between 9 to 13 years. The participants of the pilot study followed the same inclusion criteria as participants from main study. Therefore, only the right eyes of participants were included in the data analysis. The data of the current study was analysed using non - parametric statistical methods (cf. 3.8, pp. 42 - 43), as the data was found not normally distributed.

5.2 **Objective 1: To compare the AA results for 9 to 13 year old participants**

Although the current AA results appear to reduce with increasing age for all the techniques used, the measurements differed between the different techniques. The difference in findings may affect the clinical interpretation of the amplitude of accommodation (AA) and measurements found may lead to false diagnoses and the implementation of the wrong treatment plan. However, the median AAs of all the measuring techniques (PU, PA, DR as well as the average results of the PU / PA techniques) in the current study, were found within the minimum and maximum norms as stated by Hofstetter.

The PU (cf. 3.6.2.1, pp. 37 - 38) technique is a common, easy and quick method used by clinicians to measure AA on a daily basis in clinical practice. Even though PU has been reported to overestimate AA, most researchers are still using this technique as the AA assessment procedure of choice (Hashemi *et al.,* 2018; Castagno *et al*., 2017; Moodley, 2008). According to the results found in the current study for the PU technique, the median AA of the participants aged 9 to 13 years ranged from 15.5 D at age 9 years to 12.9 D at age 13 years, with a median AA of 14.3 D (Interquartile range: 13.3 D - 15.9 D) (cf. Table 4.5, p. 49). The box and whisker plot (cf. Figure 4.2, p. 50) shows that the median AA between the different age groups reduces with an increasing age. This was also observed on the lower (25%) and upper (75%) quartile values of the AA found in this study. It may be seen in Table 4.5 (cf. p. 49) that the 9 - year - old participants were found to always show a higher AA in the lower (25%) quartile (14.3 D) and upper (75%) quartile (16.8 D) if compared to the older age groups. For instance, older age groups have showed lower (25%) quartile AA as follows: 10 years (13.9 D); 11 years (13.6 D); 12 years (12.7 D) and 13 years (11.9 D) and upper (75%) quartile AA as follows: 10 years (16.2 D); 11 years (15.6 D); 12 years (15.2 D) and lastly 13 years (13.5 D). However, if Figure 4.2 (cf. p. 50) is considered, the same 9 - year - old participants are found to show a smaller distribution of the AA range (from 11.3 D to 17.3 D as 6.0 D) if compared to other age groups except for that of 13 years [10 years: from 11.5 D to 18.9 D (is 7.4 D); 11 years: from 11.1 D to 18.1 D (is 7.0 D); 12 years: from 11.0 D to 17.7 D (is 6.7 D) and 13 years: from 10.3 D to 14.4 D (is 4.1 D)].

The median results of the current study were found to be similar to that of Moodley (2008) especially for the age groups 9, 10, 11 and 12 which differed with the current results by 0.6 D or less per age. However, Moodley (2008) used the mean AA and not the median AA as in the current study. Moodley's (2008) results showed the following: 9 years (15.3 D); 10 years (15.0 D); 11 years (14.9 D) and for 12 years (14.4 D). When the results of the current participants aged 13 years (12.9 D) were compared to that of the 13 - year - old participants in the study of Moodley (2008) (13.8 D), the difference was almost a diopter, despite the small sample sizes of both studies. If the distributions of the AA values are compared between the current study and that of Moodley (2008), it may be seen that the study of Moodley (2008) showed a wider distribution of AA in all age groups. Furthermore, the minimum values were always found lower and the maximum values higher compared to the results of the current study. For example, participants aged 9 years showed a range of 11.3 D (minimum AA) to 17.3 D (maximum AA) whereas Moodley (2008) found a range of 7.5 D (minimum AA) to 20 D (maximum AA). However, three possible outliers in the data set of the current participants aged 9 years were identified. Outliers were seen as AA values above 17.3 D. A study conducted by Metsing and Ferreira (2012) considered only measurements above 20 D as outliers for all the age groups, whereas, in the current study, outliers were regarded as measurements higher than 17.3 D. The outliers found in the age group 9 years were greater compared to that of the other age groups and this may be due to the participants not understanding the instructions of the procedures or not knowing when or what to report as the endpoint (leading to words poor response).

Measurements of the 9 (median= 15.5 D), 10 (median= 14.9 D) and 11 (median= 14.3 D) year old participants in the current study showed to have a higher median if compared to the measurements of the Australian children (Hashemi *et al.,* 2018) of the same age. The results of the Australian children in the study of Hashemi *et al*. (2018), revealed to have a mean AA of 14.51 D (with a median or 50th percentile of 14.3 D) for 9 - year - old participants, 14.13 D (with a median or 50th percentile of 13.7 D) for 10 - year - old participants and 13.95 D (with a median or 50th percentile of 13.3 D) for 11 - year - old participants. Castagno *et al*. (2017) used medians when analysing the measured AA results of school children aged 6 to 16 years. The results of the study by Castagno *et al*. (2017) showed a median AA of 14.3 D (Interquartile range: 13.3 D - 16.7 D) for a complete sample of 867 participants aged 6 to 16 years. However, if the results of this same study by Castagno *et al*. (2017) are compared to that of the current study, the results are similar for 9 to 12 - year - old participants. A median AA of 15.5 D was found for 9 and 10 - year - old participants and a median AA of 14.2 D was found for 11 and 12 - year - old participants. The median AA for the 9 and 10 - year - old participants in the current study was 14.9 D - 15.5 D whereas the median AA for the 11 and 12 - year - old was found to be 13.8 D to 14.3 D (cf. Table 4.5, p. 49). Statistically significant differences between these related studies were not investigated, as this was not the objective of the current study.

If the results of the current study are further compared to the results of other studies, some differences are found. A study by Sterner *et al*. (2004) found both mean and median AA results to be lower compared to that of the current study, which were further found to be lower than that found by Ovenseri - Ogbomo *et al*. (2012) and Wold (1967). Possible explanations for these inconsistencies found between the studies compared, may relate to variables within the measurement protocol such as: PU procedure, tools / equipment used, the accommodative target used and the end - point used for recording. The age range and the differences in sample sizes between studies further complicates comparison and may have further attributed to the measurement differences observed during the comparisons.

The PU procedure requires the movement of an accommodative target towards the participant. This motion reduces target distance, increases the angular size of the retinal image as well as an increase in proximal stimulation to accommodation. Consequently, depth of focus also increases as the target is brought closer. During this process, the circle of confusion will decrease as the pupil diameter is getting smaller. As a result, the ability to perceive and report blur may be delayed in some participants, resulting in higher accommodative amplitudes being measured. The modified PU technique which uses supplementary minus lenses moves the near point of accommodation farther away from the participants, enabling participants to detect the presence of blur earlier. This technique, however, was not used in the current study. Similar to the findings of the study by Ovenseri - Ogbomo *et al*. (2012), the current study did not utilise supplementary lenses nor conduct refraction before the AA assessment. Even though refraction was not conducted during the current study, the minimum habitual 6/6 VA line and VA worse than 6/9 with plus 2.50 D lenses formed part of the inclusion criteria used to rule out possible refractive errors such as myopia or hyperopia.

Uncorrected myopia may elevate the AA and similarly, uncorrected hyperopia may lead to a too low AA being measured. A study conducted by León *et al*. (2016) has found lower AA in hyperopic participants and higher AA in myopes. Therefore, minor refractive errors such as 0.25 D (which León *et al*., 2016 has classified as emmetropic in their study) would not have impacted the measurements of the AA and could not be accounted for measuring false high AA in this study (relative to literature such as study by Sterner *et al*. (2004). In addition, Scheiman and Wick (1994) encouraged the management of significant refractive errors (such as hyperopia ≥ 1.50, myopia ≥ -1.00, astigmatism ≥ -1.00 and anisometropia (1.00 D difference in either the sphere or cylinder between the two eyes)) before resuming with accommodation and vergence assessment techniques. They further indicated that less agreement has been reached about the management of low degrees of refractive errors. It is possible that failure to use supplementary lenses may be suspected as a cause of high AA in the current participants. This was observed from the studies which used distance correction and supplementary lenses and afterwards reported low AA compared to the current results (Sterner *et al*., 2004; Benzoni and Rosenfield, 2012). On the contrary, Wold (1967) reported higher AA results even though he made use of the distance correction and supplementary lenses during the PU (letter target) assessment technique of AA. The latter results further reported that only retinoscopy showed a pattern of AA reducing with increasing age when compared to other techniques performed monocularly (concave sphere, letter target, parallel - thread target and optometer) (Wold, 1967).

The results of the current study conform to the knowledge that AA reduces with an increasing age (cf. Figure 4.2, p. 50 and Figure 4.3, p. 51). However, the rate at which AA changes between different age groups has been found different, to that of Hofstetter. Hofstetter's formulae suggest a constant change of 0.3 D yearly but in this study change is not constant. Furthermore, Hofstetter in his longitudinal study showed the rate of reduction to be slightly greater than 0.4 D per year. The current study has observed a similar rate of change (0.6 D) between age groups 9 and 10 and 10 and 11 years. From ages 11 to 12, the AA reduced by 0.5 D and a great change of 0.9 D was observed between age groups 12 and 13 years. These findings need to be interpreted with caution due to the small sample size found in the age group, 13 years. A similar trend of a small sample size in 13 year participants was observed by Moodley (2008). It should always be kept in mind that Hofstetter used Donders' and Duane's results of AA which were described in terms of mean AA when establishing the three formulae. This may also attribute towards the variation of measurements and the differences found between the norms and clinical findings.

When the current results of PU technique were compared to the age expected norms, the median AA results for all age groups were found to be consistently higher than the minimum age expected norms and lower than the maximum age expected norms (cf. Figure 4.3, p. 51), as calculated from the Hofstetter's formulae. A study conducted by Ovenseri - Ogbomo *et al*. (2012) has found the mean AA of the Ghananian children to be higher than the average and minimum age expected norms as calculated from Hofstetter's formulae. However, these measured mean AA results were lower than the maximum age expected norms. Sterner *et al*. (2004) reported an average difference of 3.60 D for monocular measurements when compared to Hofstetter's age expected (average) norms.

For the analysis of categorical data, the following categories were used: **LOW**, **NORMAL** and **HIGH** (cf. p. 45). **LOW** was classified if the measured average AA of a participant is less than the minimum Hofstetter's value of a relevant age group. **NORMAL** if the measured average AA is greater than the minimum Hofstetter's value but less than the maximum Hofstetter's value of a participant of a relevant age. **HIGH** if the measured average AA of a participant of a certain age is greater than the maximum Hofstetter's value of a relevant age group. While using this categorization, as can be seen in Figure 4.4 (cf. p. 52), the majority (86.7% - 93.3%) of participants in each age group were categorized in the **NORMAL** AA group of between 11.8 D and 21.4 D (normal values) per age group as calculated by Hofstetter's formulae. The age group 9 years showed a high percentage (5.7%) of participants that presented with AA greater than 21.4 D (**HIGH** category) when compared to the age groups 10 (2.2%) and 12 (1.9%) years. This could be due to a poor understanding of the instructions during measurements or may on the other hand confirm the flexibility of the accommodative system in younger participants. This may also explain the higher number of outliers found in the age group 9 years, as can be seen in Figure 4.2 (cf. p. 50), compared to fewer outliers found in age groups 10,11 and 12 years. The participants aged 13 years showed a high percentage of **LOW** AA (13.3%) but again this must be interpreted with caution due to a small sample size found within this age group (cf. Figure 4.4, p. 52). In the subsequent section, the AA results of the same participants aged 9 to 13 years, measured using the pull - away (PA) technique, are presented.

The second technique used to measure AA was the PA technique (cf. 3.6.2.1, pp. 37 - 38). The results for the PA technique yielded slightly lower results compared to that measured by the PU technique (cf. Table 4.5, p. 49 and Figure 4.2, p. 50). The complete sample of the same participants aged 9 to 13 years, showed a median AA result of 13.4 D with an interquartile range of 12.5 D to 14.8 D (cf. Table 4.6, p. 53), when measured with the PA technique, as compared to 14.3 D measured with the PU technique. Similar to the PU technique, the median results between the different age groups included, shows a pattern of reduction from 14.4 D in the younger age group (9 years) to 12.2 D in the older group (13 years) (cf. Figure 4.5, p. 54 and Figure 4.6, p. 55). The current median results measured from the PA technique also conform to the general expectation that AA decreases as you grow older. Just as seen with the PU technique (cf. Table 4.5, p. 49), younger participants showed consistently higher AA values in the lower (25%) and upper (75%) quartiles (9 years: 13.4 D and 15.3 D) as compared to older age groups (cf. Table 4.6, p. 53).

With the PA technique, the target is moved slowly away from the participant until first clarity. The instructions to the participant during the PA technique is easy to understand, and it is also easier to recognize a clear target compared to recognizing first blur, which is expected during the PU technique. However, a participant (especially young participants) may fail to report immediately when the target is clear. As a result, lower AA measurements may be taken. The complete sample showed a range from 9.9 D to 16.9 D (minimum to maximum AA values). As can be seen in Figure 4.2 (cf. p. 50) and Figure 4.5 (cf. p. 54), most of the AA minimum and maximum values observed with the PA technique are lower compared to that observed with the PU technique. This may explain why many more outliers were identified in the PA measurements compared to that found with the PU measurements. Furthermore, these outliers are both below the minimum AA and above the maximum AA values, especially in the age group 9 years (cf. Figure 4.5, p. 54). The distribution of the AA range values observed with PA measurements also compared lower to the distribution of the AA range seen with the PU measurements. Amongst all the participants, the age group 11 years (10.4 D to 16.9) showed a wider distribution of AA range as compared to other age groups. The small sample size found in the age group 13 years could explain the smallest distribution of AA range values found between the 25% and 75% percentiles (cf. Figure 4.5, p. 54), as also seen with the PU measurements.

Even though the current study has found the PA technique to measure lower results compared to the PU technique, these results compared higher to that of León *et al*. (2016) who conducted a study on participants aged 5 to 60 years. The mean results of the age group 5 to 9 years and 10 to 14 years in the study of León *et al*. (2016) were 12.60 D and 12.50 D, respectively. However, in this same study, a -4.00 D trial lens (or supplementary lens power) was added to the distance refractive correction prior to the push - down / PA procedure (called Modified push - down), which was not done in the current study. Koslowe *et al*. (2010) reported roughly similar results (average of 14.06 D) to the current study (median AA= 13.4 D) when considering a similar age group of 7 to 12 years. This could be due to the fact that Koslowe *et al*. (2010) used the traditional PA procedure which did not use the trial lenses to modify the position of the near point. Once again it should be kept in mind that the results by León *et al*. (2016) and Koslowe *et al*. (2010) were reported in terms of mean AA and not medians, as in the current study, and this may have contributed to the slight noted differences.

As seen with the PU technique, the AA results obtained from the PA technique also showed to change at various rates between the different age groups. A great change was observed between the age groups 9 and 10 years, and 12 and 13 years. When the measured PA results were compared to the age expected norms calculated from Hofstetter's formulae, the participants aged 13 years measured a similar AA of 12.2 D to the minimum expected norms (11.8 D), with a difference of 0.4 D (cf. Figure 4.6, p. 55). Other age groups showed a difference of 1.0 D to 1.6 D between the measured results of the PA technique and the minimum expected norms. However, this difference was less compared to the difference found between the measured results of the PU technique and the minimum expected norms, which showed to be between 1.1 D to 2.7 D (cf. Figure 4.3, p. 51).

The results of the PA technique were further described using the categorical classification: **LOW**, **NORMAL** and **HIGH** as described earlier with the PU technique (cf. Figure 4.4, p. 52). In this case, as seen in Figure 4.7 (cf. p. 56), the majority of the participants (66.7% to 86.1%) were classified as **NORMAL**, although the percentage was found lower if compared to the results of the PU technique. Furthermore, many participants (11.4% to 33.3%) were classified as **LOW** and very few (between 1.9% and 2.9%) as **HIGH**. All of these results confirm that the PA technique measures lower AA results compared to the PU technique. According to these results, the classification of the measured results of the participants as **LOW**, **NORMAL** or **HIGH,** depends on the procedure used to measure AA.

A similar trend of the PA technique measuring lower results compared to the PU technique, was observed with other previous studies found in literature (Momeni - Moghaddam *et al*., 2014; Benzoni and Rosenfield, 2012; Koslowe *et al*., 2010). The mean difference between the criterion of ‘clear to first blur’ known as PU and ‘blur to first detection’ known as PA, was 1.40 D which was a statistically significant difference for the monocular amplitude measured (Chen and O’Leary, 1998). León *et al*. (2016) further introduced minus lenses when performing the PA technique (named as modified push - down in their study) to minify the target size. In contrast, Taub and Shallo - Hoffmann (2012) did not find any significant difference between the PU and PA techniques. Despite all the differences reported between the PU and PA, a perfect agreement was found between the two techniques through the intraclass correlation coefficient (Momeni - Moghaddam *et al*., 2014). The use of the average results of the PU / PA was encouraged to counteract the overestimation and underestimation resulting from the PU and PA techniques respectively (Momeni - Moghaddam *et al*., 2014; Benzoni and Rosenfield, 2012). According to Burns *et al*. (2014), the techniques involving the movement of a target are more likely to be influenced by reaction time (source of error) between the patient and the examiner. During the PU procedure, the delay in reaction time may occur when the patient has to detect or register the defined blur. With the PA similar to the push - down procedure, the delay in reaction time may occur during the detection of clarity. This may be affected by the scaling error which equates 1 cm to 1 dioptric change, thus if the examiner keeps on moving the target slightly after clear or blur was reported, this may skew the results.

The combination of the PU and PA techniques when measuring AA is believed to offset the errors that might have occurred during the procedures, making measurements more accurate. As such, the last set of subjective AA results was calculated from the average results of the PU / PA techniques. This method of the AA results generated lower results when compared to the PU results (14.3 D) and higher when compared to the PA results (13.4 D). The complete sample showed a median result of 13.8 D, which is 0.4 D higher compared to the median result with the PA technique and 0.5 D lower compared to the PU median result. Majority of the participants aged 9 to 13 years, presented with AA results of between 12.9 D and 15.4 D as their interquartile ranges (cf. Table 4.7, p. 57). The median AA results of the same participants showed the same pattern of reducing from 15.0 D at a younger age (9 years) to 12.5 D at an older age group of 13 years, as it was seen with both the PU and PA techniques (cf. Figure 4.8, p. 58 and Figure 4.9, p. 59). Once again, the current results generated from the average PU / PA techniques also agree with the understanding that AA reduces as the participant ages. These results include medians, lower (25%) and upper (75%) quartile results of the participants as seen with the PU and PA measurements.

The distribution of the AA range among the complete sample of participants observed with this method of the average results of the PU / PA techniques (10.1 D to 17.5 D), compared lower to that of the PU measurements (10.3 D to 18.9 D) and higher to that of the PA measurements (9.9 D to 16.9 D). A wider distribution of AA values was seen in the age group 11 years as seen with the PA measurements. Measurements of the age group 13 years, showed a smaller distribution of AA values as compared to other age groups (cf. Figure 4.8, p. 58). The results of the current method of using the average PU / PA measurements were found to be a good average of the results of both the PU and PA techniques as compared to PU and PA individual results.

A limitation is noted that complicates comparison between previously done studies to that of the current study. A previous study done by Benzoni and Rosenfield (2012) used the results of the average subjective techniques (PU / PA) and the means for data analysis whereas the current study used the same average results of the subjective techniques (PU / PA) but medians for data analysis. The median AA of 9 - year - old (15.0 D) and 10 - year - old (14.3 D) participants of the current study, were higher compared to that of the study done by Benzoni and Rosenfield (2012) who found means of 12.3 D and 12.4 D for these age groups respectively. The median difference observed on the measurements of the younger participants (e.g. age group 9 years) may be attributed to the inability of the participants to understand the exact meaning of the end - point ‘first sustained blur’. Other reasons for the difference between the current study and the study of Benzoni and Rosenfield (2012), could be due to the difference in the procedure for the PU technique and that the AA measurements in the study of Benzoni and Rosenfield (2012) were described by means and not medians. The Benzoni and Rosenfield study (2012) further introduced auxiliary or supplementary minus lenses (-5.00 D) during the PU procedure to move the near point further away from the participants. This may account for them finding lower AA possibly related to minification of the target making it difficult to detect. In addition, the same study did not include the profile of refractive errors of the participants. According to various authors who studied the relation of AA and refractive error, a lower AA was found in hyperopes as compared to myopes and emmetropes (McBrien and Millodot, 1986; Maheshwari *et al*., 2011; León *et al*. 2016).

When considering the AA values generated from the average PU / PA technique, the outliers identified were similar to that of the PU technique and were considered as AA values above 17.5 D (cf. Figure 4.8, p. 58). Similarly, as seen before with the PU and PA techniques, the

AA shows a pattern of changing medians with different intervals between the different age groups, with a bigger change observed between the age groups 9 and 10 years and 12 and 13 years (cf. Figure 4.9, p. 59). The results of the average PU / PA techniques were also compared to Hofstetter's norms (cf. Figure 4.9, p. 59). A difference of between 0.7 D to 2.2 D is noted between the current results determined from the average PU / PA techniques and the norm values determined from the minimum Hofstetter's formula. This difference is lower compared to the PU results (1.1 D to 2.7 D, cf. Figure 4.3, p. 51) and higher compared to the PA results (0.4 D - 1.6 D, cf. Figure 4.6, p. 55). Similarly, age group 13 years showed a smaller difference of 0.7 D between the average PU / PA technique result and Hofstetter's minimum, although this was higher for PA (which is 0.4 D, cf. Figure 4.6, p. 55) and lower for PU (which is 1.1 D, cf. Figure 4.3, p. 51) compared to other age groups which showed a difference of more than 1.5 D.

When the categorical classifications for **LOW**, **NORMAL** and **HIGH** were considered as seen in Figure 4.10 (cf. p. 60), the majority of the participants (73.3% to 91.1%) were still categorized as **NORMAL**. The current method classified more participants as **NORMAL** compared to the PA technique (cf. Figure 4.7, p. 56) but fewer participants compared to the PU technique (cf. Figure 4.4, p. 52). Furthermore, the same average results of the PU / PA technique considered fewer participants to have a **LOW** AA (6.7% - 26.7%) when compared to 11.4% - 33.3% for the PA technique (cf. Figure 4.7, p. 56) but more participants when compared to 4.4% - 13.3% for the PU technique (cf. Figure 4.4, p. 52). Varied results of AA have been reported on the same participants when using different techniques. Subjective techniques such as PU and PA depend on the participants for the response; and therefore, the quality of the results may not be consistent between different techniques.

The last technique for measuring AA involved an objective measurement of AA, evaluated by means of Dynamic Retinoscopy (DR) (cf. 3.6.2.2, p. 38 - 39). This technique yielded higher AA results when compared to all the subjective techniques investigated in this study. The complete sample showed a median AA result of 19.7 D (cf. Table 4.8, p. 61) which is roughly 5.4 D higher compared to the PU results (cf. Table 4.5, p. 49), roughly 6.3 D higher compared to the PA results (cf. Table 4.6, p. 53) and roughly 5.9 D higher compared to the average PU / PA results (cf. Table 4.7, p. 57). The majority of participants presented with AA results of between 18.3 D and 21.6 D (interquartile (25% - 75%) ranges, as indicated in Table 4.8, p. 61). The median AA found with this technique between the different age groups reduced from 21.2 D to 18.3 D in 9 to 13 year old participants (c.f. Figure 4.11, p. 62 and Figure 4.12, p. 63). The decreasing pattern was similar to that observed with the results of the PU, PA and the average results of the PU / PA techniques. The current results confirmed that even with the objective results of the DR technique, AA decreased with an increase in age.

The median results of the current study compared higher to the findings of Rutstein *et al*. (1993) and Wold (1967) who used a similar end - point for the DR technique as was done in this current study. Both studies of Rutstein *et al*. (1993) and Wold (1967) were comparing the subjective and objective results of the same participants. The study of Rutstein *et al*. (1993) found an average difference of 2.7 D higher for objective results (DR) compared to subjective results (PU). Wold (1967) initially found the subjective results (18.4 D) to be higher compared to the objective results (16.0 D). However, after considering the effects of depth of focus and excluding it by subtracting one half of the calculated depth of focus from the actual measured AA, the results of the DR technique in most of participants were higher compared to that of the subjective technique. The variation in the set - up of the DR procedure e.g. room illumination, target, etc. could have attributed to the difference in measurements of AA, both in the current study and the studies of Rutstein *et al*. (1993) and Wold (1967).

Just as seen with the PU, PA and average PU / PA results, the current results of the DR technique also changed unequally between the different age groups, with a greater difference observed between the age groups 9 and 10 years (cf. Figure 4.12, p. 63). When these results were compared to Hofstetter's norms, the measured results from the DR technique were much higher than the minimum norms and slightly below the maximum norms (cf. Figure 4.12, p. 63). These results were easily comparable to the maximum values, and not to the minimum values, as was done with the subjective techniques PU and PA as well as with the average results of the PU / PA techniques. The difference noted between the measured results and the maximum norms was between 0.2 D to 1.5 D, with the greatest variation observed in the age group 13 years. The participants aged 9 years measured almost similar results to the maximum norms. The difference between the measured results and the maximum norms as calculated by Hofstetter, increased as the age increased. The noted difference that an increase with age could mean that the level of understanding instructions, patience and cooperation may be improving with maturity. Again, when the categorical classifications were considered (cf. Figure 4.13, p. 64), the results were different from that of the other techniques used in the study. In this case, no participants were found to have **LOW** AA (cf. Figure 4.13, p. 64). The number of participants classified with **NORMAL** AA increased with age, as the number of participants with **HIGH** AA classification reduced. Despite the sample size found in the age group 13 years, the results showed to include 86.7% of participants with **NORMAL** AA and 13.3% with a **HIGH** AA. These results could possibly be due to improved understanding of the instructions by the participants and that accommodation in this case was fully effective and the testing procedures were possibly more accurate.

The AA results measured by the various techniques used in this study, show linear reduction between the ages of 9 to 13 years. However, the rate of change between the different ages was not constant (cf. Figure 4.3, p. 51; Figure 4.6, p. 55; Figure 4.9, p. 59 and Figure 4.12, p. 63). Hofstetter's formula, however, estimates the change in AA between ages to be a constant change, different to the findings of this study and others (Benzoni and Rosenfield, 2012; León *et al*., 2016). The overall change in AA between the current studied age groups was 2.50 D with PU / PA average results, 2.60 D with PU, 2.20 D with PA, and 2.90 D with DR techniques. Hashemi *et al*. (2018) observed a similar linear reduction in AA as participants become older; however, the overall change in AA between age groups in their study was about 1.00 D, thus; 1.50 D less than that found in the current study. Even though AA was found to decrease statistically significantly with age in this study of Hashemi *et al*. (2018), authors found a 1.00 D AA variation not clinically reasonable due to the instability of AA in children and is thus in agreement with others who found no significant change in children (Sterner *et al*., 2004). Castagno *et al*. (2017) again observed a variability of about 4.00 D between the 25th and 75th percentiles in the age groups 9 to 12 years with a peak in AA at the age of 10 years. The same age group (10 years) in the current study, showed a higher number of participants with **NORMAL** AA as seen in Figure 4.4 (cf. p. 52) and Figure 4.10 (cf. p. 60), when the PU technique and PU / PA average results are considered.

The linear pattern found in the current study was confirmed by the statistically significant difference that existed between the different age groups when the younger age groups were compared to the older age groups in most of the techniques used in the study (cf. Table 4.9, p. 65; Figure 4.14 a, p. 65 and Figure 4.14 b, c, and d, p. 66). For instance, age groups 9 - 11 years [0.1; 1.9] for PU, [0.2; 1.6] for PA, [0.2; 1.7] for average PU / PA and for age groups 9 - 12 years [0.8; 2.3] for PU, [0.6; 1.9] for PA, [0.7; 2.1] for average PU / PA and [0.6; 2.5] for DR (cf. Table 4.9, p. 65; Figure 4.14 a, p. 65 and Figure 4.14 b, c, and d, p. 66). Despite the numerical differences that were observed during the comparison of consecutive age groups (e.g. 9 - 10 years, 10 - 11 years, etc.) for the measurements of PU, PA and PU / PA average results, the current study did not find any statistically significant differences between consecutive age group comparisons except for the comparison between age group 12 and 13 years. If the statistically significant results of the consecutive age groups were to be considered separately, this could possibly indicate that the change in AA between age groups 9 to 12 years is too small to be statistically significant as is suggested by other literature (León *et al*., 2016). However, the comparisons of younger age groups to older age groups have revealed an interesting point in relation to AA as a function of age, as it was also stated by Duane (1908) that accommodation does not change year after year. In contrast to the current study, Sterner *et al*. (2004) has found no correlation between the AA and age, and as a result, a flat pattern which indicates no relationship between AA and age was observed. Sterner *et al*. (2004) included 72 Swedish school children aged 6 to 10 years in their study. The difference found in the age range and sample size between the current study and that of the Swedish children, could explain the difference between the two studies.

The participants aged 12 years showed a median difference of roughly 1.0 D when compared to 13 - year - old participants for the PU and PA techniques and the PU / PA average results (cf. Table 4.5, p. 49; Table 4.6, p. 53 and Table 4.7, p. 57). This difference was found to be statistically significant as seen in Table 4.9 (cf. p. 65), and its impact became significant when comparing the participants of different age groups using the categorical classification. This impact reflected on the 13 - year - old group by continually showing fewer participants with **NORMAL** AA and indirectly confirming the increase in number of participants with reduced or **LOW** AA for the following techniques: PU, PA and PU / PA average results as seen in Figure 4.4 (cf. p. 52); Figure 4.7 (cf. p. 56) and Figure 4.10 (cf. p. 60). Again, the impact was further noted during the comparisons of the participants with **LOW** AA (cf. Table 4.10, p. 67), in which a statistically significant difference existed between the age group 10 and 13 years for the PU / PA average measurements. The fact that this age group (13 years) had a smaller sample size as compared to other age groups with bigger sample sizes, it could possibly be an attributing factor to the median difference. Furthermore, Moodley (2008) experienced the same challenge with a small sample size in the same age group during the conduction of study.

Comparison of the categorical classifications described in Chapter 4 (cf. p. 45), for the complete sample of the participants aged 9 to 13 years (cf. Figure 4.4, p. 52; Figure 4.7, p. 56 and Figure 4.10, p. 60), showed a decrease in number of participants with **NORMAL** AA as the number of **LOW** AA increased with increasing age. This reduction of participants is more visible and obvious in the age group 13 years especially for the PA technique (cf. Figure 4.7, p. 56). This also agrees with literature (Benzoni and Rosenfield, 2012; Momeni - Moghaddam *et al*., 2014) reporting that the PA technique measures a lower AA compared to the PU technique in general. The same measurements for the PU, PA and PU / PA average results used for categorical classification were compared graphically to Hofstetter's minimum and maximum age expected norms as seen in Figure 4.3 (cf. p. 51); Figure 4.6 (cf. p. 55) and Figure 4.9 (cf. p. 59). Amongst those Figures, a figure for the PA technique measurements (cf. Figure 4.6, p. 55) appeared very close to the minimum age expected norms if compared to other techniques (PU and PU / PA average results) and more especially the age group 13 years, which measured almost the same value as the minimum age expected norm according to Hofstetter.

The objective measurements (DR) of AA in the study of León *et al*. (2016), found the AA to be stable between age groups 5 to 19 years. The current study has measured AA objectively using the DR technique (cf. 3.6.2.2, p. 38 - 39) and the measurements showed no significant differences in the AA between the consecutive age groups such as 9 and 10 years [-1.0; 0.8], 10 and 11 years [0 ;1.9], etc. When different age groups of two years or more apart were compared, the difference became statistically significant, e.g. 9 and 12 years [0.6; 2.5], 9 and 13 years [0.9; 3.4] or 10 and 12 years [0.7; 2.6] (cf. Table 4.9, p. 65). According to objective results of the DR technique, a change in AA between the age groups 9 to 11 years and 11 to 13 years is too small to be statistically significant. These results are somewhat in agreement with the study of León *et al*. (2016) who reported no statistically significant change in the AA of children (5 - 19 years).

A possible contribution to the reduced AA in older children may include that, as children progress in school, the classroom work requiring visual demands increases and this may result in a stressed accommodative system. A study by Ikaunieks *et al*. (2017) suggested that intensive close work may affect the accommodative system of children. In this study, AA was measured before and after lessons on the same participants aged 7 to 15 years, with the aim of establishing if a change in AA during the day is similar between different age groups. During this study, participants were not asked about activities they were engaged in before measurements were taken. The results of this study showed that, AA measured after lessons, were found to be statistically significantly lower compared to the AA measured before lessons, although the amount of decrease was found to be similar for all age groups included (~0.70 D). These results may indicate that older participants were less busy with their school work before the assessment of AA compared to younger participants, hence the similar change in AA. These results are in contrast to the findings of Castagno *et al*. (2017) who found in their research study that there was no statistically significant difference in the AA median with regard to time of day measurements (morning vs. afternoon). This study used a similar measuring technique, PU, to the study of Ikaunieks *et al*. (2017).

In this current study, auxiliary lenses were not used during measurements, which may have contributed to possible outliers with very high AA measurements (cf. Figure 4.2, p. 50; Figure 4.5, p. 54; Figure 4.8, p. 58 and Figure 4.11, p. 62). According to Castagno *et al*. (2017), the use of medians and percentiles when investigating AA by age, aids to evade the effect of outliers. However, in the current study medians and quartiles were used to describe the relationship between AA and age of the participants. Furthermore, the use of box and whisker plots helped to display the identified outliers in each technique used. The measurements by the PU technique and the average results of the PU / PA techniques, showed 7 outliers as can be seen in Figure 4.2, (cf. p. 50) and Figure 4.8 (cf. p. 58). In both measurements, more outliers were reported in the age group 9 years and were found in the measurements above the maximum AA values. With the PA technique, which was reported to measure lower readings of AA, the measurements showed 8 outliers (cf. Figure 4.5, p. 54), similar to the DR measurements (Figure 4.11, p. 62). However, the DR measurements showed outliers identified in each age group including the age group 13 years whereas with the PA technique, outliers were identified in the age groups 9 to 12 years excluding 13 years just as was seen with the PU and the average results of the PU / PA techniques. Outliers in the measurements of the PA and DR techniques were identified on measurements above the maximum AA and below the minimum AA. Metsing and Ferreira (2012) also did not use auxiliary lenses in their study, and as a result, outliers of measurements above 20 D were observed. The authors of this study did not elaborate more on the number of outliers and the age groups that were affected by these outliers.

When comparing participants according to the categorical classification between the different age groups, it may be noted that the number of participants with **HIGH** AA appeared to reduce with an increase in age when the age groups 9, 10 and 12 years are considered for the PU (cf. Figure 4.4, p. 52), PA (cf. Figure 4.7, p. 56) and PU / PA average results (cf. Figure 4.10, p. 60). The same can be noted in the results of the DR technique (cf. Figure 4.13, p. 64) where the decline in the percentages of **HIGH** AA was found from age group 10 years (44.4%) to 13 years (13.3%). It is further interesting to note that only female participants showed **HIGH** AA for all the subjective techniques: PU (cf. Table 4.14, p. 70), PA (cf. Table 4.15, p. 70) and the PU / PA average results (cf. Table 4.16, p. 71) and for DR, the percentage of females was still higher compared to that of the male participants (cf. Table 4.17, p. 71). If Figure 4.13 (cf. p. 64) is considered, it may be noted that for the results of the DR technique, the number of participants presenting with **NORMAL** AA appeared to increase with age from 55.6% in the age group 10 years to 86.7% in the 13 years' age group. A possible explanation for this could be that participants from the older age groups may have had a better understanding of instructions and may have cooperated better. Therefore, more reliable and accurate responses could possibly contribute to the higher percentage of participants with a **NORMAL** AA.

From the results presented above, it is clear that the various AA assessment techniques employed in this study, yielded different measurements on the same samples of participants. Wold (1967) conducted a study where he offered possible explanations for this phenomenon of different measurements on the same participants, depending on the technique used. He also touched on the possibility of the effect of depth of focus, but this could probably not account for all the differences found. Wold (1967) used five techniques in 125 pupils. Some of the techniques used by Wold (1967), were similar to that used in the current study. The PU technique was found to give high AA results, whereas the concave sphere technique resulted in lower AA measurements. The high measurements, even when auxiliary minus lenses were used, forced the author to consider the effect of depth of focus. However, measurements remained high even after the effect of depth of focus was excluded. Wold (1967) then considered other possible factors that cannot be predicted and that is not reliant on the individual or the technique used. The factors included the time of examination (day to day or hour to hour variation), error of measurements per technique that may have resulted from fatigue or a physiological condition of the participant, willingness of the participant to exert the required maximal effort per technique, the maturity of the participants and the alteration of the endpoint which may be due to misunderstanding. Factors such as illumination and pupil size may also affect the measurements of AA (Lara *et al*., 2014).

The measurements of the AA of participants in the current study showed that, AA reduces with an increase in age, despite the type of technique used.

5.3 **Objective 2: Comparison of the AA measurements in gender of 9 to 13 year old participants**

The second objective of the study was to compare the AA measurements according to gender within the complete sample of 9 to 13 year old participants. The numerical data of the PU / PA average results and DR technique, together with the categorical data of the PU, PA, PU / PA average results and DR were used to address this objective. Only the numerical data of the PU / PA average results (excluding the PU and PA techniques) was used, as the averaged results counteract the overestimation and underestimation of results incurred from the individual PU and PA techniques (Momeni - Moghaddam *et al*., 2014). Available literature investigating the relationship between AA and gender utilised the PU technique as a method of choice to assess AA (Hashemi *et al.,* 2018*;* Castagno *et al*., 2017 and Ovenseri - Ogbomo *et al*., 2012). Therefore, the current study decided to use the measurements calculated from the average results of the PU / PA techniques, to assess the distribution of AA in female and male participants of a given age.

The median AA for the female and male participants as determined with PU / PA average results was 13.8 D and 14.0 D respectively (cf. Table 4.11, p. 68). The median objective results determined with DR were 19.7 D for both females and males (cf. Table 4.12, p. 68). As expected, the gender difference was found to be not statistically significant when determined through the numerical data using median results (cf. Table 4.13, p. 69) and categorical data for both PU / PA average results (cf. Table 4.16, p. 71) and objective DR techniques (cf. Table 4.17, p. 71). Furthermore, the categorical data for the results of the PU (cf. Table 4.14, p. 70) and PA (cf. Table 4.15, p. 70) techniques, reported similar results of no statistically significant difference, to that of the PU / PA average results and DR technique. The results of this study agree with that of Hashemi *et al*. (2018) and Castagno *et al*. (2017). However, the current results are in contrast to the results of Ovenseri - Ogbomo *et al*. (2012) whom found statistically significant differences (p = 0.001) between 16.44 D and 17.49 D AA for females and males aged 8 to 14 years old, respectively. This indicates that the AA within female participants in the study of Ovenseri - Ogbomo *et al*. (2012) was significantly lower than that of male participants. Castagno *et al*. (2017) have found the median AA of female participants to be 14.3 D, lower compared to the 14.8 D median AA found in male participants. However, this difference in the study of Castagno *et al*. (2017) was not statistically significant.

Similarly, the female participants in this study showed lower AA compared to male participants, when the numerical data for the PU / PA average results (cf. Table 4.11, p. 68 and Table 4.13, p. 69) are considered. However, the same female and male participants were found to have equal AA when measured with the DR technique. It is interesting to note that the numerical differences that exist between the median AA of the female and male participants when using PU / PA average results were not statistically significant (cf. Table 4.13, p. 69). When considering the categorical classification for the PU results (cf. Table 4.14, p. 70), a higher percentage of female participants (91.3%) were found to have **NORMAL** AA compared to males (89.0%) and very few participants (4.9%) showed a tendency of **LOW** AA compared to male participants (11.0%). For all the subjective techniques used: PU and PA, and also the PU / PA average results, only female participants showed **HIGH** AA exceeding the maximum expected norm for the participant's age, noting that no male participants showed a **HIGH** AA. This was in contrast to the results of Marran *et al*. (2006) who used the PU technique and found that a greater number of female participants (78.6%) were classified as **LOW** AA (by dominating in the accommodative insufficiency group) whereas the current study classified a greater number of males (11%) with **LOW** AA. However, these results were not found to be statistically significant.

Different results were found when the categorical classification of PA (cf. Table 4.15, p. 70) and PU / PA average results (cf. Table 4.16, p. 71) are considered. A greater percentage of male participants (84.2%) showed a tendency of **NORMAL** AA with only a few male participants (15.9%) presenting with **LOW** AA (cf. Table 4.15, p. 70). In this case, a high percentage of female participants (20.4%) were found to have a **LOW** AA. However, the difference between the male and female AA was not statistically significant. The categorical classification results for the DR (cf. Table 4.17, p. 71) also showed different results. In this case, no male or female participants were found to have **LOW** AA as classified according to Hofstetter's norms. However, both male and female participants were found to have **HIGH** AA, although female participants were found to present more with a **HIGH** AA (35.9%) as compared to the males (31.7%). This was different from the results of the PU, PA and PU / PA average results which showed only female participants to have a **HIGH** AA. From the results of this study, no statistically significant difference was found in the AA of gender participants of the complete sample aged 9 to 13 years old. However, female participants showed a trend of **HIGH** AA in all the techniques used. Again, a greater percentage of male participants appeared with **NORMAL** AA, except for the PU technique. At the same time, a high percentage of female participants (20.4% and 13.6%) showed a tendency of **LOW** AA with the PA technique and PU / PA average results, respectively. As the result, there was no statistically significant difference between the AA in males and females.

The numerical and categorical data of AA showed no statistically significant difference for the female and male participants in the current study.

5.4 **Objective 3: To determine the prevalence of LOW AA at different age intervals in 9 to 13 year old participants**

The mechanism of accommodation enables us to change focus from far away to near and still maintain clear vision. Children require sufficient maximum accommodation to perform their classroom chores i.e. writing and reading with ease, as Sterner *et al*. (2006) has found insufficient AA to be associated with subjective symptoms among school children doing near work. Amplitude of accommodation (AA) refers to the maximum increase in dioptric power that the crystalline lens can achieve in changing focus from distance to near objects. The measurements of this parameter give an indication of the maximum refractive strength the accommodative system can exert in supplying for the near point demands. The AA is regarded as sufficient or normal if it permits sustainable clear vision on near objects in an individual of a specific age. Three formulae derived by Hofstetter are still used as reference in classifying the AA status of an individual. If a young individual experiences blurry vision on near objects after changing focus from distance to near, this may be an indication of **LOW** AA. With regard to Hofstetter's formula, the measurements of the AA are considered abnormal if they are found to be 2 diopter or more below the minimum age expected norms (Scheiman and Wick, 1994). The third objective of this study is to determine the prevalence of **LOW** AA which is the primary clinical sign of accommodative insufficiency (AI), within the different age groups per technique as stipulated in Table 4.18 (cf. p. 72), Table 4.19 (cf. p. 73) and Table 4.20 (cf. p. 73).

The prevalence of **LOW** AA was investigated within each of the age groups per technique used. The results of this study determined from the PU measurements, showed that **LOW** AA was found in the complete sample with a prevalence of 7.6% as can be seen in Table 4.18 (cf. p. 72). Due to lack of standardised criteria for diagnosing AI, some authors (Sterner *et al.,* 2004; Abdul - Kabir *et al*., 2014) were previously diagnosing this condition based on the measurements of AA only. Sterner *et al.* (2004) determined the prevalence of AI based only on the AA measurements taken from 72 Swedish school children aged 6 to 10 years, using the PU technique. The author used the following three criteria when determining the prevalence percentage: 1) AI when the AA was 2 D below the expected / average values, 2) AI when the AA was below the minimum reference value and 3) AI when the AA was 2 D below the minimum reference value. The criterion that matches the one used in this study was that of 'when AA was below the minimum reference value'. The prevalence result found from this criterion was 57% and this compared very high to 7.6% found in the current study. Factors attributing to this difference may be attributed to by the difference in age range, sample size and assessment procedure between the studies. Moodley (2008) used a similar criterion (of AA below the minimum age expected value) to the current study. The prevalence of **LOW** AA in 264 learners aged 6 to 13 years was found to be 24%. This prevalence was also found to be high when compared to the current results. An attributing factor to the prevalence difference may be sample size differences between the studies. These attributing factors make comparison between the studies difficult. For instance: The study of Metsing and Ferreira (2012) used a different criterion in which, the AA was considered **NORMAL** if the measured AA was 1 D or more above the participant's age average value as calculated from Hofstetter's formula. Furthermore, AA was regarded as **LOW** if the measured AA was 4 D or more below the age average value. In this case, the comparison would not be compatible due to different criteria.

The prevalence of **LOW** AA determined from the PU measurements (7.6%) (cf. Table 4.18, p. 72) were comparatively low to the prevalence of **LOW** AA determined from the results of the PA measurements (18.4%) (cf. Table 4.19, p. 73) and the PU / PA average results (12.4%) measurements (cf. Table 4.20, p. 73). The opposite was observed with the prevalence percentage determined from the PA measurements (18.4%), as it was found to be higher than both the prevalence determined from PU (7.6%) and the PU / PA average results measurements (12.4%). The prevalence of **LOW** AA determined from the PU / PA average results measurements (12.4%) was found to be higher compared to the prevalence determined from the PU measurements (7.6%) but lower than the prevalence determined from the PA measurements (18.4%). Furthermore, the prevalence percentages determined from the PU (cf. Table 4.18, p. 72) and PU / PA average results (cf. Table 4.20, p. 73) measurements, appear to reduce from the age group 9 to 10 years, and then from 10 years increase with age until the age group 13 years. With the PA measurements (cf. Table 4.19, p. 73), the prevalence appears to increase from the age group 9 years (11.4%) to 13 years (33.3%). The prevalence of **LOW** AA was found to be statistically significant in all age groups, for all subjective techniques including the average results of the PU / PA techniques used.

This study found a low prevalence of AA among the age group 10 years and a high prevalence among the age group 12 and 13 years when the PU (cf. Table 4.18, p. 72) and PU / PA average results (cf. Table 4.20, p. 73) measurements are considered. For the PA measurements (cf. Table 4.19, p. 73), a low prevalence was found in the age group 9 years whereas a high prevalence was found in the age groups 12 and 13 years. The majority of the participants that failed AA in the study of Moodley (2008) were between ages 9 and 11 years, which differ with the 12 and 13 - year - old participants doing grade 6 and 7 in the current study. It must be kept in mind that the smaller sample size within the 13 - year age group may have attributed to this finding, however, another possibility for the high prevalence in the higher grades may be due to a higher demand on the accommodative system as more and more near work and tasks are performed in the higher grades. Hence, Moodley (2008) emphasized the need for vision screenings which include accommodative tests during school screenings.

The categorized results were then compared between the different techniques PU, PA, and PU / PA average results to observe the agreement between the techniques on the classified participants (cf. Table 4.21, p. 75). According to my knowledge, this is the first study comparing the AA results using the participants classified categorically for each technique used except for the DR technique. As such, the following subjective techniques: PU and PA, as well as the PU / PA average results agreed that 7.6% of participants have **LOW** AA. Four point nine per cent (4.9%) of the participants that were classified as **LOW** AA by the PA and PU / PA average results, were classified **NORMAL** with the PU technique. Furthermore, 6.0% of the participants that were considered **NORMAL** by the PU and PU / PA average results were classified **LOW** by the PA technique. All in all, the PA technique has classified **LOW** AA on 18.4% of the participants, which is regarded as a higher percentage of **LOW** AA compared to other techniques used. The PA technique is thus suspected to measure low readings of AA, as was indicated by other literature as well (Benzoni and Rosenfield, 2012; Momeni - Moghaddam *et al*., 2014). As shown in Table 4.21 (cf. p. 75), PU, PA and PU / PA average results agree that 147 participants had **NORMAL** AA and 3 participants had **HIGH** AA.

It is interesting to note that, from the same participants classified with **LOW** AA, none of the participants were classified as **LOW** AA by the DR technique [CI: 0%, 2.0%]. These results may confirm the assumption that the DR procedure used in this study overestimates the AA. León *et al*. (2012), in his study commenced the DR procedure by performing a modified push - down technique. Participants were wearing distance corrective lenses and auxillary minus lenses (-4.00 DS) in a trial frame. The fixation target was firstly placed close to the trial frame and the participant pushed the target away from the trial frame until the letters appeared absolutely clear. The examiner kept the target at this position, where letters appeared clear and sharp, then positioned a retinoscope at twice this distance between the fixation target and the participant. The examiner then observed the retinoscopy reflex. The expected retinoscopic reflex movement was against. When achieved, the examiner would move closer to the participant until a neutral reflex was observed. From there, the distance between the spectacle plane and retinoscope was measured. The objective AA was taken as the reciprocal of the distance measured in centimeters, adding +4.00 D corresponding to the -4.00 D lens added prior to the procedure. León *et al*. (2012) performed DR while the target was kept at a fixed position and the criterion used was a point of neutrality. At the end of the study, the author reported low results (León *et al*., 2012). The procedure used in the current study involved the PU technique, and used the technique of moving the retinoscope and the target towards the participants. Furthermore, the end point used was when the DR reflex changed to a narrow, dim and slower 'with' movement. The current set - up is suspected to have inflated the AA measured on the participants. The PU technique was found to give higher measurements of AA when compared to other subjective techniques. Therefore, this could attribute to the higher measurements with regard to the DR technique.

The prevalence of **LOW** AA differs according to the type of technique used to measure AA. The prevalence was found to be higher with the PA measurements and lower with the PU measurements. For all subjective techniques used, including the average results of the PU / PA techniques, the prevalence of **LOW** AA was found to be statistically significant for all age groups included.

5.5 **Objective 4: To compare the subjective and objective AA results of 9 to 13 year old participants**

This objective includes the comparison of the subjective and objective measurements of the AA for each participant. All the measurements of the subjective techniques included in this study (PU, PA, and PU / PA average results), were individually compared to the results of the DR technique to determine if a statistically significant difference existed between the techniques (cf. Table 4.23, p. 77). If Table 4.22 (cf. p. 76) is considered, with the DR technique, a higher median AA was found in comparison to all the subjective techniques: PU, PA and PU / PA average results. Figure 4.16 (cf. p. 76) shows that the subjective techniques (PU, PA and PU / PA average results) measured roughly similar medians, while the DR medians were found (roughly 5 to 6 D) higher compared to the subjective medians. As can be seen in Table 4.23 (cf. p. 77), the median differences found between PU and DR (5.2 D), PA and DR (6.2 D), and PU / PA average results and DR (5.7 D), were all found to be statistically significant (95% CI). A greater median difference was found between the PA and DR techniques, which may also suggest that the PA technique measured low readings when compared to the PU and PU / PA average results. Thus, the procedure of the objective DR technique used measured higher AA measurements compared to the subjective PU, PA and the PU / PA average results.

The study by León *et al*. (2016) showed that the objective procedures measure the actual increase in dioptric power of the eye, whereas the subjective methods (modified push - down and minus lens procedures as used by the author) quantifies the closest point at which the participant's eye can see clearly. It is well known that the objective techniques are not affected by the patient's judgement (Otake *et al*., 1993). In the same way, the DR technique for measuring AA was described as partly objective since it relies on the examiner for the reflex interpretation (Burns *et al*., 2014). The current study used the same DR procedure to measure the objective AA by assessing the change in the DR reflex (cf. 3.6.2.2, pp. 38 - 39). The challenge of the end point criteria used in this study is that, it quantifies the viewing distance at which the DR reflex changes, whereas it should measure the actual refractive status of the eye (Anderson and Stuebing, 2014). During the assessment procedure, the DR reflex showed a 'with' movement, indicating a lag of accommodation which normally put the image behind the retina and causes the eye to under - accommodate for the retinoscope distance. Unfortunately, lag of accommodation was found to increase as accommodation stimulus was increasing for the measurements taken in the fixation axis (Seidemann and Schaeffel, 2003) and this may be attributed to by the pupillary near response which may lead to increased depth of focus. Furthermore, the continuous increase in stimuli reaches a point where it ends up failing to stimulate more responses and the DR reflex will change colour, thickness and speed (Rutstein *et al*., 1993). A point where the reflex changes to a narrow, dim and slower reflex was regarded as the indication of loss of focus. In this state, the near point of accommodation was exceeded (Rutstein *et al*., 1993), resulting in a high AA.

A point of neutrality which was not used in this study, would mean that the retinal conjugate point has coincided with the plane of the retinoscope. Previous studies that have used neutrality as the end point during the retinoscopy (DR) procedure of the AA, have resulted in lower AA results (León *et al*., 2012 and Mathebula *et al*., 2018). Factors such as room illumination and pupil size play major roles in the objective assessment of AA. Seidemann and Schaeffel (2003) measured lag of accommodation in a room with 120 lx low illumination to obtain a bigger pupil size which will eventually result in a reduced depth of focus. The current study performed the subjective (PU and PA) (cf. 3.6.2.1, pp. 37 - 38) and objective (DR) techniques (cf. 3.6.2.2, pp. 38 - 39) in an illuminated room with 150 - 300 lx intensity. The luminance used (150 - 300 lx) could be the cause of a high objective AA which resulted from the pupillary constriction and in turn gave rise to higher depth of focus and consequently, higher lag of accommodation. Rutstein *et al*. (1993) conducted a similar study using the same end points as the current study. However, Rutstein *et al*. (1993) performed procedures in a dimly illuminated room. Authors observed an average difference of 2.7 D higher for DR when compared to the PU technique. This finding was lower when compared to 5.2 D average difference results of the current study (cf. Table 4.23, p. 77). The difference may be due to the variation in the room set - up and that the sample size, used by Rutstein *et al*. (1993) was smaller. According to Owens *et al.* (1980), the light source of the retinoscope, when viewed monocularly in a dark illuminated room, does not stimulate accommodation effectively, as is the case when viewing in a lightened room. In a dark room, the eye assumes the intermediate focus associated with the resting state of accommodation. Furthermore, Lara *et al*. (2014) studied the changes in the objective AA with the pupil size. In their results, the objective AA was always greater in smaller pupils (found in high room illumination) compared to larger pupils (low room illumination). Therefore, the difference in pupil sizes may have contributed to the difference found between studies.

The current study also used a different target for both subjective and objective procedures. The target for the subjective procedures was a 6/9 letter from a near reading chart pasted on a tongue depressor (cf. 3.6.2.1, pp. 37 - 38). In contrast, a magnetic fixation card for grade 6, consisting of various words, was used for the objective procedure (cf. 3.6.2.2, pp. 38 - 39). The results of Chen and O'Leary (1998) showed no significant difference in the AA measured with LEA target sizes of N5 and N8. However, the choice of target together with the criterion ('clear to first blur' and 'blur to first detection') may influence the measurements of AA with regard to conventional PU method and the modified PU method. According to Seidemann and Schaeffel (2003), the size of letters showed no significant influence on the precision of accommodation, although the tendency of improved accommodation was observed at a shorter reading distance.

The DR procedure used in the current study is not commonly used in practice, as it requires skilled judgement by clinicians (Burns *et al*., 2014). In the study by Rustein *et al*. (1993), four other examiners were evaluating the degree of variability of the findings. Objective findings of the three examiners were similar to the subjective findings, whereas the last fourth examiner observed larger measurements although they did not differ significantly to the subjective findings. The results of the current study agree with that of the Rutstein *et al*. (1993) that this type of criterion or end point used has the tendency of overestimating the near point of accommodation. The procedure itself is subjected to several possible errors (Burns *et al*., 2014) as named in the previous paragraphs.

The DR technique utilizes PU or minus lens procedures to induce accommodation. The procedure is performed at a close working distance and may increase the risk of a scaling error which is described as 1 cm equivalent to 1 (D) dioptric change (Burns *et al*., 2014). The use of minus lenses may reduce this effect. In contrast, Wold (1967) used five procedures to assess accommodative amplitude. Amongst them, were letter target PU and DR which were similar procedures to that used in the current study. Annulus target and auxillary minus lenses (-4.00 or -6.00 D) were also used during the DR procedure in the study by Wold (1967), but not used in the current study. The participants in the study of Wold (1967) were wearing distance refractive error correction lenses. In the results of this study (Wold, 1967), both techniques showed a higher AA although PU was found much higher compared to the DR. For the participants' aged 9 years, AA for PU and DR was 19.82 D and 15.75 D respectively and for 10 - year - old was 18.94 D and 15.56 D respectively. However, after taking depth of focus into consideration, Wold (1967) found the DR measurements in most of participants to be higher than that of the PU technique. On the other hand, Anderson and Stuebing (2014) compared the AA measured subjectively using PU and objectively with a proximal stimulated and minus lens stimulated Grand Seiko autorefractor. The study was done on 236 participants aged 3 to 64 years old. In the results, the objective proximal stimulated AA for the youngest children were almost half that of the subjective PU measurements.

The subjective and objective AA measurements were further compared using categorical classification for the complete sample. As can be seen in Table 4.24 (cf. p. 77); Table 4.25 (cf. p. 78) and Table 4.26 (cf. p. 78), the Bhapkar test results show the difference between the AA results measured with the PU and DR techniques, PA and DR techniques and PU / PA average results and DR techniques to be statistically significant ($p < 0.01$) at a 95% confidence level. From these tables: Table 4.24 (cf. p. 77); Table 4.25 (cf. p. 78) and Table 4.26 (cf. p. 78), it can be seen that, the same participants in this study were classified differently by the various techniques and the classification difference was found to be statistically significant ($p < 0.01$). For example: 14 participants that measured **LOW** AA with the PU technique were found to have **NORMAL** AA with the DR technique (cf. Table 4.24, p. 77), probably due to overestimation of AA by the DR technique. This classification difference was found to be statistically significant ($p < 0.01$) with the Bhapkar test. Again, 60 participants that measured **NORMAL** with the PU showed **HIGH** AA with the DR technique. The two techniques showed agreement on 107 participants classified as **NORMAL** and 3 participants as **HIGH**. When considering the measurements taken from the PA and DR techniques (cf. Table 4.25, p. 78), 34 participants measured a **LOW** AA with the PA technique, 32 of the participants measured a **NORMAL** AA with the DR and 2 participants measured **HIGH** with the DR technique. This may be as a result of the overestimation of AA measurements by the DR technique. The same applied to the measurements calculated from the PU / PA average results when compared to DR measurements (cf. Table 4.26, p. 78). Of the hundred and fifty - nine (159) participants who were classified as **NORMAL** with the PU / PA average results, 99 participants measured **NORMAL** with the DR and 60 participants measured **HIGH** with the DR technique. The comparison of the techniques was also done within the different age groups using Bhapkar and McNemar tests and the differences were all found to be statistically significant (cf. Table 4.27, p. 79).

The DR procedure used in this study, resulted in AA measurements that were statistically significantly different from the measurements of the PU and PA techniques (as well as the PU / PA average results) performed on the same participants in the same study. Thus, the objective AA measurements were statistically significantly higher than the subjective AA measured on the same participants.

The following four objectives were discussed in this chapter:

1. To compare the AA results for 9 to 13 year old participants.
2. To compare the AA measurements in gender of 9 to 13 year old participants.
3. To determine the prevalence of **LOW** AA at different age interval in 9 to 13 year old participants.
4. To compare the objective and subjective AA results of 9 to 13 year old participants.

Results for the investigation of each of these objectives were presented and interpreted. The conclusions made from these interpreted results and discussions are presented in the next chapter.

CHAPTER 6: CONCLUSION

6.1 **Introduction**

Vision is responsible for 80% of a child's sensory input (Colyar, 2011). Accommodative demands such as reading and writing increase as children are progressing to higher grades in school and may later result in the manifestation of accommodative anomalies. Sufficient AA is necessary for children to perform optimally in the classroom.

The aim of the study was to investigate the AA in 9 to 13 year old school children of Mankweng circuit, Limpopo province.

In this chapter, an overview and conclusion of the final findings of the study are provided. It also includes a brief discussion on the limitations of the study, the significance of the study and recommendations for future studies.

6.2 **Overview of the study**

The investigation of the AA of school children aged 9 to 13 years was carried out based on the following four objectives:

1. To compare the AA results for 9 to 13 year old participants.
2. To compare the AA measurements in gender of 9 to 13 year old participants.
3. To determine the prevalence of **LOW** AA at different age interval in 9 to 13 year old participants.
4. To compare the objective and subjective AA results of 9 to 13 year old participants.

These objectives guided the study on the materials and methods to be used to achieve the presented results. The recommendations given in the study were guided and informed by the findings of this study. The subsequent section reviews each objective with its main findings.

6.2.1 **To compare the AA results for 9 to 13 year old participants**

The AA results for participants aged 9 to 13 years were compared within the different age groups in order to understand the distribution, trend and rate of change in AA among the participants. The participants were grouped into five age groups of 9, 10, 11, 12 and 13 years. The AA was measured subjectively (using push - up and pull - away techniques) and objectively (using dynamic retinoscopy). The distribution and pattern of AA with age was observed from the results. The measured average results were compared using numerical and categorical data. The numerical data was described using medians (as data was found to be not normally distributed and non - parametric statistical methods were used for analysis) and percentiles whereas the categorical data was described by frequencies and percentages. The categorical data was derived using the indicated five groups, based on the minimum and maximum age expected norm values calculated from Hofstetter's formulae. As described in chapter 4 (cf. p. 44), if a measured average AA value was below the age expected minimum value, a participant was classified as having a **LOW** AA. When a measured average AA was greater than the minimum norm value but less than the maximum norm value (meaning that the result was within the reference values), this was classified as a **NORMAL** AA. Lastly, if a measured average AA result exceeded the maximum norm value for a participant's age, the measurement was classified as a **HIGH** AA.

From the investigations, the numerical data showed that the median results, together with the lower (25%) and upper (75%) quartile results of the participants aged 9 to 13 years, reduces with increasing age for all the procedures used in the study. However, the rate of change in AA between the different age groups is not constant. Statistical significant differences existed between the AA of the age groups 12 and 13 years, and also between the AA of the age groups 2 years or more apart. The categorical data showed a statistical significant difference between the age groups 10 and 13 years when different age groups were compared for **LOW** AA for the measurements of the PU / PA average calculated results. Furthermore, more participants in each age group were found to have a **NORMAL** AA within the reference values (of minimum and maximum) according to Hofstetter's formulae. However, the percentage of participants with **NORMAL** AA showed to decrease with an increase in age from age group 10 to 13 years when using subjective measurements (PU and the calculated PU / PA average results) and the percentage showed to increase with increasing age when using objective measurements (DR). The percentage of participants classified as **NORMAL** is high with PU, followed by the calculated PU / PA average results and lastly the PA technique when considering subjective measurements.

Ideally, the measuring techniques of AA should give similar results. The challenge of different results from different techniques on the same participants, may affect the final diagnoses and possibly lead to the wrong treatment plan.

The second objective compared the AA results in female and male participants of the complete sample.

6.2.2 **To compare the AA measurements in gender of 9 to 13 year old participants**

The AA measurements in female and male participants were compared to assess if the AA is distributed equally between female and male participants. The current objective was achieved by comparing the measured average results (for all techniques) of all the female participants aged 9 to 13 years to the average measured results (for all techniques) of all the male participants aged 9 to 13 years. Numerical and categorical data was used to address the objective.

During the comparison of AA in female and male participants of the current study, the numerical differences found when using subjective (the calculated PU / PA average results) and objective (DR) measurements were not statistically significant. However, female participants showed a tendency of presenting with a greater percentage of **HIGH** AA exceeding the maximum norm as predicted by Hofstetter's formula for all the procedures used. Therefore, there is no statistically significant difference found between the AA in female and male participants.

6.2.3 **To determine the prevalence of LOW AA at different age interval in 9 to 13 year old participants**

The prevalence of **LOW** AA was determined in each age group using categorical data. The purpose was to identify the age group in which **LOW** AA is more prevalent among the participants of the study.

The investigation has revealed that the type of technique used to measure AA has a great influence on the results of the prevalence of **LOW** AA. In the current study, the prevalence of **LOW** AA among the participants aged 9 to 13 years, appeared to be higher with the PA technique (18.4%), followed by a slightly lower result for the calculated PU / PA average results (12.4%) and lastly, the lowest result was found with the PU technique (7.6%). For the PU and the calculated PU / PA average results, the prevalence of **LOW** AA appeared to increase with increasing age, from age group 10 to 13 years. With the PA measurements, the prevalence of **LOW** AA appeared to increase with increasing age from the age group 9 to 13 years. The prevalence of **LOW** AA was found to be statistically significant in all age groups, for all subjective techniques used in the study. Furthermore, the prevalence of **LOW** AA appeared more prevalent on the age group 13 years for all subjective techniques used in the study including the calculated PU / PA average results. For the same sample of participants, the DR technique did not find any prevalence of **LOW** AA. This could possibly indicate that the measurements taken with DR are higher than the measurements taken with the subjective techniques.

The current study used techniques which involve the movement of a target, which according to Burns *et al*. (2014) are affected by the error of reaction time. Minus lens - to - blur measuring technique was reported to give lower AA measurements as compared to the PU and PA techniques (Momeni - Moghaddam *et al*., 2014). It is recommended that more studies be conducted using the minus lens procedure and the same procedure of the DR technique incorporated with the auxillary minus lenses and performed in a recommended dim illuminated room to confirm the reported prevalence rate.

6.2.4 **To compare the objective and subjective AA results of 9 to 13 year old participants**

As indicated previously, AA measurements were collected objectively using DR and subjectively using PU, PA and the calculated average results of PU / PA techniques. The purpose of this objective was to assess if there is any similarity or difference between the AA measured objectively and subjectively on the same participants of Mankweng circuit.

During the investigations, the objective AA results measured using DR technique on the current participants were found to be statistically significantly different to the subjective results measured using PU and PA, and also to the calculated average results of the PU / PA techniques. The DR procedure and the room set - up used in the current study are suspected to have contributed on the inflated measurements of AA in the current participants. The current study did not utilize the auxillary lenses which are believed to move the end - point away from the participant, reducing the effect of overestimation of AA measurements.

With regard to the subjective techniques, PU reported higher results than PA and the calculated average results of the PU / PA techniques. However, the statistical significant difference was not tested.

6.3 **Conclusion**

The measured AA reduces with increasing age for all the techniques used in the study. The rate at which AA changes between different age groups, was found to be different in all techniques used. However, this change in AA was found to be statistically significantly different between the age groups 12 and 13 years and between the age groups of two or more years apart. Furthermore, the median AAs of all measuring techniques used, were found within the minimum and maximum norms as stated by Hofstetter. No statistically significant difference was found in AA in female and male participants. The prevalence of **LOW** AA among the participants was found to be 7.6% with PU, 12.4% with the calculated PU / PA average results and 18.4% when using the PA technique. Furthermore, the prevalence of **LOW** AA was found to be statistically significant in all age groups for all subjective techniques used. It is noted that each technique yields different measurements and may affect the clinical interpretation of AA. Again, it may result in false diagnoses and the implementation of the wrong treatment plan. The AA measured objectively, was found to be statistically significantly different to the subjective measurements with a 5 to 6 diopter difference. The criterion of the (retinoscopic reflex changing to a dim, narrow and slow motion) DR technique used in the current study may have led to overestimation of the AA results. The room illumination may have contributed to the difference in technique measurements.

6.4 **Limitations of the study**

Despite the AA being a monocular component and essential to each person, the current study measured AA on normal, healthy participants with good vision of 20/20 in each eye, both at 6 m and 40 cm and with a phoria at 40 cm that was within the norms as described by Scheiman and Wick (2008). This was due to the initial plan of establishing the normal values of AA among the Limpopo children aged 9 to 13 years and such a group was believed to yield a better response and results compared to a symptomatic group. Amblyopic and strabismic children were excluded and it is likely that different results would have been obtained from this group if not excluded. Cycloplegic or subjective refractions were not conducted, however, the +2.50 lens test was conducted to exclude participants with possible latent hyperopia.

The subjective and objective techniques used in the current study, were previously reported to overestimate AA measurements. In addition, the current study performed DR technique in a highly illuminated room compared to other studies which used dim illumination. The disadvantage of the DR procedure used in the current study is the need for a competent clinician, confident in the administering of the procedure. The current study did not test the statistical significant difference between the measurements of the PU and PA techniques, which could have added on the existing literature about the PU and PA.

6.5 **Contributions of the Research**

The current research is believed to be new knowledge that will contribute to the existing knowledge of the AA measurements on school children. It will assist clinicians when making a better choice of technique to be used when measuring AA.

6.6 **Recommendations**

Further studies are required using the same DR technique procedure used in this current study and incorporating the procedure with methods such as auxillary minus lenses recommended to take the near point away. Also, a longitudinal study on a larger sample size which includes symptomatic participants is recommended to observe the changes in AA on the same participants.

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APPENDICES

Appendix A. Consent form for Parents/ Guardians - English version

Consent form for Parents/ Guardians

Participant Name: ___________________

School Name: ______________________ Grade#: ______________

Certificate of Consent

I have read and understood the information sheet and accept the invitation requesting that my child should voluntarily takes part in the research study. I confirm that I was given an opportunity to ask questions and the questions were answered to my satisfaction. I therefore give permission that my child may participate in the study, conditional to the assent provided by the child.

Parent/ Guardian's name: __________ Signature: ____________ Date: _________

NB: Kindly complete the section below if consent has been granted!!

*Is your child's eyes crossed /squint?

*Does your child have problem in seeing on chalkboard or reading a book?

*Is your child on any medication?

*When last did your child see an eye doctor?

Kindly submit this letter back to the school no later than _____________ (date).

Thank you very much for your time.

Appendix B. Consent form for Parents/ Guardians - Sepedi version

Latlakala la go fa tumelelo ka Motswadi goba Mohlokomedi

Leina la motšeakarolo: ____________________

Leina la sekolo: _______________________ Mphato: _______________

Seteficate sa tumelelo

Ke badile letlakala la ditsebišo ka kwešišo, ebile ke dumelela ngwana waka go tšeya karolo dinyakišišong tše. Ke fa bohlatse bja gore ke filwe monyetla wa go botšiša dipotšišo, ebile dipotšišo tšeo difetotšwe ga go kgotsofatša.

Motswadi/ Mohlokomedi: ___________ Signature: ___________ Letšatši: ________

NB: Ka kgopelo araba dipotšišo tše dilatelago fela geo file ngwana wa gago tumelelo-

*Naa mahlo a ngwana wa gago a kaba a leyane /go sekama?

*Naa ngwana wa gago a kaba a na le bothata bja go bona letlapeng ka phaphošing ya sekolo goba ge a bala dipuku?

*Go ka ba go na le dihlare tšeo ngwana wa gago a dinwago ka se sebaka?

*Naa ngwana wa gago o bonwe neng la mafelelo ke ngaka ya mahlo?

Le kgopelwa go bušetša lengwalo le sekolong pele ga letsatsi la _______________

Ke rata go leboga nako ya lena.

Appendix C. Information sheet - English version

Information sheet

Date:

Re: Participation in a Masters' study

I would like to invite your child to take part in my study that forms part of the requirements of a Masters' Degree in Optometry that I am currently undertaking at the University of the Free State. Underneath is detailed information about the study. You are advised to read it carefully. Please do not hesitate to ask questions were you do not understand.

Previously it was assumed that children under the age of 10 had good vision at near, meaning that they could read with ease since they were still young and their eyes were flexible. Current studies from other countries have confirmed that a reduced ability to see at near during school ages may affect school performance. In this study, the researcher aims to assess the eyes of school children aged 9 to 13 for the ability of their eyes to see at near and to estimate what the relevance of this ability is per age group.

The results will help us to know how common difficulty with reading is amongst school children as a result of this reduced ability of the eyes. It will further our knowledge in planning the optimal management for these school children. For us to achieve our goal, we therefore invite your child to have his/her eyes screened by the team of optometrists and optometry students.

This study will involve only eye screening and no harmful techniques and medication/drops will be applied into your child's eyes. The screening will be free and should your child be found to have eye problem, he/she will be referred for a comprehensive eye examination at any institution providing eye care services and a referral letter will be provided in assistance. There will be no reward or any payment given to your child after participation.

The child's screening results will be kept confidential and will not be accessible to anyone outside the study except to you as a parent. Your child's name will not be disclosed anywhere in the study. We would like to emphasise that your child's participation is voluntarily and can still be withdrawn at any time during the study.

This study has been approved by Health Science Research Ethics Committee with the interest of protecting the participant from any harm that may be involved during the study. For more questions and clarities you can call the researcher named Mrs M.E. Mafeo on these numbers: 078 3653 802/ 060 5000 862.

Appendix D. Information sheet - Sepedi version

Letlakala la ditsebišo

Letšatši:

Ngwana wa lena o memiwa go tšea karolo dinyakišišong tša ka tša lefapa la mahlo (Optometry), tše ke di dirago le sekolo sa godimo sa Free Setata. Tše di latelago ke ditaba ka botlalo go ya ka dinyakišišo tše. Le eletšwa go di bala ka hlokomelo. Le se ke la tšhaba go botšiša ge le sa kwešiše.

Mengwageng ye e fetilego, go be go na le setlwaedi sa gore bana ba ka tlase ga mengwaga ye lesome ba bona gabotse kgauswi, ebile ba bala ga bonolo ka gore mahlo a bona a ba dumelela. Go ya ka dinyakišišo tša go na bjale go tšwa dinageng tša ka ntle, di gonthišišitše gore phokotšego ya go bonela kgauswi go ka ama go tšwelela ga ngwana mengwageng ya gagwe ya sekolo.

Maikemišetšo a dinyakišišo tše, ke go bona gore bana ba ka tlase ga mengwaga ye senyane go iša go ye lesometharo go la tikologo ya Mankweng, ba kgona go bonela kgauswi le go bona ge e le gore bokgoni bja go bona bo magareng ga mengwaga ya bona. Dipoelo tša dinyakišišo tše, di tla re thuša gore re tsebe gore bothata bja go bala bjoo bo hlolwago ke go fokotšega ga bokgoni bja mahlo go ka bonela kgauswi bo tletše ga kakang mo baneng ba mengwaga ye senyane go iša go ye lesometharo go la tikologo ya Mankweng. Mo dinyakišišong tše, re ya go hlahloba mahlo fela. Ga go na dihlare goba didirišwa tše bogale tše re yago go di šomiša tše di ka bago le di tla morago. Ga go na tefo yeo e tlogo nyakega gotšwa go motšeakarolo goba go tšwa go mohlahlobi ka motšeakarolo. Ge ngwana a ka hwetšwa a na le mathata a mahlo, o tlo romelwa dingakeng tša mahlo tša kgauswi, e ka ba bookelong bja mmušo goba lekala le esego la mmušo (private).

Dipoelo tša dihlahlobo e tlaba sephiri sa monyakišiši le motswadi goba mohlokomedi wa ngwana. Dinyakišišo tše di dumeletšwe ke lekgotla la Health Science Research Ethics Committee bakeng sa go šireletša batšeakarolo kgahlanong le dikgobalo. Ka go realo, re kgopela tumelelo ya go hlahloba ngwana wa lena ka nako ya dinyakišišo. Go hwetša tshedimošo ka botlalo, ekopantšhe le Mrs M.E Mafeo mogaleng wo o latelago: 078 365 3802/ 060 5000 862

Appendix E. The Participant’s Assent form - English version

The Participant’s Assent form

There are games that I want you to play with us. You are allowed to refuse to play or to stop at any time during the play if you no longer want to play. The game will include the following activities, but you will start by telling us your full names and answer some questions:

I _______________ agree to play the games and I understand that I may stop at any time I want.

Date: ________________

Appendix F. The Participant’s Assent form - Sepedi version

Tumelelo ka motšeakarolo

Go na le dipapadi tše tharo tšeo ke nyakago gore o bapale le rena. O dumeletšwe go ka gana go bapala goba wa tlogela gare ge e kaba ga go sana kgahlego ya go bapala. Pele o thoma go bapala, o tshwanetše go ngwadiša maina a gago ka botlalo le go fetola dipotšišo tše mmalwa. Dipapadi tša go na di ka tsela ye e latelago:

Nna ________________________ ke dumela go tšea karolo dipapading tše, ebile ke a kwešiša gore nka tlogela nako ye nngwe le ye nngwe ge ke nyaka.

Letšatši: __________

Appendix G. Screening sheet

Section 1: (Station 1)

School Name: ________________ Assessment Date: ____________

Child's ID#: _______D.O.B: _____________ Age: ______Gender: M____ F _____

Section 1: (Station 2)

CASE HISTORY

1. What were you doing before coming here (for screening): In class- studying, teaching in progress or playing? Answer: ___________________
2. Do you have any eye problem(s)? Yes / No
3. Can you see well on the chalkboard and / or when reading? Answer: _____________
4. Did you drink any medication this morning? Yes / No

   If yes, what for: ___________

Section 2: (Station 2)

VISUAL ACUITY (VA) ASSESSMENT EXAMINER ID# _____________

	Habitual Visual Acuity (HVA) at 3 m:	Plus Lens Test (+2.50 D) at 3 m. (only if HVA at 3 m is 6/6 in each eye)	Habitual Visual Acuity (HVA) at 40 cm. (only if HVA at 3 m is 6/6 in each eye)
OD			
OS			

Section 3: (Station 3)

COVER TEST at 40 cm

____

Section 4: (Station 2)

OCULAR HEALTH: Direct Ophthalmoscopy

OD		OS
	EYELIDS	
	LASHES	
	CONJUNCTIVA	
	CORNEA	
	IRIS	
	PUPILS	
	(Direct, consensual and swinging flash reflexes)	
	LENS	
	OPTIC DISC	
	CD RATIO	
	RETINA	

Appendix H. Referral Letter

To: Eye Care Provider

Dear Colleague

Re: Referral for further assessment and management

This confirms that _______________ (scholar's name) was screened by a team of Optometrists and Optometry students on the _______________ (date) and the following were found:

Clinical notes:

____

____

____

____

____

____

____

Please assess and manage further.

Referring Officer Name and Surname: ______________________

____

Signature

Name of Principal Investigator: _____________________

Qualification: ____________________

____

Signature

Appendix I. Data Sheet

AMPLITUDE OF ACCOMMODATION MEASUREMENTS

Push - up Technique in cm

	1st	2nd	3rd	4th	5th	Ave	Ave AA in Diopters
OD							
OS							

Pull - away Technique in cm

	1st	2nd	3rd	4th	5th	Ave	Ave AA in Diopters
OD							
OS							

Objective measurements of AA in cm

	1st	2nd	3rd	4th	5th	Ave	Ave AA in Diopters
OD							
OS							

Hofstetter's Rule in Diopters

Norms	Min value	Max value

Appendix J. Health Sciences Research Ethics Committee Approval (HSREC NR: UFS-HSD2017/0130)

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA

UFS·UV
HEALTH SCIENCES
GESONDHEIDSWETENSKAPPE

IRB nr 00006240
REC Reference nr 230408-011
IORG0005187
FWA00012784

03 April 2017

ME MMAKOMA
DEPT OF OPTOMETRY
FACULTY OF HEALTH SCENCES
UFS

Dear ME Mmakoma

HSREC 20/2017 (UFS-HSD2017/0130)
PROJECT TITLE: AMPLITUDE OF ACCOMMODATION IN 9 TO 13 YEAR OLD SCHOOL CHILDREN OF MANKWENG CIRCUIT, LIMPOPO PROVINCE.

1. You are hereby kindly informed that the Health Sciences Research Ethics Committee (HSREC) approved this protocol after all conditions were met. This decision will be ratified at the next meeting to be held on 25 April 2017.

2. The Committee must be informed of any serious adverse event and/or termination of the study.

3. Any amendment, extension or other modifications to the protocol must be submitted to the HSREC for approval.

4. A progress report should be submitted within one year of approval and annually for long term studies.

5. A final report should be submitted at the completion of the study.

6. Kindly use the **HSREC NR** as reference in correspondence to the HSREC Secretariat.

7. The HSREC functions in compliance with, but not limited to, the following documents and guidelines: The SA National Health Act. No. 61 of 2003; Ethics in Health Research: Principles, Structures and Processes (2015); SA GCP(2006); Declaration of Helsinki; The Belmont Report; The US Office of Human Research Protections 45 CFR 461 (for non-exempt research with human participants conducted or supported by the US Department of Health and Human Services- (HHS), 21 CFR 50, 21 CFR 56; CIOMS; ICH-GCP-E6 Sections 1-4; The International Conference on Harmonization and Technical Requirements for Registration of Pharmaceuticals for Human Use (ICH Tripartite), Guidelines of the SA Medicines Control Council as well as Laws and Regulations with regard to the Control of Medicines, Constitution of the HSREC of the Faculty of Health Sciences.

Yours faithfully

....

PROF WJ STEINBERG
VICE CHAIR: HEALTH SCIENCES RESEARCH ETHICS COMMITTEE
cc: Dr M Oberholzer

Health Sciences Research Ethics Committee
Office of the Dean: Health Sciences
T: +27 (0)51 401 7795/7794 | F: +27 (0)51 444 4359 | E: ethicsfhs@ufs.ac.za
Block D, Dean's Division, Room D104 | P.O. Box/Posbus 339 (Internal Post Box G40) | Bloemfontein 9300 | South Africa
www.ufs.ac.za

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA

UFS·UV
HEALTH SCIENCES
GESONDHEIDSWETENSKAPPE

Health Sciences Research Ethics Committee

02-Aug-2019

Dear **Mrs Mmakoma Mafeo**

Ethics Number: UFS-HSD2017/0130

Ethics Clearance: **AMPLITUDE OF ACCOMMODATION IN 9 TO 13 YEAR OLD SCHOOL CHILDREN OF MANKWENG CIRCUIT, LIMPOPO PROVINCE**

Student/Student Group leader: **Oberholzer, Marsha M**

Supervisor: *****NF*****

Department: **Optometry Department (Bloemfontein Campus)**

UNDERGRADUATE SUBSEQUENT SUBMISSION APPROVED

With reference to your application for ethical clearance with the Health Sciences Research Ethics Committee, I am pleased to inform you and your student(s) on behalf of the HSREC that you have been granted ethical clearance for your request as stipulated below:

The removal of the last objective (number 5) which is " To compare the measured AA results to the norms according to Hofstetter formula".

The HSREC functions in compliance with, but not limited to, the following documents and guidelines: The SA National Health Act. No. 61 of 2003; Ethics in Health Research: Principles, Structures and Processes (2015); SA GCP(2006); Declaration of Helsinki; The Belmont Report; The US Office of Human Research Protections 45 CFR 461 (for non-exempt research with human participants conducted or supported by the US Department of Health and Human Services- (HHS), 21 CFR 50, 21 CFR 56; CIOMS; ICH-GCP-E6 Sections 1-4; The International Conference on Harmonization and Technical Requirements for Registration of Pharmaceuticals for Human Use (ICH Tripartite), Guidelines of the SA Medicines Control Council as well as Laws and Regulations with regard to the Control of Medicines, Constitution of the HSREC of the Faculty of Health Sciences.

For any questions or concerns, please feel free to contact HSREC Administration: 051-4017794/5 or email EthicsFHS@ufs.ac.za.

Thank you for submitting this request for ethical clearance and we wish you and your student(s) continued success with your research.

Yours Sincerely

Dr. SM Le Grange
Chair : Health Sciences Research Ethics Committee

Health Sciences Research Ethics Committee
Office of the Dean: Health Sciences
T: +27 (0)51 401 7795/7794 | E: ethicsfhs@ufs.ac.za
IRB 00006240; REC 230408-011; IORG0005187; FWA00012784
Block D, Dean's Division, Room D104 | P.O. Box/Posbus 339 (Internal Post Box G40) | Bloemfontein 9300 | South Africa
www.ufs.ac.za

Appendix K. Provincial Department of Education Approval

LIMPOPO
PROVINCIAL GOVERNMENT
REPUBLIC OF SOUTH AFRICA

DEPARTMENT OF
EDUCATION

Ref: 2/2/2   Enq: MC Makola PhD   Tel No: 015 290 9448   E-mail: MakolaMC@edu.limpopo.gov.za

Maefo ME
P O Box 1518
Dwars River
0812

RE: REQUEST FOR PERMISSION TO CONDUCT RESEARCH

1. The above bears reference.

The Department wishes to inform you that your request to conduct research has been approved. Topic of the research proposal: **"AMPLITUDE OF ACCOMMODATION IN 9 TO 13 YEARS OLD SCHOOL CHILDREN OF MANKWENG CIRCUIT, LIMPOPO ."**.

2. The following conditions should be considered:

3.1 The research should not have any financial implications for Limpopo Department of Education.

3.2 Arrangements should be made with the Circuit Office and the schools concerned.

3.3 The conduct of research should not anyhow disrupt the academic programs at the schools.

3.4 The research should not be conducted during the time of Examinations especially the fourth term.

3.5 During the study, applicable research ethics should be adhered to; in particular the principle of voluntary participation (the people involved should be respected).

3.6 Upon completion of research study, the researcher shall share the final product of the research with the Department.

REQUEST FOR PERMISSION TO CONDUCT RESEARCH MAEFO ME

CONFIDENTIAL

Cnr. 113 Biccard & 24 Excelsior Street, POLOKWANE, 0700, Private Bag X9489, POLOKWANE, 0700
Tel: 015 290 7600, Fax: 015 297 6920/4220/4494

The heartland of southern Africa - development is about people!

4 Furthermore, you are expected to produce this letter at Schools/ Offices where you intend conducting your research as an evidence that you are permitted to conduct the research.

5 The department appreciates the contribution that you wish to make and wishes you success in your investigation.

Best wishes.

Ms NB Mutheiwana
Head of Department

17/02/2017
Date

REQUEST FOR PERMISSION TO CONDUCT RESEARCH MAEFO ME

CONFIDENTIAL

Appendix L. Department of Education Mankweng Circuit Approval

LIMPOPO

PROVINCIAL GOVERNMENT

REPUBLIC OF SOUTH AFRICA

PRIVATE BAG X 1108
SOVENGA
0727

TEL: 015 267 5641
FAX: 015 267 5243

DEPARTMENT OF EDUCATION
MANKWENG CIRCUIT

Enq: KEKANA M.J
Tel No: 015 27 5641

2017.02.28

MAFEO M.E
UNIVERSITY OF FREE STATE
P.O Box 1518
Dwars River
0812

PERMISSION TO CONDUCT A RESEARCH BASED ON AMPLITUDE OF ACCOMODATION IN 9 TO 13 YEARS OLD CHILDREN OF MANKWENG CIRCUIT, LIMPOPO PROVINCE.

1. **The above matter refers.**
2. **We acknowledged the receipt of your letter dated 2016-02-28 to conduct a Research to the following Schools Moriting, Mmaphotla, Makgefola and Toronto Primary based: Amplitude of Accomodation in 9 to 13 years old children of Mankweng Circuit.**
3. **Permission is granted for the above mentioned request.**
4. **Wishing you Good luck in your studies.**

MAGAGANE M.D
(CIRCUIT MANAGER)

28/02/17
(DATE)

Appendix M. A summary report compiled through Turnitin Plagiarism Search Engine

AMPLITUDE OF ACCOMMODATION IN 9 TO 13 - YEAR - OLD SCHOOL CHILDREN OF MANKWENG CIRCUIT, LIMPOPO PROVINCE

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