THE DEVELOPMENTAL EYE MOVEMENT TEST AND ITS APPLICATION TO CANTONESE-SPEAKING CHILDREN

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CERTIFICATE OF ORIGINALITY

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Signed: ____________________

Peter, Chi-kong PANG
(Candidate)

DEDICATION

This thesis is dedicated to my wife Sophia and my mother Mui-ping.

ABSTRACT of thesis entitled "**The development eye movement test and its application to Cantonese-speaking children**" submitted by **Peter Chi-kong PANG** for the degree of "**Master of Philosophy**" at the Hong Kong Polytechnic University in July 2004.

Purpose

The developmental eye movement (DEM) test is a visuo-verbal test to determine problems of saccadic eye movements and automaticity in children. Studies have reported that an early diagnosis of problems in saccadic eye movements in children may be remedied by vision training exercises to improve reading skills. However, the DEM test relies heavily on the administrator's subjective judgement in the measurement and quantitative analysis of the raw score. Is there any way to improve the repeatability of scoring the DEM test? The DEM test is a standardized test and the test results should be compared with the given norms, which were derived from English-speaking children. To our best knowledge, there are no norms for languages other than English and Spanish. We do not know whether these norms are suitable for Cantonese-speaking children in Hong Kong. Furthermore, there has been argument as to whether reading disability, which is associated with poor eye movement quality, is related to various visual functions. We would like to know if there are any differences in visual functions among different types of children (normal, saccadic eye movement dysfunction and automaticity dysfunction) as diagnosed by the DEM test.

In this study, our first objective is to investigate possible objective ways to improve the repeatability of the measurements of this test, regardless of whether the administrator is

experienced or not. Our second objective is to investigate whether the given DEM norms are suitable to Cantonese-speaking children. We will compare the mean of the DEM scores of a group of Cantonese-speaking children aged 6 to 11 years with the existing norms in English and Spanish. Our third objective is to ascertain whether there are any differences in visual skills among the children aged 6 to 8 years with different problems as diagnosed from the DEM scores.

Method

In the evaluation of the accuracy of the DEM scores, five voice clips were prepared by recording the voices of five children aged 6 to 8 years during a DEM test. Each contained different combinations of reading times and errors. These voice clips were presented to ten DEM administrators. Five of the administrators were experienced in using the DEM test and the other five were naive to the test. Prior training was provided to the naive administrators. The administrators were requested to record the reading times and errors from each voice clip. Then the adjusted vertical and horizontal times for each measure were calculated. The differences from pre-set or expected values of the adjusted vertical and horizontal times from these two groups of administrators were compared. Next, an investigator repeated the measurement of the reading time from ten pre-recorded voice clips of a DEM test. The single, mean of two, mean of three, mean of four and mean of five measurements were compared.

In the investigation for the suitability of the DEM norms for Cantonese children, 347 Cantonese-speaking children aged from 6 to 11 years were recruited. A letter describing the study was sent to the principals of 5 primary schools. Information about the study and consent forms were then sent to the parents of the students via the teachers. The children in this study were matched in age-to-grade factor with the original norms (English population study) of the DEM test. The DEM test was administrated individually to each child in a quiet room in the school. The procedures and inclusion criteria followed those in the test manual. A digital recording was made of the voice of the child during the test. The reading times and reading errors in each subtest were recorded and averaged by the investigator, who listened to the voice clips twice after the test. The reading times in both the vertical and horizontal tests were adjusted according to a formula, in which the factors of omission and addition errors were included. A ratio was determined where the adjusted horizontal time was divided by the adjusted vertical time. The mean of the adjusted vertical time and the adjusted horizontal time from boys and girls were compared. The means of each DEM score were compared with the published norms (English and Spanish). The prevalence of automaticity and saccadic eye movement dysfunction in our samples were derived.

In the study of the relationship between the DEM test and visual functions, a subgroup of children aged 6 to 8 years (from the above population) were recruited for further visual function assessments. The same investigator measured the following visual functions for each child. Habitual distance and near vision, retinoscopic refraction, near phoria test by Maddox Wing, gradient AC/A (using +1.00 with Maddox Wing), positive fusional amplitude, stereoacuity (using the Randots stereo test), amplitude of accommodation (using the push-up method), accommodative facility (using +/-2.00 flipper at 40 cm) and lag of accommodation (using the MEM at 40 cm) were determined. These children were grouped according to their DEM scores into the four types of diagnosis. The visual functions among different types of diagnosis were compared.

This study followed the tenets of the Declaration of Helsinki and informed assent was obtained from the parents of the participants.

Results

In the repeatability of scoring of the DEM test, all administrators recorded a difference of one second or more from the expected values in each voice clip. There was a significant difference in the mean of the differences in the adjusted vertical time (t-test; $p < 0.05$) from the pre-set values between the experienced and inexperienced DEM administrators. These results suggest that using the conventional method of assessing DEM test, the test administrators are very likely to make errors regardless of whether they are experienced or not. In addition, the mean of two repeated measurements of the reading time in the DEM test falls within 0.5 seconds of the mean-of-five measurement. It is highly advised that an audio recording be made of the voice of the child and that this be assessed at least twice for an accurate determination of the DEM scores.

Three hundred and five children were included in this study. There was no difference in the adjusted vertical and horizontal times between boys and girls in our study. In both vertical and horizontal subtests, the Cantonese-speaking children completed the tests much faster than their English-speaking or Spanish-speaking counterparts in all group groups from 6 to 11 years. The differences of the means of the reading time were statistically significant (unpaired t-test; $p<0.01$) in all these age groups. The mean horizontal errors made by the Cantonese-speaking children were similar to the English norms except that the Cantonese-speaking children in age groups of 6 made fewer horizontal errors than their English counterparts. The mean ratios were similar amongst different populations. The results suggested that the published DEM norms in English and Spanish were not suitable to use in Cantonese-speaking population. Hence, Cantonese norms of the DEM test were proposed for verification and adoption. The prevalence of saccadic eye movements and automaticity dysfunction in our samples (ages between 6 and 11) were 4.3% and 6.9% respectively. There was a trend towards increasing prevalence of "automaticity dysfunction" across age.

In a group of 108 children aged 6 to 8 years, the children were classified into the four diagnostic types according to the DEM scores. As there were too few cases in the Type IV, only Types I, II and III were included for data analysis. As a result, there were significant differences (one-way ANOVA, $p < 0.01$) in the means of lag of accommodation among these Type I (normal), II (saccadic eye movement dysfunction) and III (automaticity dysfunction) children. Children with automaticity dysfunction (Type III) had a relatively higher lag of accommodation ($+1.20 \pm 0.19$ D).

Conclusion

The conventional method as suggested in the manual for recording the DEM test scores is not sufficiently accurate. With our findings we established a more objective procedures for the DEM test. We suggest recording the response from the child during the DEM test and this allows re-listening to and reassessment of the data. The recorded time should be measured twice to obtain the mean to ensure good repeatability. We believe that using this method for the DEM test will permit the clinicians to obtain more accurate results and thus reduce the chance of false positive or false negative findings or an incorrect diagnosis.

We found significant differences in the DEM scores amongst Cantonese, English and Spanish-speaking populations with matched ages. It is very important to obtain normal values for a particular population to minimize the bias caused by other factors such as languages or education. We established the norms for the Cantonese-speaking children in Hong Kong. Our norms will be communicated to the Department of Health, Department of Education and other clinicians who frequently use the DEM test for adoption and verification. We also established the prevalence of automaticity and saccadic eye movement problems in this population. The prevalence of automaticity dysfunction in our sample is quite high and this figure is alarming. Further investigation into confirming the diagnosis and treatment for this group of children may enhance the referral criteria.

There is an association between lag of accommodation and automaticity dysfunction. Further investigation is yet to confirm the validity of our findings.

The DEM test is a fast and simple test of saccadic eye movements and automaticity. The norms of the DEM test are language dependent. Therefore, appropriate norms of individual languages should be used if an administrator wants to provide an accurate result and diagnosis for the children. The Cantonese norms of the DEM test are proposed for further verification.

Key words: DEM test, DEM norms, saccadic eye movement, language

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PUBLICATIONS ARISING FROM THE THESIS

Conference publications

Pang, P, Lam C, To CH. (2003) The norms of developmental eye movement test in Chinese (Cantonese) speaking children. [APOC abstract: P38]

Pang, P, Lam C (2004) Lag of accommodation and refractive status in Chinese children [AAO Academy 2004 Global-Pacific Rim abstract: P145]

AAO: American Academy of Optometry
APOC: Asia-Pacific Optometric Congress

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Peter CK PANG
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LIST OF ABBREVIATIONS

Abbreviation	
"	Inch
+ve	Positive
-ve	Negative
Δ	Prism Dioptre
AC/A	Accommodative Convergence /Accommodation
cm.	Centimeter
CPD	Cycle per degree
CPM	Cycle Per Minute
D	Dioptre
Dist.	Distance
DEM	Development Eye Movement
Exo	Exophoria
Hyper	Hyperphoria
MEM	Monocular Estimate Method
Min. of arc	Minute of Arc
mm.	Millimeters
Msec.	Milliseconds
N	Sample size
No.	Number

NS	Not Significant
NSUCO	Northeastern State University College of Optometry
p	Probability
R	Right
RAN	Rapid Automatic Naming
SCCO	Southern California College of Optometry
SD	Standard Deviation
Sec	Second
Sec. of arc	Second of Arc
WPM	Words per minutes

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Chapter 1: Introduction

1.1 Reading problem and eye movement

In contemporary society, reading is regarded as the most popular channel for learning and acquiring knowledge and skills to strive for academic performance, career excellence and improved quality of life. There is no doubt that good reading skills combined with good intelligence are regarded as key success factors in this modern world.

As early as the nineteenth century, reading problems were recognized among some people. In 1887, Berlin (cited by Griffin, 1997) first introduced the term "dyslexia" to describe those people with an inability to read. Subsequently, Hinshelwood (1896) differentiated the term "dyslexia" from "alexia", the former meaning partial impairment and the latter complete impairment (word blindness) with regard to reading difficulty.

Reading dysfunction can be categorized into "non-specific" and "specific" types (Evans, 1998; Evans and Bruce, 2001). Dyslexia belongs to the specific type. It represents a deficit in an individual's ability to interpret the symbols of written language associated with minimal brain dysfunction or differential brain function (Griffin et al., 1997; Snowling, 2000). People with dyslexia are characterized as having decoding difficulties with written words or symbols, while there is no deprivation of educational opportunity and the IQ is normal. The general or non-specific type of reading dysfunction is characterized by a lack of educational opportunity, low intelligence and/or socio-cultural deprivation. A mild non-specific reading dysfunction is generally not a disease or a problem requiring excessive concern.

Other classifications of reading disability have been advocated by optometrists and psychologists. Clinically, reading disability or dysfunction is defined as a reading age two or more years behind the chronological age of the child (Beech, 1994; Kiely et al., 2001). Psychologists refer to reading dysfunction as the discrepancy between the person's ability and his/her achievement in reading (Gunning, 1998).

Nowadays, some researchers have agreed that reading involves two major processes, namely "decoding" and "comprehension" (Simons, 1987; Rack, 1994; Griffin, 1997; Evans and Bruce, 2001; Muter and Snowling, 2003). Young children in their early school years are highly dependent on "decoding"; when they grow older "comprehension" becomes increasingly important.

Usually, reading dysfunction starts with a problem of decoding of an "object or text" when viewed. Young readers recognize the shape of familiar words and they build up their own "sight vocabulary" by these visual images (Evans and Bruce, 2001). At this stage, they tend to understand words directly from sight analysis. As developing readers enter into the comprehension phase, they employ phonetic analysis to break down complex unfamiliar words into different phonetic segments. Mature readers employ both sight analysis and phonetic analysis when reading. Dysphonetic dyslexia is characterized by a difficulty with the phonetic analysis pathway, while in dyseidetic dyslexia there is a problem in the visual analysis pathway. People of the former (dysphonetic) type generally read quickly but inaccurately, while those in the latter (dyseidetic) group tend to read slowly and rely on phonetic analysis.

It has been suggested that defects in the transient system of the magnocellular pathway are the cause of dyslexia (Greatrex and Drasdo, 1995; Demb et al., 1998; Stein, 2001; Omtzigt et al., 2002). This transient system responds preferentially to low contrast, large contour and moving objects. It determines "where" the eyes should move. Therefore, a deficiency in the magnocellular pathway may result in difficulty moving the eyes efficiently during reading.

Reading requires fundamental co-ordination of the two eyes. At the same time, comprehension develops rapidly in the higher centres of the brain. Eye movements, more specifically saccadic eye movements, play an important role in reading (Poynter et al., 1982; Eden et al., 1994). As eye movements form part of the visual system, it is logical that imperfect eye movements may hinder the performance of reading and as a consequence hinder learning as a whole.

1.2 The controversy

Recently, there have been vigorous debates about whether there is a relationship between visual anomalies and reading difficulty. In the main, there are two contrasting views. In 1998, the Committee on Children with Disabilities (comprising input from the American Academy of Pediatrics, the American Academy of Ophthalmology and the American Association for Pediatric Ophthalmology and Strabismus) proclaimed that "there is no known visual cause for these learning disabilities and no known effective visual treatment." They held the strong view that "vision problems are rarely the cause of learning difficulties". They argued that there is no scientific support for the use of eye exercises, vision therapy or tinted lenses in what is a complex condition arising from genetic influences and anomalies of the brain structure and function. However, Bowan (2002), who carried out an extensive literature search, claimed that the citations quoted by the Committee on Children with Disabilities were highly selective and there were inconsistencies in their argument. In fact, ample studies suggested that visual problems are more prevalent in those with reading dysfunction (Simons and Grisham, 1987; Grisham et al., 1993; Latvala et al., 1994; Evans, 1998). This evidence suggests that vision and reading are highly associated and that a deficiency in visual function may lead to reading dysfunction.

On the other hand, Griffin et al. (1997) proposed a model which attempted to subdivide people with reading dysfunction according to the causes and manifest signs and symptoms. They suggested three groups: (1) certain vision problems causing general reading dysfunction; (2) coding problems of dyslexia causing specific reading dysfunction and (3) other problems that cause general reading dysfunction, such as attention-deficit disorder and auditory problems. The three areas can overlap and hence form 4 additional subsets. Using these categories, it is clear that if the reading dysfunction is caused by visual problems, appropriate management of these visual problems to improve visual function and alleviate associated signs and symptoms should allow people to optimize their full reading potential. In addition, there is evidence that many visual problems such as accommodative, vergence and oculomotor disorders can be effectively treated by vision therapy (Cohen, 1988; Rounds et al., 1991; Ciuffreda, 2002).

1.3 The need for a standardized eye movement test

Although there is considerable controversy within the literature as to whether visual anomalies have any significant influence on learning, there is an increasing demand for the educational authorities to examine the value of regular screening and assessment of visual function for children diagnosed as having learning or reading disabilities (Education Department, 2002; Junghans et al., 2002). The aim is to eliminate or, at least, minimize the visual problems that may hinder the development of reading performance and/or effective learning. After all, reading ability is regarded as an essential component in the learning process. A multidisciplinary approach would be most useful to identify and treat this problem more efficiently and effectively (Fawcett and Nicolson, 1994).

With the increasing availability of tests, the diagnosis of reading dysfunction is becoming more specific. For example, saccadic eye movements are an important element in reading (Poynter et al., 1982). However, in the ophthalmic field, there are some gaps in our knowledge; eye movement tests need to be standardized and validated across different ethnic groups; screening protocols need to be standardized; referral criteria for eye movements or reading dysfunction need to be defined and a standardized vision therapy programme should be formulated for specific reading problems.

The clinical tests commonly used for screening for abnormal saccadic eye movements will be reviewed and the repeatability of the scoring method of one of them, namely, the Development Eye Movement (DEM) test will be studied. Further, we will apply this test in a group of Cantonese-speaking children to establish if there are any differences in the norms between them and those English-speaking and Spanish-speaking children in previous studies. Finally, whether or not there are any differences in visual skills among the children with the different types of diagnosis from the DEM scores will be investigated.

Although eye movement problems are not the only cause of reading dysfunction, they may contribute to the overall difficulty that a child experiences when reading. In other words, eye movement problems may serve as a predictor of present or future reading dysfunction in children. Diagnosing the eye movement anomalies and treating the visual problems should help the child to cope with reading and hence the learning process.

Chapter 2: Review of eye movement and clinical eye movement tests

2.1 Classification of eye movements

There are two main types of eye movements namely vergence and version. Vergence eye movements are disjunctive eye movements whereby the eyes move in opposite directions in a plane. This occurs when a person changes the fixation from distance to proximity or vice versa. In version eye movements, the two eyes move in the same direction, for example saccadic and pursuit eye movements.

2.1.1 Vergence eye movement

Vergence eye movements are disjunctive during changes of fixation distance. Disparity between the two retinal images stimulates vergence eye movements. The classification of convergence dates back to the studies of Maddox (1893) (reviewed by Morgan 1983), who divided convergence into four types namely, tonic, accommodative, fusional and proximal. "Tonic convergence" is the result of tonus in the extraocular muscles and represents the physiologic position or resting state of the eyes. "Accommodative convergence" occurs as a result of the close association of convergence and accommodation. "Fusional convergence" is the ability to maintain the fusion of two corresponding retinal images. "Proximal convergence" is caused by the awareness of a near object. Humans can use these fusional eye movements to align the eyes such that the two visual axes are directed onto objects at different working distances. Bobier et al. (2000) demonstrated the presence of a cross-link between convergence and accommodation as early as 3 to 6 months. They commented that the cross-links appear near the time when rapid maturation of the accommodation and vergence systems occurs and confirmed that sub-cortical visuo-motor activity is present in the early months of life, which had been reported earlier (Braddick, 1996). Accommodative vergence occurs as early as the second week of life (Aslin and Jackson, 1979) and improves in accuracy when accommodation starts to develop.

2.1.2 Pursuit eye movement

In addition to maintaining the position of the eyes at different fixation distances using the vergence system, it is equally important to locate the object of interest in our visual field or perceptual span. This requires eye tracking and searching ability. The "following eye movements" are known as pursuits and they require constant target foveation. Hence, the development of pursuit movements is dependent on post-natal foveal development. The newborn's smooth pursuit movements are short in duration, approximately 300 to 400 msec (Moore, 1997) and require a target size of at least 12 degrees. In general, smooth pursuit eye movements are found in infants at around 3 months old (Phillips et al., 1997), however, the type of eye movement is still not adult-like and there is a fixation lag behind the target. The quality of pursuits improves during childhood (Harris et al., 1993) and becomes mature at adolescence (Katsanis et al., 1998).

2.1.3 Saccadic eye movement

Saccadic eye movements are rapid shifts in fixation from one point to another. Infants can normally make saccades in the correct direction toward the target, each covering only a fraction of the required distance (Aslin and Salapatek, 1975). The number of saccades needed to fixate a new target gradually reduces during infancy; however, the accuracy is still not adult-like. The latency of a saccadic response is also longer in the infant and gradually decreases during childhood (Kowler and Fachiano, 1982; Kowler and Martins, 1982).

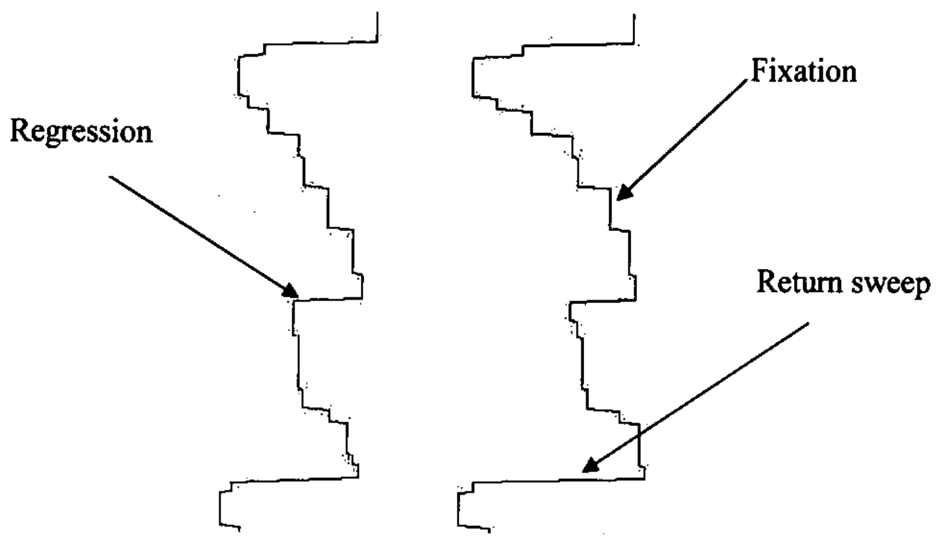
2.1.4 Fixation

Fixation occurs between saccades. It is highly correlated with the foveal vision. As visual acuity is quite poor at birth due to the immature fovea, fixation is also poor during the first 2 to 3 post-natal months (Harris et al., 1985). Aslin and Salapatek (1975) reported that newborns tend to fixate on an object and shift fixation to another object and that this tendency increases during the first 3 months. Kowler and Martins (1982) and Kowler and Fachiano (1982) both reported that pre-school and 10-year-old children had less accurate fixation control than adults. Young children have large saccadic corrections and higher drift rates during fixation. However, Aslin and Ciuffreda (1983) suggested that this behaviour may be attributed to "attention" factors, in addition to immature oculomotor control.

2.2 Normal eye movement in reading

Eye movements involved in reading are mainly saccades, in which the two eyes travel six to eight character spaces. In between saccades, the eyes stop and fixate on visual targets. In general, when an adult reads English, each fixation lasts approximately 225 msec (Ciuffreda and Tannen, 1995b) and covers 6 to 8 characters of text within the foveal region. Sometimes, we need to move our eyes backwards to re-read the same text; this backward shift is called a regression. Normally, regression only extends to a few characters and typically, it is triggered by some text confusion or comprehension problem. In addition, there is a large right-to-left saccadic eye movement from the end of one line to the beginning of next. This kind of saccade is called a "return-sweep saccade" and covers approximately 12 to 20 degrees and has a duration of 40 to 54 msec (Ciuffreda and Tannen, 1995b). In a return-sweep, over-convergence with amplitude of 0.1 to 0.3 degree is not uncommon. This is followed by a corrective dynamic divergence response (approximately 300 msec in duration) to regain accurate bi-foveal fixation. There are various experimental setups, such as the infrared corneal reflex tracking system, to plot the position of the eye over time. This technique, adopted by the Visagraph II, can record the details of eye movements during reading. Figure 2.1 illustrates a typical eye movement pattern during reading as recorded by using a Visagraph II by the investigator in the Optometry Clinic of the Hong Kong Polytechnic University.

Figure 2.1 Sample from Visagraph II (The Hong Kong Polytechnic University)



Rayner (1979) found that fast readers tend to have longer saccades, shorter fixation time and fewer regressions than slow readers. However, the level of difficulty of the reading material, word ambiguity, grammatical function and predictability all affect the frequency and duration of fixations.

2.3 Eye movement control

There are two main ways to studying eye movement control:

1. The neuro-physiological approach, which studies the brain activities in relation to the control of eye movement and
2. The behavioural or psychological approach which focuses on the characteristics of the eye movement and fixations.

2.3.1 Neurological approach

Pulse-step innervations

Saccades are driven by rapid, high frequency bursts of neural activity; which produce high speed ocular acceleration (Zuber, 1981). The innervation of a saccade has a pulse-step form (Ebenholtz, 2001). The "pulse" means a burst of nervous signals, which stimulate the extra-ocular muscles to move the eye to a new position and the "step" means a tonic control of neural activity to maintain the extraocular muscles, thus, holding fixation in the new position. The longer the pulse duration, the greater will be the eye movement amplitude. Anatomically, these impulses are generated by two types of neurons namely "burst" and "pause" neurons. The "burst" neurons are located in the paramedian pontine reticular formation, pons and rostral interstitial nucleus of the medial longitudinal fasciculus (Ciuffreda and Tannen, 1995b).

The neural information flow

When a person fixates on a visual target, information processing occurs during this short period of "pause" (Ciuffreda and Tannen, 1995b). The visual signals flow from the retina to the lateral geniculate nucleus (LGN). At this moment, neural transmissions are sent in parallel to two different pathways.

One pathway, the parvocellular system, projects to area 17 of the visual cortex. It is mainly involved in determining "what we see" or analyzing the pattern of the target. The visual target details are sent from area 17 to other areas (layer 4C beta) of the visual cortex for further detailed analysis. The parvocellular system is characterized by low contrast sensitivity, high spatial resolution and analysis of fine details.

The other pathway, named the magnocellular system, projects to the superior colliculus from the magnocellular layers of the LGN. This pathway determines "where we look" or selects the next target for a saccade (Wurtz and Mohler, 1976). The neural information flows from the superficial layer of the superior colliculus to the frontal eye fields and the parietal cortex, both of which are involved in "directing visual attention" (Crowne, 1983). After receiving triggering information from the frontal eye fields and parietal lobe, the superior colliculus encodes the desired change in eye position with respect to the fovea and relays this information to the brainstem. Thence, the brainstem forwards this information to the cerebellum and those structures involved in generation of the saccade. A nervous impulse is fired to the extraocular muscle to produce the desired saccadic eye movement. Thus, the magnocellular system accounts for the initiation of the eye movement and is characterized by low spatial resolution and motion detection. On account of this unique feature, the magnocellular system is also known as the "transient" system.

These two pathways maintain their independence during the flow of neural information, although there are projections from the visual cortex to the frontal eye fields. This cross linking of the neural systems allows the object of regard to influence on the triggering of new eye movement when attention is shifted to a new position. Posner (1980) studied the relationship between the eye movement system and visual attention. He suggested that there are three mental processes involved in "directing visual attention":

1. Disengagement of attention;
2. Change of attention to a new location and
3. Engagement of a new target.

The parietal lobe may be involved in the disengagement of attention, the superior colliculus is thought to be responsible for moving attention to a new position and the frontal eye fields may have a role in engaging the new visual target (Posner et al., 1982; Posner et al., 1984).

Obstruction to or under-development of any component of the above neurological pathways may lead to eye movement dysfunction and subsequently affect reading ability. Stein (2001) proposed that dyslexia is related to a deficit in magnocellular development. He used a computerized procedure to test children's sensitivity to the visual motion of an array of dots. He found that children with reading disabilities had poorer motion sensitivity than the normal controls. Poor motion sensitivity seems a typical deficit in the transient or magnocellular system.

From the above research, both the neural control of eye movements and the transient deficit in reading dysfunction appear to involve the magnocellular system. This intimate relationship further suggests that eye movement dysfunction could be a predictor of reading disability.

2.3.2 Behavioural approach

The neurological studies suggest that there are two control pathways utilizing the visual information to determine "when" and "where" the eyes should move. Attentional mechanisms also have eye movement control centres in the brain. These characteristics fit well with the behaviour evidence derived from data obtained from monitoring eye movements during reading. The "saccade length" and the "landing position" are measures of "where to look" next in a line of text. The process of determining "when to move" the eyes is expressed by the "fixation duration".

<u>"Where to look"</u>

In a line of words, there are three regions with respect to the point of fixation:

1. Foveal, which approximates a 2-degree central visual field;
2. Parafoveal, which extends 5 degrees in each direction from fixation;
3. Peripheral, which represents the region outside the parafoveal area.

The decision "where to look" is generated by information from the parafoveal region, such as the length of the upcoming word and the presence of parafoveal letters (Morris et al., 1990). They showed that the fixation time is shorter, if the words are visible in the parafoveal region prior to fixation.

The location of fixation is not random in nature. Rayner (1979) suggested that during reading, the eyes go most frequently to a location slightly left of the centre of a word. This finding was confirmed by McConkie et al. (1988) some years later. Sixty-six subjects were requested to read a long extract from a novel in a two-hour session. The texts were displayed on a computer screen one line at a time. Eye movements were recorded by a Purkinje Image Eyetracker. The authors attempted to collect large samples of eye movement information over a long testing period (2 hours), which may have affected the results due to the fact that some subjects were very tired with the long duration of reading.

As a conclusion, information from the foveal and peripheral region is of less important in determining "where to move" the eyes. Parafoveal information thus plays the most important role in "where to move" and "where to stop" the eyes in a saccade.

"When to move"

Acquisition of foveal information is the major factor determining when our eyes are moved and the length of a fixation. "Word frequency" affects the fixation time for a word, that is, the duration of fixation for common words is less than for less frequently used words (Just and Carpenter, 1980). In addition, if the letters of the word are visible in the parafoveal region on the prior fixation, the fixation time on that word is shorter (Rayner and Duffy, 1986; Morris et al., 1990). Epelboim (1994) claimed that un-spaced text is more easily read by reading-disabled persons, however, other recent researchers (Rayner and Pollatsek, 1996; Rayner et al., 1998) showed that the absence of space information disrupted eye guidance and slowed the reading speed. In conclusion, the fixation time is highly dependent on foveal information, in addition to being affected by the familiarity and the difficulty of the text.

These behavioural studies show that during reading the saccadic eye movements are influenced by the word under fixation (foveal information) and by the surrounding words and spaces (parafoveal information). Hence, the design of an eye movement test should minimize these influences. As a result, most psychometric tests (Garzia et al., 1990; Kulp and Schmidt, 1997b) use single-digit numbers as targets, which eliminates effects due to the length of the word and its level of difficulty.

2.4 Eye movement in poor readers

Many researchers have studied the quality of saccades in individuals with reading difficulties (Ciuffreda et al., 1985; Pavlidis, 1985; McConkie et al., 1988; Ygge et al., 1993b; Eden et al., 1994; Solan et al., 1998). Most found poor quality of eye movements, including increased numbers of saccades and long fixation times for problematic readers. An excessive number of regressions are also common because the reading-disabled person needs to double-check the correctness of previously decoded words.

To what extent eye movement problems will cause reading disability is a controversial issue. Obviously, people with oculomotor disturbances, such as saccadic intrusions (Ciuffreda et al., 1983), low vision (Bullimore and Bailey, 1995; Bowers and Reid, 1997) or nystagmus (Ciuffreda, 1979) have difficulty reading. Therefore, there might be different reasons other than oculomotor dysfunction causing reading disability. Pavlidis (1981) showed that dyslexic readers make more right-to-left saccades than normal and backward readers when presented with a non-text target (a moving dot on computer screen). Similarly, Eden et al. (1994) reported that poor fixation stability is present in dyslexic children during non-verbal visual tasks. Pirozzolo and Rayner (1978) showed eye movement characteristics in dyslexic patients, which were similar to those reported by Pavlidis (1981). However, the findings of Pavlidis (1981) have not been successfully replicated in other studies (Brown et al., 1983; Stanley et al., 1983; Black et al., 1984). These controversial findings further suggest a need in confirmation of the relationship between eye movements and dyslexia.

There is also a relationship between poor reading performance and text difficulty. As the text difficulty increases, the fixation duration increases, saccadic length decreases and the number of regressions increases (Morris and Rayner, 1991). Poor readers have eye movement patterns that are similar to normal readers when reading difficult texts (Elterman et al., 1980). Therefore, it is possible that the poor eye movement control is a secondary outcome of a deficiency in cognitive processing in poor readers.

People with reading or dyslexic problems are likely to have language processing deficits, as their eye movement characteristics (long fixation and many regressions) reflect their difficulties with processing language. The findings of Pirozzolo and Rayner (1978) support this phenomenon. They asked dyslexic subjects to read text that was appropriate for their reading level (or reading age) and found that their eye movements were similar to those of normal readers for the same age level. However, when age appropriate text was given, their eye movements were again abnormal. So, the saccadic eye movement problem as shown in clinical testing could be treated as a reflection of one of the problems in a reading-disabled person.

Whether the saccadic eye movement dysfunction is primary or secondary, it is important, from the patient's point of view, to identify the presence of the problem rather than looking into the cause and effect relationship between the reading difficulty and eye movement problems. As reading dysfunction can be a serious problem affecting a child's ability to learn and study effectively, many parents are eager to ascertain the reason and the solution. Therefore it is important to establish a fast and accurate test to identify the saccadic eye movement problems.

2.5 Clinical eye movement tests

Some eye movement tests require complex and expensive equipment, for example electro-oculography (EOG), the infrared limbal reflection technique, the magnetic search coil technique, the contact lens optical lever and the SRI eye tracker (Ciuffreda and Tannen, 1995a). These laboratory-based tests are precise research tools but are not practical in the clinical environment. Clinically, there are three main types of saccadic eye movement tests: electrodiagnostic, direct observation and psychometric tests.

2.5.1 Eletrodiagnostic tests

Visagraph II is a newly developed electrodiagnostic device to record eye movements during reading (Colby et al., 1998; Solan et al., 1998). The system consists of infrared goggles and a recording unit which is attached to a computer. The infrared sensors in the goggles eliminate the influence of head movement and this design removes the need of individual calibration for each user. At the beginning of a recording, a subject was requested to read an age-appropriate material from the test booklet. The software was designed to record the details of the eye movements, including the number of fixations, the quality of the return sweep, the number of regressions duration fixation and reading rate. After reading the material, the subject was requested to answer ten "Yes or No" questions related to the article provided by the test-book. If the subject's comprehension was less than 70%, the examiner should retest the subject by another test material on the same level. Each of these sets of data can be compared with established norms. The objective nature of this instrument makes it suitable for monitoring changes in eye movement functions over time or during a period of treatment (Rounds et al., 1991). However, this device is very expensive and not popular in clinical practice.

2.5.2 Direct observation test

Direct observation in free space tests are usually carried out when a child is sitting right in front of the examiner. In general, small target(s) are presented and the child is asked to look at the target with the command of the examiner. The examiner holds two small targets at arm-length apart and asks the child to change fixation from one to the other. The examiner observes the quality of fixation and the eye movements, for example, jerky, overshooting etc. The disadvantages of this testing method are that it is too subjective, lacks standardization and has poor inter-observer repeatability.

2.5.2.1 SCCO test

Southern California College of Optometry (SCCO) modified the direct observation test by introducing a scoring system (Maples, 1997). The examiner holds the two targets (20/60 to 20/80 in size) 40 cm in front of a child and 15 cm apart. The child is required to fixate one and then the other target upon verbal command from the examiner. The examiner evaluates the accuracy and latency in each saccadic eye movement by careful judgment of the quality of fixation and movement. There are four different scores from 4+ to 1+ and these grading are given according to the number of fixation losses as recorded by the examiner. The drawback of the SCCO system is the lack of standardized procedures and of normative data for comparison.

2.5.2.2 NSUCO oculomotor test

The Northeastern State University College of Optometry (NSUCO) oculomotor test was the first standardized direct observation test, which included a standardized scoring system and normative data (Maples, 1997).

The administration of the test is similar to the SCCO test: The examiner holds two targets not more than 40 cm from a child and each target is about 10 cm from the midline of the subject. The child is asked to look from one target to the other on verbal command. This is repeated for a total of 5 times. The child is not given any advice or reminder regarding head movement. The examiner observes the eye movement, body movement, ability and accuracy and gives a score according to a table. Then the scores are compared with the given norms. Although this test was proved to have good inter-rater and test-retest reliability (Maples and Ficklin, 1988), it still requires a subjective judgment from the examiner.

2.5.3 Psychometric tests

Some psychometric tests use the principle of rapid automatic naming (RAN). These tests usually provide a standard procedure and norms for comparison.

2.5.3.1 Rapid automatic naming (RAN)

Rapid automatic naming (RAN) is the ability of a person to name highly familiar objects with maximum speed. This automatic ability allows a person to carry out certain mental operations, e.g. number, letter or word naming, without significant awareness or attention when compared with subjective effortful processes which require conscious attention to the task (Hahser and Zacks, 1979). When the task becomes more automatic, less time is required to complete the task. Early study of RAN involved naming items such as letters, colour patches or digits in a matrix of 10 x 5 format (Denckla and Rudel, 1976). Denckla and Rudel (1976) considered that the errors in RAN test were infrequent, so they examined only the time for completion of the naming.

RAN tests are commonly used by developmental psychologist to assess the naming skills of those having reading problems. Most of the tasks are listed inside a matrix of regular spacing. Minimal saccadic eye movement skill is required in their setup.

According to the model proposed by LeBerge and Samuels (1974), the central processing mechanism is a "letter-by-letter" analysis at the beginning phase of learning to read. At this stage, reading is slow and comprehension is minimal. When more and more experience is gained through practice, letters and then words are identified more easily and finally become automatic, thus allowing the higher processing centres to attend to other activities, such as comprehension.

Therefore, automaticity of naming letters, numbers and words must be developed to allow effective reading skills and permit the allocation of attention to higher level processes. Yap and van der Leij (1994) defined automaticity as follows:

"*Automaticity is normally defined as a mode of processing that is executed rapidly, is free from demands on processing capacity, is not subject to voluntary control and is not susceptible to interruption by competing activity that interferes in the same domain.*"

When a letter or number is presented to a child, the naming of such letter or number requires a bridging between visual, cognitive and linguistic, sub-processes such as feature analysis, attention and articulation. Reading is similar and also requires interconnections of these processes. If reading and naming of letters share these common processes, then we believe that the quality of the rapid automatic naming should show a relationship to reading ability.

The eye movement tests described earlier are either expensive and/or lack objectivity. Psychometric tests for eye movements have been developed to overcome these shortcomings. The following tests are quantitative and are designed using similar principles to the RAN test. All of these tests require visual-verbal responses from the subject.

2.5.3.2 The King-Devick Test

The King-Devick (K-D) test was developed from the Pierce Saccadic test, which is based on the RAN test concept. It consists of three test cards, each containing eight horizontal rows of five single-digit numbers. The child is asked to read the numbers as fast as possible. These numbers are randomly printed on the sheet to simulate saccades as in reading conditions. Spacing becomes more complex from one card to another; therefore, the test requires progressively finer saccades. The time and number of errors are recorded and compared with the normal scores based on chronological age. As reviewed earlier, the saccadic eye movements are affected by the length of surrounding words (Morris et al., 1990). Therefore, the use of "numbers" as targets eliminates the effect of the uneven length of English words.

Richman et al. (1983) studied the K-D test with 64 children aged 6.1 to 8.5 years old. The children were subjected to the K-D test first and then subjected to a television display set up that the digit appeared on the screen one by one, which is designed to assess the child's digit call-out ability without the need for eye movements. The results of that study supported the claim that automaticity of number knowledge is significantly related to the K-D test results. However, the test could not distinguish eye movement deficiency from the inability to rapidly verbalize numbers. The test and re-test reliability of the K-D test was also challenged by Oride et al. (1986), who found poor reliability of the K-D test results, when the same group of children were re-tested 2 weeks later.

2.5.3.3 The Developmental Eye Movement test

The Developmental Eye Movement (DEM) test (Richman and Garzia, 1987) was developed to improve the K-D test by adding a vertical sub-test. The DEM test has been used widely in the field of optometry to evaluate saccadic eye movements. The major difference between the DEM and the K-D tests is that the DEM test includes the vertical arrays of numbers, which can determine the effect of automaticity and thus differentiate the score with regards to automaticity and eye movement problems.

The DEM test was developed by Richman and Garzia in 1990. It consists of three subtests:

1. Pretest
2. Vertical tests and
3. Horizontal test.

In the pretest (Figure 2.2), the child is asked to read out all numbers correctly. The pretest is to rule out the possibility of deficit of number knowledge and to ensure the child can see the numbers. Anyone who fails in the pretest (i.e. take longer than 12 seconds to complete the test) should not proceed into the remainder of the test.

Figure 2.2 The DEM pre-test (Extracted from the DEM test, original chart in size of 8.5" X 11" (Richman and Garzia, 1987))

PRE-TEST

3 7 1 9 2 6 5 4 8 2

Next, the child is asked to read the vertical array subtest, which is composed of two plates, each consisting of 40 numbers. Test plate A (Figure 2.3) is placed in front of the child and the child is asked to read the numbers down the first column and then the second column as fast as possible. During the test, the child is not allowed to use a finger to point nor make any head movement. The time taken and the number of errors made while completing test plate A are recorded. The child is then tested using plate B (Figure 2.4) in the same fashion. The vertical reading time is the sum of the time to complete both tests A and B. In the two vertical subtests, there are no particular demands on saccadic or eye searching movements when reading the numbers.

In the horizontal test, the numbers are arranged with unequal horizontal separation. All of the 80 numbers are printed on test plate C (Figure 2.5). The child is asked to read the numbers across the rows as quickly as possible.

The time for completion and the number of errors are recorded. Because "omission" and "addition" errors are rather common, a corrective formula is recommended to adjust the reading time accounting for the horizontal test:

Adjusted horizontal time (sec) =

$$\frac{\text{Horizontal time (sec)} \times 80}{(80 - \text{omission errors} + \text{addition errors})}$$

The 'ratio score' is determined by dividing the adjusted horizontal time by the vertical time. The total number of errors made is the error score of the test. The results are compared with the norms supplied in the test manual.

Figure 2.3 The DEM vertical subtest A (Extracted from the DEM test, original chart in size of 8.5" X 11" (Richman and Garzia, 1987))

TEST A

3	4
7	5
5	2
9	1
8	7
2	5
5	3
7	7
4	4
6	8
1	7
4	4
7	6
6	5
3	2
7	9
9	2
3	3
9	6
2	4

Figure 2.4 The DEM vertical subtest B (Extracted from the DEM test, original chart in size of 8.5" X 11" (Richman and Garzia, 1987))

TEST B

6	7
3	9
2	3
9	9
1	2
7	1
4	4
6	7
5	6
2	3
5	2
3	5
7	7
4	4
8	6
4	3
5	7
2	5
1	9
7	8

The vertical test assesses visuo-verbal automatic naming skills or the RAN ability. In the horizontal test, it covers the visuo-verbal automaticity with the added effect of ocular fixation and saccadic programming (Richman et al., 1983; Richman and Laudon, 1997).

Figure 2.5 The DEM horizontal subtest C (Extracted from the DEM test, original chart in size of 8.5" X 11" (Richman and Garzia, 1987))

TEST C

3		7	5			9			8
2	5			7		4			6
1			4		7		6		3
7		9		3		9			2
4	5				2			1	7
5			3		7		4		8
7	4		6	5					2
9		2			3		6		4
6	3	2		9					1
7				4		6	5		2
5		3	7			4			8
4			5		2			1	7
7	9	3			9				2
1			4			7		6	3
2		5		7			4		6
3	7		5			9			8

Garzia et al. (1990) commercialized the DEM test in 1990. The norms were established from a group of 6 to 13 year-old English-speaking children. In general, the score result is considered below standard if the score is in the 15th percentile or lower. This is one standard deviation away from the mean. According to the manual, there are four possible clinical conditions derived from the DEM scores.

Type I is characterized by "normal performance" in all subtests. **Type II** is characterized by an increased horizontal reading time (below 15th percentile) but with a relatively normal vertical reading time. The ratio score from these children is usually high. Therefore, children who passed the vertical test and failed both the horizontal test and the ratio were classified as having "saccadic eye movement dysfunction. Grazia et al. (1990) suggested that oculomotor dysfunction (or a saccadic eye movement problem) is the cause of this manifestation. A Type II child should not have a problem with rapid number naming, but fails in the horizontal test time, which means that this task critically challenges saccadic eye movement function. **Type III** is characterized by higher than normal vertical and horizontal reading times but with a normal ratio score. Children with Type III outcomes have poorly developed automaticity, such that the performance in both the vertical and horizontal tests is affected. The normal ratio score represents a basic difficulty in the automaticity of number naming. Garzia et al. (1990) were unclear as to what should be done for a child with an automaticity problem, merely suggesting that further investigation is required. According to Yap and van der Leij (1994), reading-disabled children have an automaticity deficit in word reading. However, the discovery of an automaticity deficit does not confirm that the child is suffering from learning or reading difficulty. They suggested that such a child should be referred for further assessment of other developmental milestones, such as intelligence quotient, or other visual perceptual functions. **Type IV** combines the characteristics of both Type II and Type III. Vertical time, horizontal time and ratio score are all subnormal. These children suffer from both automaticity and oculomotor deficiencies. Table 2.1 illustrates the four types of clinical conditions based on the DEM test scores.

Table 2.1 Four types of diagnoses derived from the DEM test scores (Extracted from manual, Garzia et al. (1990))

Diagnosis		Vertical test score	Horizontal test score	Ratio score
Type I	Normal	Normal	Normal	Normal
Type II	Oculomotor or saccadic eye movement dysfunction	Normal	Subnormal	Subnormal (relatively higher)
Type III	Automaticity dysfunction	Subnormal	Subnormal	Normal
Type IV	Both automaticity and oculomotor dysfunction	Subnormal	Subnormal	Subnormal

Among the four types of diagnosis, there are other possible combinations of DEM scores that lead to some conditions not clearly identified by the authors. The other possibilities are listed in Table 2.2.

Table 2.2 Other possible additional DEM diagnosis

Diagnosis	Vertical test score	Horizontal test score	Ratio score
Type V	Normal	Subnormal	Normal
Type VI	Subnormal	Normal	Normal

If a child fails in horizontal reading time (below 15th percentile) but passes in both vertical reading time and ratio, it is not strictly diagnosed as a "Type II". What would be an appropriate description of this problem? On the other hand, a child could fail in vertical test, but passed in both horizontal test and ratio score. What are the reasons for these situations? Perhaps the child is too nervous at the beginning of the test and causing such unsatisfactory result in the first test (vertical test). So it is worthwhile to re-test these children again sometime later.

Most of the studies of the DEM test have focused on its application to eye movement functions (Garzia et al., 1990; Fernandez-Velazquez and

Fernandez-Fidalgo, 1995; Jimenez et al., 2003), however, there are few reports on the prevalence of the DEM diagnosis involving saccadic eye movements and automaticity problems.

Garzia et al. (1990) noted that the reliability of the error score was rather low and suggested that the error score should be treated as additional information. This indicated that the subject was not likely to repeat the same error at the same location, this implied that the intra-subject repeatability of the DEM error was not high. However, this factor did not alter the overall repeatability of the test results as different studies obtained repeatability DEM scores when the test was repeated one week apart (Garzia et al., 1990; Adler et al., 2004)}. Garzia et al. (1990) also found the vertical errors in most of the children were so minimal that this error could be neglected and there was no need to adjust the vertical reading time. Garzia et al. (1990) did not publish the details of the vertical error in different age groups but Jiménez et al. (2003) reported very low mean vertical error ranged from 1.4 ± 1.9 to 0.55 ± 0.9 for Spanish-speaking children aged from 6 to 11 years.

The advantages of the DEM test are that it is inexpensive and fast permitting optometrists to diagnose saccadic eye movement dysfunction efficiently, especially for young children. From the results of the DEM test, clinicians can differentiate children who have automaticity problems from those with saccadic oculomotor dysfunction. If a child scores well in the vertical subtest but reads very slowly or with many errors in the horizontal subtest, he is likely to be suffering from saccadic eye movement dysfunction. On the other hand, if a child reads slowly in both vertical and horizontal subtests and the ratio is in the normal range, it is highly likely that the child's automaticity has not developed to an appropriate level for his age. Thus, referral is required for further developmental assessment to find out if the child is suffering from problems like dyslexia, which is associated with poor rapid automatic naming (Wolf and Bowers, 1999; Compton et al., 2001). Recently, the DEM test was found to be as sensitive as other tests in the assessment of word recognition problems (Lowther et al., 2001). It is a useful screening tool to detect reading problems in young children.

Comparing the DEM test results from a group of Spanish-speaking children with the published norms for English-speaking children showed no difference (Fernandez-Velazquez and Fernandez-Fidalgo, 1995). These two languages belong to the same group of Indo-European-related idioms. The authors suggested that norms might need to be developed for different languages. Hatch et al. (1994) used the DEM test in a group of migrant children. whose mother languages were not English. Even though they were tested in English, the authors found significantly different DEM scores from the norms suggested by Garzia et al. (1990). Hence, these studies implied that the norms not only reflected the saccadic eye movement function but also other related factors such as language, education level and the cognitive development of the children particularly those with different cultural and linguistic backgrounds. All these external factors can affect the result of many developmental processes such as rapid naming ability as determined by the DEM test.

Although the DEM test had been used for many years, there was no study benchmarking the test with other objective eye movement test, for example, the Visagraph II test. Therefore there exists a research area to compare the DEM test with other eye movement test results.

2.5.4 Comparison of different eye movement tests

Each eye movement test has its advantages and disadvantages; Table 2.3 summarizes these tests under the following categories: the nature of test (objective or subjective), availability of normal values by chronological age, cost of the test, and complexity of the set-up and administration time.

The DEM test is the best test to use clinically for the assessment of saccadic eye movements. It is inexpensive, less subjective than some other tests and norms are provided for performance ranking. In addition, it is the only test, in which vertical and horizontal reading performance can be compared to enable detection of automaticity (Garzia et al., 1990; Hatch et al., 1994; Kulp and Schmidt, 1997b; Lowther et al., 2001).

2.6 Summary

Saccadic eye movements and fixation are the two key ocular functions of reading. Both neurological and psychological researchers found that there are mechanisms and factors affecting "where to see" and "what we see". These factors must be considered in the design of an objective and reliable saccadic eye movement test. Among the clinical eye movement tests, the Developmental Eye Movement test is an efficient, economic and objective test for screening for both saccadic eye movement and automaticity problems (Garzia et al., 1990; Lowther et al., 2001). The DEM test relies heavily on the subjective judgment of the administrator in judging the reading time and the errors made by a child. If there is a way that can minimize the personal inaccuracy during the data collection in the DEM test, it will certainly improve its accuracy and the reliability of the test result. The current norms for chronological ages are derived from English-speaking children. There appear to be no norms established for languages other than English and Spanish (Fernandez-Velazquez and Fernandez-Fidalgo, 1995). English and Spanish belong to the same Indo-European idioms, and we do not know whether the norms from these two languages are suitable for Asian languages such as Cantonese, which is a dialect of Chinese used in Guangdong province including Hong Kong, China. As a result, we included these two points as part of our study objectives.

Table 2.3 Comparison of different saccadic eye movement tests

Tests	Nature	Norms	Cost	Setup	Administration time	Remarks
Visagraph II	Objective	Yes	Expensive	Complex – requires computer system	Medium 5 to 10 minutes	Difficult with inattentive and hyperactive child
SCCO test	Subjective (requires careful observation of the examiner)	No	Very low cost	Simple, two hand-held targets	Very fast 1 minute	No norms for comparison
NSUCO test	Subjective (requires careful observation of the examiner)	Yes	Very low cost	Simple, two hand-held targets	Very fast 1 minute	Result relies highly relied on the examiner's observation
King-Devick test	Subjective (requires accurate timing and error pick up)	Yes	In- expensive	Simple, test books and stop watch	Fast 3 minutes	Cannot differentiate the problem from automaticity
The DEM test	Subjective (requires accurate timing and error pick up)	Yes	In- expensive	Simple, test books and stop watch	Fast 3 minutes	Can differentiate problems in automaticity and oculomotor problem

Chapter 3: Visual functions and eye movements

The human visual system comprises sensory, integrative and motor processes. The sensory process requires unobstructed anatomic, physiologic and psychological development to bring visual acuity, refractive error and accommodation to their normal levels of function. The integrative process requires maturation of the visual pathways and development of normal correspondence between the two eyes. The motor processes engage proper alignment of the two eyes at various distances and gazes but this depends on coordinated vergence and eye movements. As there is intimate relationship between eye movements (motor skill) and various visual functions (mostly sensory skills), this Chapter reviews some of the key visual functions and their relationship to eye movements.

3.1 Visual acuity

Visual acuity is the resolving power of the eye. At birth it is quite poor in development but it shows a rapid improvement through the first 6 months of life (Mayer et al., 1995). Visual acuity subsequently refines at a slower rate reaching adult acuity (30 cpd = 20/20), which occurs at 3 to 5 years of age (Mayer and Dobson, 1982; McDonald et al., 1985; Mayer et al., 1995; Salomao and Ventura, 1995).

There are few studies which have investigated the relationship between visual acuity and eye movements. In contrast, there are numerous studies, which have examined the relationship between reading and visual acuity. Grisham and Simons (1986) reviewed many of these studies and concluded that "distance visual acuity" is not associated with reading skills, however, they also mentioned that some other studies indicated that poor near visual acuity is related to poor reading ability. In our earlier discussions, we noted that saccadic eye movements depend on foveal information. As reading is a near task, it is logical to state that poor near acuity should affect the duration of fixation and thus the quality of reading.

3.2 Refractive error

In general, infants are hyperopic (Banks, 1980b; Ehrlich et al., 1997; Leat et al., 1999; Atkinson et al., 2000). During the period from infancy to about 6 years of age, there is a general reduction in hyperopia (Mayer et al., 2001). The change in the distribution of refractive error from Gaussian at infancy to leptokurtic in the first several years of life is accompanied by a shift to emmetropia and this mechanism has been called emmetropization (van Alphen, 1986; Gwiazda et al., 1993a; Atkinson et al., 2000; Mayer et al., 2001).

Refractive errors vary significantly across different ethnic groups (Chandran, 1972; Baldwin, 1981; Kleinstein et al., 2003). The Chinese are known to have a high prevalence of myopia (Lam and Goh, 1991; Edwards, 1999; Lin et al., 1999; Zhao et al., 2002). Edwards and Shing (1999) followed the refraction changes of thirty two Chinese children from their early infancy to 7 or 8 years old. The mean spherical equivalences were +2.81 D at 11 weeks and -0.31 D at 94 months, indicating the development of myopia in young Chinese children. Table 3.1 describes the findings of some recent studies of Chinese children.

Table 3.1 Refractive errors in Chinese children

Investigators (year)	Number of subjects	Age (years)	Region	Mean refractive errors (D ± SD)
Lin et al. (1999)	11178	7 - 18	Taiwan	Myopia started at 9 years of age Age 18: -3.92 D in girls and -2.71 D in boys
Edwards (1999) (a 6-years longitudinal study)	123	7 - 12	Hong Kong	Same subject group in 6 years: Age 7: +0.32 ±0.91D (n=123) Age 8: +0.14 ±1.18 D (n=112) Age 9: +0.20 ±1.54 D (n=109) Age10: -0.30 ±1.82 D (n=105) Age 11: -1.07 ±1.94 D (n=94) Age 12: -1.09 ±1.68 D (n=83)
Lam and Goh (1991)	383	6-17	Hong Kong	Age 6-7: -0.09 ±1.50D (n=35) Age 8-9: -1.24 ±1.69D (n=50) Age 10-11: -1.77 ±2.21D (n=59) Age 12-13: -1.31 ±1.88D (n=86) Age 14-15: -1.46 ±1.96D (n=102) Age 16-17: -2.05 ± 2.08D (n=51)

Does refractive error affect the quality of eye movement? There is no simple answer to this question. As poor eye movements are associated with poor reading (Poynter et al., 1982; Eden et al., 1994), the relationship between eye movements and refractive status can be established indirectly. Simons and Gassler (1988) claimed that hyperopia is associated with "below average reading"; myopia is associated with average or above-average reading while astigmatism is unrelated to reading performance. The authors suggested that the hyperope requires extra accommodative effort for reading and this effort may lead to eye strain and fatigue, making reading more difficult. This explanation implied that the subjects were uncorrected or under-corrected hyperopes, so the fundamental cause of the below average reading performance may be the overloading of accommodative system. Further research is needed to differentiate reading performance in fully corrected and uncorrected hyperopes.

Recently, Buehren et al. (2003) demonstrated that the force exerted by the eyelid during reading can create slight change in corneal topography. As a result, the refractive error as well as the image quality on the retina will be affected. The authors questioned if the lid force would be one of the causes of creating focusing blur and thus triggering the eyeball to grow bigger. This still needs further research.

3.3 Accommodation

Accommodation provides a sharp retinal image at different working distances and it functions from the first few weeks of life (Banks, 1980a). Accommodative function includes the amplitude, response and facility of accommodation.

3.3.1 Amplitude of accommodation

The amplitude of accommodation is a measure of the maximum accommodative response. The amplitude of accommodation can be measured monocularly or binocularly. There are two common clinical assessments of accommodative amplitude, namely the push-up and minus-lens methods. The push-up method usually gives higher amplitudes of accommodation than the minus-lens method (Atchison et al., 1994), because when the target gets closer to the eye in the push-up test, the angular size of the target is increased. In addition, the depth-of-focus is increased as the pupil constricts with a near target (Atchison et al., 1994).

Using the push-up method, the binocular amplitude is greater than that found monocularly due to the addition of fusional convergence. In contrast, if the minus lens method is used to determine the binocular amplitude of accommodation, the value will be lower than the monocular amplitude because the vergence demand is fixed and accommodation increases convergence (Cooper, 1987).

The amplitude of accommodation declines with age (Hamasaki et al., 1956; Edwards et al., 1993). Table 3.2 shows various formulae for amplitude of accommodation (as a function of age).

Table 3.2 Amplitude of accommodation

Investigators (years)	Number of subjects	Age (years)	Method	Best fit formula to derive amplitude of accommodation
Hofstetter (1944)	-	8 - 62.5	Push-up	EAA=18.5-0.30 x age
Beers and Heijde (1996)	20	15 – 55	Push-up + Ultrasonic biometry	MAA=11.9 – 0.19 x age
Chen et al. (2000)	405	1-17	Push-up	MAA=16.58-0.52 x age
Jiménez et al. (2003)	1056	6-12	Dynamic retinoscopy	MAA=16.16-0.40 x age BAA=15.80-0.33 x age

EAA: Expected amplitude of accommodation

MAA: Monocular amplitude of accommodation

BAA: Binocular amplitude of accommodation

Using the data from Donders (1864) and Duane (1912), Hofstetter (1944) proposed a general formula for amplitude of accommodation, although there were no data provided for children under 8 years old. Beers and van der Heijde (1996) found an equation for the maximum monocular accommodative amplitude as a function of age. Because of the older age sample used (15 to 55 years), they found smaller amplitude of accommodation than other studies which usually included children. The small number of subjects (n=20) makes their formula less reliable. Edwards et al. (1993) studied the amplitude of accommodation for Chinese aged 11 to 65 years using the push-up method. They found relatively lower amplitudes of accommodation in Chinese than Caucasian counterparts. Chen et al. (2000) used a modified Donder's method to measure accommodative amplitude for children of age 1 to 7 years. In their study, they discovered that the monocular amplitude declines more rapidly after 5 years of age than in younger children, in whom the drop in amplitude of accommodation is gradual. Their findings implied that the age of five years is a good starting point for research into the amplitude of accommodation. Jiménez et al. (2003) used modified dynamic retinoscopy to determine the accommodative amplitude. Although the authors proposed that dynamic retinoscopy is more objective and more reliable than the push-up method, they found similar accommodative responses in children aged 6 to 12 years as Chen et al. (2000), who used the push-up method.

From these studies, it is likely that both subjective and objective measurements of amplitude of accommodation can produce similar results. The formulae suggested by various authors were derived from subjects of different ages, indicating that each formula would be best applied to its appropriate age group.

3.3.2 Lag of accommodation and monocular estimate method

If an accommodative response is less than the stimulus, the image is formed behind the retina. This condition is called "lag of accommodation". In contrast, a lead of accommodation occurs when the response exceeds the stimulus. The automatic refractor and the computerized photorefractor are common experimental instruments, which measure continuously the refractive status in response to changes in accommodative stimulus (Rosenfield et al., 1996; Gilmartin et al., 2002; Wolffsohn et al., 2002; Seidemann and Schaeffel, 2003).

Clinically, the monocular estimate method (MEM) is a popular choice for the objective assessment of accommodative lag or lead. The MEM measures the monocular accommodative response under binocular conditions, using dynamic retinoscopy and the rapid interposition of spherical lenses (Rouse et al., 1984; Locke and Somers, 1989; Cacho et al., 1999). The MEM has been shown to be valid (Rouse et al., 1982) and to have good inter-examiner reliability (McKee, 1981; Locke and Somers, 1989).

To obtain normative MEM data, Rouse et al. (1984) studied 721 school children from kindergarten to sixth grade. A mean accommodative lag of +0.33 ± 0.35 D was found and the authors suggested that the normal range for MEM is 0.00 to +0.75 D. In their study, 8.6% of the children had accommodative lead and 5.5% had accommodative lag that exceeded +0.75 D. However, the children were not necessarily wearing full corrective lenses for their ametropia when the MEM was administered, which could give rise to incorrect MEM results. Five other MEM studies on populations of various ages showed that mean lags ranged from +0.23 to +0.74 D. The details are listed in Table 3.3.

Table 3.3 Lag of accommodation by the MEM

Investigators (year)	Subject no.	Age (years)	Method (working distance)	Mean MEM (D ± SD)
Poynter (1982)	74	Grade 4th and 6th	MEM (40 cm)	4th grader: 0.63 ± 0.23 6th grader: 0.60 ± 0.19
Jackson and Goss (1991a)	244	7.9 to 15.9	MEM (40 cm)	0.23 ± 0.29
Cacho et al. (1999)	50	15 to 35	MEM (40 cm)	0.74 ± 0.72
Tassinari (2002)	211	6 to 37	MEM (Harmon distance)	0.35 ± 0.34
Jiménezet al. (2003)	1056	6 to 12	MEM (40 cm)	0.39 ± 0.45

All studies used 40 cm as the working distance for the MEM, except Tassinari (2002), who considered the "Harmon distance" to be a better choice. The Harmon distance is the habitual reading distance of a person. With such a study design, the MEM results, measured using non-standardized working distances, should not be treated as norms for comparison. Tassinari (2002)'s result would be more reliable if the study had been masked. On the other hand, the author found a higher lag of accommodation in the myopic group (0.48 ± 0.33 D) than in the emmetropic (0.24 ± 0.31 D) or the hyperopic (0.30 ± 0.29 D) groups. These findings support claims that an increased lag of accommodation in myopes is due to a reduction in the steady-state accommodative response (Gwiazda et al., 1993b) and blur sensitivity (Rosenfield and Abraham-Cohen, 1999).

These findings were supported by a study in accommodative lags in Chinese recently (Chat and Edwards, 2002). They used open-field autorefractor to measure the lag of accommodation in Chinese children of ages 4 to 6 years. They found myopes (1.37D) exhibited a significantly higher accommodative lag than hyperopes (0.96D). The mean of accommodative lag of in their study (mean age 6.9 ± 1.2 years) is much higher than other published norms by using the MEM as the measurement method (Table 3.3). There were only 33 subjects in Chat and Edwards (2002)'s study, further investigation with bigger sample size is indicated. In contrast, Chen et al. (2003) did not find a difference in the lag of accommodation between groups of myopic (0.45 ± 0.37 D) and emmetropic (0.63 ± 0.31 D) Chinese children aged 8 to 12 years. Similarly, there were no significant differences in the accommodative lag of emmetropes (0.63 ± 0.31 D), stable myopes (0.25 ± 0.62 D) and progressing myopes (0.50 ± 0.27 D). The difference among these studies could be due to age group, methodology or ethnicity, which gives an additional reason to investigate the MEM response in Chinese children in younger ages.

3.3.3 Accommodative facility

Accommodative facility is the speed of accommodative change. The binocular accommodative facility (BAF) test has been suggested as a reliable test to identify accommodative and binocular dysfunction (Garcia et al., 2000; Goss, 2001). The commonly accepted norm of BAF is approximately 8 ± 5.0 cpm for the general population (Hennessey et al., 1984; Rouse et al., 1992; Scheiman and Wick, 1994b). Table 3.4 shows the results of several normative studies of accommodative facility.

The accommodative facility appears to be different in various age groups. It has been shown that low accommodative facility is associated with visual symptoms in children (Hennessey et al., 1984). These investigators found that children, in whom the binocular accommodative facility is 1 SD (3 cpm) below the mean, are likely to have asthenopic symptoms. Rouse et al. (1991) found a relatively higher facility (10.35 ± 5.65 cpm) in a group of children aged 10 to 18 years. The findings from Burge (1979) are of less clinical significance because the age range is too wide (6 to 30 years).

Scheiman et al. (1988) requested the subjects aged 6 to 12 years to call out 3 numbers in each flip of the ± 2 lenses during the facility test. As a result, Scheiman et al. (1988) found a lowered mean of accommodative facility in younger children (3 ± 2.5 cpm for age 6 years, 3.5 ± 2.5 for age 7 years and 5 ± 2.5 cpm for children of ages 8 to 12 years old). According to the authors, the lowered means were due to the difference in the instruction accompanying their BAF test and those in previous studies, which requested the subject to say "now" or "clear" during each flip. In testing BAF, polarized targets were used for monitoring suppression in some studies (Hennessey et al., 1984; Scheiman et al., 1988).

Table 3.4 Accommodative facilities

Investigators (years)	No. of subjects	Age (years)	Method	Suppression monitor	mean ±SD (cpm)
Burge (1979)	30	6 - 30	± 2 D (40 cm)	Polarized target	7.05 ± 4.25
Scheiman et al. (1988)	542	6 - 12	± 2 D (40 cm)	Polarized (hand-held) target	6 yr: 3.0 ± 2.5 7 yr: 3.5 ± 2.5 8-12 yr: 5.0 ±2.5
Rouse et al. (1991)	40	10 - 18	± 2 D (40 cm)	Polarized target	10.35 ±5.65
Kulp and Schmidt (1996)	181	5 - 7	± 2 D for 30 sec	Red/Green suppression check	Cycle per 30 sec. 5 yr: 3.02 ±1.94 6 yr: 3.43 ±1.56 7 yr: 3.56 ±1.36
Jiménez et al. (2003)	290	6 - 7 8 - 12	± 2 D (40 cm)	Polarized target	6 -7 yrs: 2.9 ± 1.8 8-12 yrs: 4.1 ± 2.5

Suppression checking is sometimes unreliable for young children and this may complicate the interpretation of the results (Kulp and Schmidt, 1996). In addition, Kulp and Schmidt (1996) studied 181 children aged 5 to 7 years and found that the accommodative facility increases slightly with age (Table 3.4), however, their results could not be directly compared with other studies because they used 30 seconds as the time for accommodative facility determination and the effect of fatigue will be less than in the other studies, which used 60 seconds as the testing time.

Jiménez et al. (2003) evaluated the accommodative facility in 1,056 children aged 6 to 12 years. Their results were similar to those of Scheiman et al. (1988), although the instrumentation was different in the two studies. Jiménez et al. (2003) used a polarized target at 40 cm, which was similar to that of Rouse et al. (1991). Although the age groups in these two studies were different (with overlapping at age range 10 to 12 years), Rouse found a much faster facility (10.35 ± 5.65 cpm) than in Jiménez et al. (2003) (4.1 ± 2.5 cpm). It is unknown whether the lower value in Jiménez et al. (2003) is due to fatigue because the investigators arranged a lot of tests (retinoscopy, MEM, monocular and binocular accommodative facility, monocular and binocular amplitude of accommodation, direction observation of saccades and the DEM test) for their subjects and the order of these tests was not randomized. The variations in the normal values reported from different studies is likely to be due to the differences in equipment and in experimental design (Siderov and Johnston, 1990).

3.3.4 Accommodative convergence/accommodation (AC/A) ratio

AC/A ratio is the accommodative convergence in prism dioptres per dioptre change of accommodation (Goss, 1986). Classically, Morgan (1944) suggested that the normal value for the AC/A ratio is $4 \pm 2\ \Delta/D$. Studies among Caucasians have shown an elevated response AC/A in myopic children as compared to non-myopic children (Rosenfield and Gilmartin, 1987; Gwiazda et al., 1999). Gwiazda et al. (1999) studied the response AC/A induced by lenses and by changes in working distances for 101 subjects in the age range of 5.8 to 21.1 years. For myopes, negative correlations were found with age but not for emmetropes. In other words, young myopes show elevated AC/A ratios compared to older myopes. Recently, Chen et al. (2003) compared the response AC/A in myopic and emmetropic Chinese children using the Howell-Dwyer card. They measured the phoria change with +2.00 lenses. They found that the AC/A ratios for Chinese myopic and emmetropic children were $3.24 \pm 4.19\ \Delta/D$ and $2.46 \pm 3.38\Delta/D$, respectively. These results did not show a statistically significant elevation of the AC/A ratio in the myopic group.

3.3.5 Accommodative system and eye movements

In general, low accommodative amplitude is found in some reading-disabled persons (Evans et al., 1994; Motsch and Muhlendyck, 2000). Subsequently, this could lead to a poor or unstable near visual acuity, affecting the accuracy of foveal information, which is an important component determining the duration of fixation as discussed earlier.

Kulp and Schmidt (1996) reported accommodative infacility in poor readers. Yet some dyslexics were found to have better than normal accommodative facility in the pilot study by Buzzelli (1991), however, the sample size in this study was too small (N=13) to draw a meaningful conclusion. Kiely et al. (2001) did not find significant differences in various visual functions and reading performance. Although they found that the accommodative facility was slightly higher in the normal readers (8.6 ± 0.3 cpm) than the poor reading groups (8.0 ± 0.6 cpm), there was no statistically significant difference in accommodation facility between the two groups.

3.4 Binocularity

3.4.1 Heterophoria

The distribution curve of near heterophoria has been reported as normal (Jackson and Goss, 1991a) or platykurtic and symmetrical (Letourneau and Giroux, 1991). The commonly accepted normal value is exophoria of about 0 to 6 prism dioptres at near (Saladin and Sheedy, 1978; Jackson and Goss, 1991a; Letourneau and Giroux, 1991). Lam et al. (1996) ,who used the cover test, found that 96.9% of a total of 12,000 normal children aged between 1.5 to 5.5 years were orthophoric (no eye movement in the cover test). Chen et al. (2003) used the Howard-Dwyer card to compare the near phoria in different refractive-status groups of Chinese children aged 8 to 12 years. They found the mean phorias at near for myopes and emmetropes were -1.04 ± 1.95 Δ exophoria and -0.71 ± 2.41 Δ exophoria, respectively and there was no significant difference between these two groups. In their study, the myopic children included very few esophores.

3.4.2 Fusional vergence

Vergence eye movements are disjunctive during changes of fixation distance. Disparity between the two retinal images stimulates vergence eye movements. Bobier et al. (2000) demonstrated the presence of a cross-link between convergence and accommodation as early as 3 to 6 months. As early as 1944, Morgan proposed the normative values of near convergence (Table 3.5).

Table 3.5 Near convergence norms of Morgan (1944)

Near Test	Mean (Δ)	Acceptable range
Phoria	3 ± 3Δ	Ortho to 6Δ exophoria
Base-out to blur	17 ± 3Δ	14Δ to 20Δ
Base-out to break	21 ± 3Δ	18Δ to 24Δ
Base-out to recovery	11 ± 4Δ	7Δ to 15Δ

Scheiman et al. (1989) differentiated between the direct measurements of smooth and step vergence and provided norms for step vergence in children. They found that the mean of base-out to break is significantly higher in step vergence (23 ± 8 Δ) than in smooth vergence (21 ± 3 Δ) by Morgan (1944). The main reason for the difference is the experimental setup. In measuring smooth vergence, a phoropter was used and the examiner could not see the eyes of the child. In contrast, a prism bar was used in measuring the step vergence and the examiner could directly observe the movement of the child's eyes. The presence of the peripheral cues during the step vergence testing provided conditions which might closely resemble natural conditions. Scheiman et al. (1989) suggested the failure criteria for the step vergence and the values are listed in Table 3.6.

Table 3.6 Failure criteria in step vergence by Scheiman et al. (1989)

A child is considered to fail the step vergence test if the results are less than the followings:		
Age (years)	**Base-out to break/recovery**	**Base-in to break/recovery**
6	12 / 5 Δ	7 / 2 Δ
7 to 12	15 / 10Δ	7 / 3 Δ

3.4.3 Heterophoria, vergence and eye movement

Evan et al. (1994) found that binocular instability, which is characterized by unstable phoria and reduced fusional reserves, correlates with reading disability. However, they used the unilateral cover test to determine the amplitude of the phoria as they considered this method to be more natural and less likely to dissociate the two eyes. If they used only the unilateral cover test, the eyes may not have been fully dissociated and the magnitude of the phoria may not have been fully revealed. Hence, their results are questionable.

Several different aspects of near heterophoria have been reported to be related to the reading disabled (Sucher and Stewart, 1993), however, in controlled studies, no differences were found in the size and type of phoria or the associated phoria between dyslexic and normal children (Ygge et al., 1993a; Evans et al., 1994).

Stein et al. (1988) found that children with learning difficulties have poor vergence control with small object. Using a synoptophore, they found 64% of the 39 dyslexic children were unable to make proper vergence movements when macular sized fusion targets (2.5°) were used, while a bigger target (7°) showed improved vergence movements. They explained that dyslexics have perception problem for stimuli falling on the macula. Stein et al. (1986) also suggested that binocular instability was the possible cause of fluctuating diplopia (or moving letters) in some specific reading disabled persons. This was supported in their other studies, in which they found that short term monocular occlusion improves reading at a faster rate than in the non-occluded group (Stein and Fowler, 1985; Stein et al., 2000).

Buzzelli (1991) compared 13 dyslexic and 13 normal young teenagers for their visual acuity, presence of strabismus, stereopsis, accommodative facility and vergence facility. They found that the dyslexics completed the vergence eye movement task significantly slower (300 sec) than the normal readers (240 sec). There were no differences in the other measurements.

In contrast, Moorse et al. (1998) found that some dyslexic adults had normal vergence control across saccades. A recent study by Morad et al. (2002) suggested that convergence amplitude is correlated with the scores of a saccadic eye movement test, when accommodation was controlled. Further investigator is therefore suggested based on these controversial results.

3.4.4 Stereoacuity

Simultaneous perception is present from birth (Shimojo et al., 1986), while stereopsis appears to develop simultaneously with fusion (Petrig et al., 1981; Birch, 1985; Gwiazda et al., 1989). Stereoacuity continues to develop gradually during the preschool ages. Oduntan et al. (1998) found that the mean stereopsis of 56 Arabian children aged 6 years was 29.11 seconds of arc (SD not provided). Leat et al. (2001) reported the mean value of Randot in children of age 5 to 8 years is 30.2 ± 1.43 seconds of arc.

It is still unclear whether there is a relationship between stereoacuity and reading difficulties. Kulp and Schmidt (1996) suggested that poor stereopsis may be present in some poor readers but most other studies have been unable to find a relationship between reading disability and stereopsis (Ygge et al., 1993a; Evans et al., 1994). Further investigation in this direction is warranted.

3.5 Summary

Although there were not many studies investigating saccadic eye movement and visual functions directly, there were ample researches in the area of reading disability and visual functions. Uncorrected ametropia, low accommodative amplitude, unstable binocularity and low fusional reserve were suggested to be related with reading disability. Since poor eye movement quality is also a typical characteristic in poor reader. It is valuable to determine if there is similar association between poor eye movement quality and these parameters. Therefore we attempt to study the visual parameters amongst children diagnosed as types I, II, III and IV by the DEM test.

Chapter 4: The study objectives and methodology

4.1 Preamble

According to the information from The Department of Health and The Department of Education in Hong Kong (Lam, 2001; Education Department, 2002), the percentage of children with a specific learning difficulty (dyslexia) is approximately 5%, i.e. 40,000 children at school ages (6 to 18 years old). Learning difficulties are likely to be associated with some visual problems, such as the coordination of two eyes, focusing ability and eye movement accuracy. Studies emanating form Hong Kong describe the percentages of refractive status (Edwards and Yap, 1990; Edwards, 1991; Chan and Edwards, 1993; Goh and Lam, 1993; Chan and Edwards, 1994; Edwards, 1999), binocular status (Chen et al., 2003) and accommodative amplitude (Edwards et al., 1993) of school-age children, however, no well-conducted study has investigated the characteristics of eye movement function in Chinese children. This study intends to test the saccadic eye movements of children in Hong Kong and possibly find out the prevalence of saccadic eye movement dysfunction which is one of the indicators of reading dysfunction.

As reviewed earlier, the Developmental Eye Movement (DEM) test is a visuo-verbal test to assess saccadic eye movements and automaticity in children (Garzia et al., 1990). In this test, the child is asked to read a "single digit" and this is purely a phonological demand, there is no eidetic factor in the task. The DEM test is simple and can be applied to children as young as 6 years old. The advantages and disadvantages have been discussed in the Chapter 2. If the DEM test is to be used for Hong Kong Cantonese-speaking children, we need to find out if there is any less subjective scoring method; the published norms are suitable for them to use; and will different visual parameters affect the DEM diagnosis? We try to answer these questions in this study.

4.2 Study Objectives

In this study, there are three primary objectives and null hypotheses:

1. To evaluate the repeatability of scoring method in the DEM test:

   i. Between experienced and inexperienced administrators;

   ii. Number of repeated time measurement needed.

   Null hypothesis is (i) there is no difference in accuracy between experienced and inexperienced administrators of the DEM test and; (ii) there is no difference in one and multiple repeated measurements

2. To compare the mean DEM scores in Cantonese-speaking children with the published norms for English and Spanish-speaking children in matched age groups;

   Null hypothesis is that there is no difference in the DEM scores in Cantonese, English and Spanish-speaking children

3. To evaluate the relationship between visual skills and the DEM scores in Cantonese-speaking children 6 to 8 years of age.

   Null hypothesis is that there is no difference in visual functions in different types of children diagnosed from the DEM test.

From these primary objectives, three secondary outcomes will be derived:

1. To establish a less subjective procedure for the DEM test ;

2. To establish the norms of the DEM test for Cantonese-speaking populations; and
3. To determine the prevalence of automaticity and saccadic eye movement problems among Cantonese-speaking children.

4.3 Study Protocol

There are three parts to this investigation. Each individual part of the study was given approval by the Human Subjects Ethics Committee, The Hong Kong Polytechnic University to conduct the research with human subjects. Information about the study and informed consent forms were also designed for each part of the investigation.

4.3.1 Accuracy of scoring in the DEM test

4.3.1.1 Experienced versus inexperienced administrators

Five experienced DEM administrators (optometrists) and five inexperienced administrators (who were optometrists or fourth year optometry students in the Hong Kong Polytechnic University) were recruited. Briefing and training on the administration of the DEM test were given to the inexperienced users prior to the experiment. The investigator of this study was not included in these ten persons.

The collection of data was conducted in a quiet room in The Hong Kong Polytechnic University Optometry Clinic. The administrator was asked to score the DEM test by listening to five different pre-recorded audio clips, each of which had different DEM errors. A stopwatch with accuracy of 1/100 second was used and the audio clips were played back by a hand-held digital audio recorder.

After a sample was played to obtain a comfortable volume, the administrator was asked to record the time and the number of errors for each of the components of the test, in the order of vertical subtest A, vertical subtest B and finally horizontal subtest C in each voice clip set. These voice clips were played back once only. This sequence follows the DEM manual. The order of the five clip sets was pre-assigned according to a random table generated by a computer programme (Microsoft Excel 2002). Finally, the adjusted vertical time and adjusted horizontal time were obtained from the data:

Adjusted vertical time =

$$\text{Vertical time (sec) (total of subtest A \& B)} \times \frac{80}{80 - \text{omission error} + \text{additional error}}$$

Adjusted horizontal time =

$$\text{Horizontal time (sec)} \times \frac{80}{80 - \text{omission error} + \text{additional error}}$$

Voice clips were prepared by taping five children aged between 6 and 8 years by digital recorder, while they were performing the DEM test. The children spoke Cantonese during the test. Each clip contained a different mix of reading errors in both the vertical and horizontal test. Tables 4.1 and 4.2 describe the characteristics of each voice clip. The highest number of errors appeared in voice clips 2 and 3. These two clips simulated more difficult cases.

Table 4.1 Distribution of inbuilt vertical error sub-types in the voice clips

Voice clip	Omission	Addition	Substitution	Transposition	Total
1	0	8	1	0	9
2	0	16	0	0	16
3	0	12	0	0	12
4	0	2	0	0	2
5	0	5	1	0	6

Table 4.2 Distribution of inbuilt horizontal error sub-types in the voice clips

Voice clip	Omission	Addition	Substitution	Transposition	Total
1	6	4	0	1	11
2	1	22	0	0	23
3	1	17	0	0	18
4	25	1	0	0	26
5	0	5	1	0	6

The "pre-set values" for the adjusted vertical and horizontal times for each clip set were established. This was carried out by a third party person (not from those ten investigators). The reading times for the vertical and horizontal sub-tests were obtained by taking the mean of two repeated measurements in each voice clip. By using the same formulae described above, the "pre-set values" were calculated and these are listed in Table 4.3.

Table 4.3 Pre-set values from the voice clips

Voice clip	Adjusted vertical time (second)	Adjusted horizontal time (second)
1	40.31	57.11
2	56.88	66.15
3	35.40	36.15
4	39.33	42.41
5	47.42	67.51
Mean	43.87	53.87

The adjusted vertical and horizontal times from each administrator were compared with those in the "pre-set values". The mean differences for these two parameters between experienced and inexperienced administrators were compared by the unpaired t-test.

4.3.1.2 Number of repeated measurements required to ensure accuracy

In this part of the study, ten voice clips of the vertical subtest A were recorded from ten different children aged between 6 to 8 years. An investigator, who is an experienced administrator of the DEM test, listened and recorded the reading time of the 10 clips. He repeated the measurement five times for each voice clip. A stopwatch with accuracy of 1/100 second was used and the voice clips were played back by a digital audio recorder (JNC USB-350, Korea).

In order to find out the number of measurements required to determine the reading time accurately, the measurements of single, the mean of two, mean of three, mean of four were compared with the mean of five measurements.

4.3.2 Comparison on the mean DEM scores in Cantonese-speaking children with the norms of English-speaking children in age-matched groups

4.3.2.1 Subject selection

Children aged 6 to 11 years were invited to join the study. All the subjects should match the age to grade criterion: only subject with appropriate age at that grade will be included. In Hong Kong, children reached 6 years old before 31 Dec could be admitted to the primary one in September of the same year. They were recruited from five primary schools in different districts of Hong Kong. The cohorts had similar social status, background, educational methods and curricula. The samples were not biased due to selection from clinical referral populations. Permission and informed consent were obtained from the principals and parents or guardians for the children to participate in the study. All subjects were required to pass the pretest of the DEM test, otherwise, no other exclusion criteria were used.

4.3.2.2 Sample size

Calculation of the sample size was based on a study, in which the prevalence of abnormal eye motility in grades one, two and three children was found to be 3.61%, 2.14% and 3.09%, respectively (Helveston et al., 1985). The average prevalence 2.94% (p = 0.0294) was used and assuming the chance of error was 5% or 0.05, the sample size would be:

$$n = \frac{1.96^2 p (1 - p)}{\text{Chance of error}^2}$$

n = 44

Therefore, fifty children were recruited for each age group (allowing for some attrition from the pre-test or not showing up) and the total number of children required was 350 with ages from 6 to 11 years.

4.3.2.3 Experimental procedures

The test was conducted in a quiet room in the school. Depending on the time made available by the school, one or two investigators took part in administering the DEM test. In total, three investigators were involved and training was provided to each of them to assure the consistency of the operation procedures and instructions.

The DEM test was carried out for each child according to the standard protocols as advised in the manual (Richman and Garzia, 1987). The test was carried out at the working distance of 40 cm and the original DEM test plates were used. The child was asked to perform a pretest in which he was asked to read twelve single-digit numbers. If he read these twelve numbers correctly in 12 seconds or less, he passed the pretest. As all children used habitual vision in the DEM test, a pass in the pre-test suggested that they could at least see and read the numbers clearly on the DEM test chart.

The vertical test comprised of subtests A and B. In each of these sub-tests, two vertical columns were separated by 98.5 mm apart. Each column contained 40 numbers vertically. The numbers were separated by a space of 5.5 mm vertically. During the subtest A, the child was requested to read the numbers down the each column carefully, and as quickly as possible. No finger pointing was allowed. The subtest B was continued without significant delay.

The horizontal test C comprised of 80 numbers arranged in a horizontal array of 16 rows and five numbers in each row. Each row was separated by 5.5 mm vertically. The first and fifth numbers of each row were in the same horizontal position in line with the preceding one. The spacing between the three numbers internally was randomly arranged within each row. Without significant delay from the subtest B, the child was asked to read the numbers across the rows as quickly as possible in the horizontal test C. The response of the child was recorded by a digital recorder (JNC, USB-350, Korea). All instructions were based on the advice presented in the manual except that the wording was translated into Chinese (Cantonese).

After recording, the investigator listened to the voice file and assessed the reading time and reading errors for each subtest, twice. The mean of the two measurements was used for further analysis. There are four possible types of reading error made by a child, namely substitution, omission, addition and transposition. "Omissions" occurs when the child skips numbers in the presented text. "Addition" is an error, when the child adds numbers to those presented in the list. "Transposition" is the error, in which the order of the numbers is changed, while a "substitution" error occurs, when one number is replaced by another. If there was any inconsistency in the counting of reading errors during the two assessments of the voice records, the investigator repeated the procedure, until two consistent consecutive counts were obtained.

After obtaining the reading time and the reading errors, four DEM scores could be computed as follows:

1. The adjusted vertical time

Adjusted vertical time (sec) =

$$\text{(Reading time in sub-test } A + B) \times \frac{80}{80 - \text{omission errors} + \text{additional errors}}$$

2. The adjusted horizontal time

$$\text{(Reading time in test } C) \times \frac{80}{80 - \text{omission errors} + \text{additional errors}}$$

3. Ratio

   The ratio score was the function of the adjusted horizontal time divided by the adjusted vertical time.

4. Error

   The error score was the total of all errors from the horizontal test.

4.3.2.4 Data analysis

The effect of gender was evaluated by comparing the mean of the adjusted vertical time and the adjusted horizontal time for boys and girls at each age group using an unpaired t-test. The correlation between individual DEM scores and ages (6 to 11 years) was calculated by using the nonparametric Spearsman correlation. Norms (mean DEM scores) were established for each age group of children by frequency distribution according to the percentile ranks as listed in the DEM manual. Unpaired t-tests were used to compare the individual means of different scores for the Cantonese-speaking and English-speaking children.

In the DEM manual, no specific cut-off point was recommended to distinguish normal from subnormal performance. Kulp and Schmidt (1997a) screened the eye movement function of young children (aged 5 to 6 years) in kindergarten by using the DEM test. Due to the lack of published DEM norms for kindergartners, they considered "test times or errors in excess of the mean plus 1 SD (or at the 15th percentile rank) were considered subnormal performance (Kulp and Schmidt, 1997a). The cut-off point as advised by Kulp and Schmidt (1997a) was adopted in this study. By using the 15 percentile as a cut-off point, scores below the 15 percentile were considered "subnormal" or "poor". According to Table 2.1 in Chapter 2, each child was classified into a diagnostic type with respect to the three

DEM scores. The prevalence of the five types of the DEM diagnoses was established for these Cantonese-speaking children.

4.3.3 Relationship between visual skills and the DEM test scores

4.3.3.1 Subject selection

One hundred and twelve children aged 6 to 8 years were recruited from the norms study above. This age group was selected because the oculomotor problem in these children were reported to be more prominent than other age groups (Garzia et al., 1990). Children with ocular pathology, strabismus or severe anisometropia (with no binocularity) were excluded.

4.3.3.2 Experimental procedures

In addition to the DEM test, the following visual functions were assessed by the same investigator.

i) Habitual monocular distant and near vision

The child was asked to read aloud letters from charts at 3 meters and 40 cm, respectively. The logMAR crowded test (formally called the Glasgow acuity test (McGraw and Winn, 1993; 1995) and The Hong Kong Polytechnic University Near Vision charts (the chart is modified in accordance with the near vision chart of the University of Waterloo; (Cheng and Woo, 2001) were used for distance and near test, respectively. Distant and near monocular threshold acuities were recorded in logMAR format.

ii) Subjective refraction

The subjective refractions of the children's eyes were obtained using trial lenses refraction after retinoscopy. "Maximum plus monocular acuity" was used as the end point of the monocular refraction. Monocular visual acuity was also recorded. No diagnostic drug was used.

The spherical equivalent refraction (SER) was calculated using the following formula:

SER = Spherical power + (cylindrical power (negative) / 2)   (D)

Children with SER having -0.5 D or more was considered as "myopic". "Hyperopia" was defined as SER equal to +0.75 D or more. SER between -0.5D and +0.75 were defined as "emmetropia".

iii) Near phoria and accommodative convergence ratio (AC/A ratio)

Each child was asked to look into the Maddox Wing, in which a septum was used to separate the images for left and right eyes. Under such an arrangement, one eye observed a line with a numbered scale and the other eye an arrow. Then, the child was asked to read aloud the number, at which the arrow was apparently pointing. Both the horizontal and vertical phorias were measured. A pair of +1.00 D lenses was placed in front of the eyes and the child was asked to clear the image and then again report the position of the arrow. The AC/A ratio was obtained from the difference between the two readings, before and after the addition of the +1.00 D lenses.

iv) Stereoacuity

The Randot stereotest was used to measure stereoacuity. In this test, the child was asked to wear a Polaroid goggle and to identify the three-dimensional circles in ten test rows of different stereo-acuity at 40 cm. The last correct answer in the ten levels was the stereoacuity threshold.

v) Positive fusional amplitude

Each child was asked to fixate on a vertical line of 0.30 logMAR letters at 40 cm away from the eyes. A prism bar with base-out prism was placed in front of the right eye. The power of the prism was increased in steps until the child reported consistent double vision (diplopia). The break point represented the maximum amplitude of convergence. Then, the power of the prism was reduced until the child reported single (recovery). The procedures were repeated for a second reading. The means were recorded.

vi) Amplitude of accommodation using the push-up method

If the children's refractive errors were emmetropic (+0.50 D $\geq$ each meridian power $\leq$ -0.50 D) in both eyes, this test of accommodation amplitude was carried out without trial lenses. Each child was asked to read a 0.30 logMAR letter printed on a near vision card. The card was moved towards the child until he or she reported blur. Then the test was repeated again. In case in which the trial frame was used, the back vertex distance was set at 12 mm. The distance of the near-point-blur was measured by a retractable metal ruler between the card and the spectacle plane or the corneal plane. The ocular amplitude of accommodation (D) was the reciprocal of the near-point-blur distance from the cornea. The amplitude of spectacle accommodation was converted to ocular accommodation by incorporating the effect of back vertex distance and the refractive error.

vii) Accommodative facility

If the children's refractive errors were emmetropic (+0.50 D $\geq$ each meridian power $\leq$ -0.50 D) in both eyes, this test was carried out without any trial lens. Otherwise, the subjective trial lenses were placed in front of and 12 mm from the children's eyes. Each child was asked to read out the small letters (0.6 logMAR) printed on a near vision card. Then a pair of +2.0 D lenses were placed in front of his/her eyes (or the trial lenses) and the child was asked to clear the image after insertion of the lenses. The child was requested to read out a letter when the image became clear, at which stage the investigator turned the lens flipper so that the -2.0 D lenses were placed before the eyes. Then the child was asked to report when the image was clear again. The number of cycles for clearing alternate +2.00 D lens and -2.00 D lenses in one minute was recorded.

viii) **Lag of accommodation**

The monocular estimation method (MEM) was used to determine the lag of accommodation. With the best corrective lenses inserted in front of the eyes, the child was asked to read a line of small letters (0.6 logMAR) on a paper, which was attached to a retinoscope. The working distance was 40 cm. Next, the investigator observed the retinoscopic reflex in each eye and neutralized the reflex using trial lenses when the child was reading the letters. To avoid the influence of the neutralizing lens, the investigator held the lens in front of the eye for only a brief time during retinoscopy. The neutralization power was the lag of accommodation.

4.3.3.3 Data analysis

The mean of each visual function was calculated and compared with normal values. From the DEM norms derived in earlier part of this study, a diagnosis (from Type I to V) was given to each child according to the combination of the four DEM scores. Then the means of each visual function were compared among the five types of diagnosis. One way ANOVA with Tukey-Kramer multiple comparison post-hoc test was used for parametric analysis. If any data set failed the normality test, non-parametric Kruskal-Wallis Test was used to compare the means. Dunn's Multiple Comparisons post-hoc test was used in the non-parametric analysis. Statistical analyses were performed by two computer programmes: GraphPad InStat version 3.00 for Windows 95 and SPSS version 11.0 for Windows.

Chapter 5: Result and discussion: Repeatability of scoring method in the DEM test

5.1 Result

5.1.1 Experienced versus inexperienced DEM administrators

The adjusted vertical time and adjusted horizontal time for each administrator was calculated by using the formulae described in Section **4.3.2.3**. Difference between the pre-set value and individual's recorded time were also calculated for each of the five voice clips. Tables 5.1 and 5.2 list the mean differences of the five voice clips between the pre-set values for both the adjusted vertical time and the adjusted horizontal time for the ten administrators.

Adjusted vertical time differences from the pre-set values in the experienced and inexperienced administrators were 2.22 ± 0.77 seconds and 3.57 ± 0.88 seconds respectively. The difference was statistically significant (unpaired t-test, $p < 0.05$); the experienced administrators measured the time more accurately than the inexperienced administrators.

With respect to the adjusted horizontal time differences from the pre-set values, there was no statistical difference ($p > 0.1$, unpaired t-test) between inexperienced (2.34 ± 0.22 seconds) and experienced administrators (1.88 ± 0.62 seconds).

Table 5.1 Adjusted vertical time differences from the pre-set values

	Experienced administrator (N=5)	Inexperienced administrator (N=5)
Case 1	1.49	4.63
Case 2	3.47	3.46
Case 3	1.71	4.26
Case 4	2.20	2.46
Case 5	2.25	3.06
Mean ± SD	2.22 ± 0.77	3.57 ± 0.88
Unpaired t-test: $p < 0.05$, significant difference		

Table 5.2 Adjusted horizontal time differences from the pre-set values

	Experienced administrators (N=5)	Inexperienced administrators (N=5)
Case 1	2.03	2.19
Case 2	2.37	2.14
Case 3	1.34	2.50
Case 4	1.13	2.22
Case 5	2.54	2.65
Mean ± SD	1.88 ± 0.62	2.34 ± 0.22
Unpaired t-test: $p > 0.1$, not significant		

There were four types of reading errors inbuilt into the voice clips. The reading errors in the five voice clips were used to assess the accuracy in picking up errors in the administrators. The inbuilt numbers of addition, omission, substitution and transposition errors were different in vertical and horizontal test. If the administrator picked up all the errors correctly, he would have zero difference from the original. Table 5.3a and 5.3b show the difference in the number of error from the inbuilt number of errors for both the experienced and inexperienced administrators in vertical test and horizontal test respectively. Positive values are overestimates and negatives are underestimates.

Table 5.3a Difference in number of errors from the inbuilt number of errors for the experienced and inexperienced administrators in vertical test

		Omission error	Addition error	Substitution error	Transposition error
Total inbuilt error		0	43	2	0
Experienced Administrators (N=5)	1	0	-9	0	0
	2	3	-19	2	2
	3	2	-9	-1	0
	4	0	-9	1	0
	5	5	-10	-2	0
	Mean	**2**	**-11.2**	**0**	**0.4**
Inexperienced Administrators (N=5)	1	2	-15	-1	0
	2	3	-16	3	0
	3	2	-17	2	0
	4	2	-14	1	0
	5	2	-23	5	0
	Mean	**2.2**	**-17**	**2**	**0**

Table 5.3b Difference in number of errors from the inbuilt number of errors for the experienced and inexperienced administrators in horizontal test

		Omission error	Addition error	Substitution error	Transposition error
Total inbuilt error		33	49	1	1
Experienced Administrators (N=5)	1	0	-17	0	-1
	2	-6	-9	5	-1
	3	-2	-1	2	-1
	4	0	-1	1	-1
	5	2	-14	1	-1
	Mean	**-1.2**	**-8.4**	**1.8**	**-1.0**
Inexperienced Administrators (N=5)	1	3	-14	-1	0
	2	-1	-12	4	3
	3	2	-12	1	0
	4	0	-6	2	-1
	5	7	-13	4	-1
	Mean	**2.2**	**-11.4**	**2.0**	**0.2**

Inaccurate recording of the "addition error" was most common in both groups; every administrator underscored the "addition error".

5.1.2 The repeatability in recording the time

To consider the number of repeated measurement required ensuring a reasonable estimate of the recording of the time, the difference between the mean of five repeated measurements and the means of fewer than five repeated measurements were compared (Table 5.4). The mean vertical time from the ten voice clips was 17.95 ± 6.04 seconds. The single measurement differed from the mean of five repeated measurement by 0.21 second with the standard deviation of 0.23 second. Taking the mean of four repeated measurements approximated the mean of five repeated measurement within 0.03 seconds with a standard deviation of 0.02 seconds.

Table 5.4 Comparison of number of repeated measurement

	Number of Measurement				
	Single	**Mean of repeated 2X**	**Mean of repeated 3X**	**Mean of repeated 4X**	**Mean of repeated 5X**
Mean recorded time in 10 voice clips ± SD (second)	17.81 ± 5.96	17.90 ± 6.02	17.93 ± 6.03	17.95± 6.05	17.95 ± 6.04
Mean difference from mean of five ± SD (second)	0.21 ± 0.23	0.11 ± 0.10	0.05 ± 0.06	0.03 ± 0.02	-
No of measurement set fell within 1 second of mean of five, N (%)	10 (100%)	10 (100%)	10 (100%)	10 (100%)	-
No. of measurement set fell within 0.5 second of mean of five, N (%)	8 (80%)	10 (100%)	10 (100%)	10 (100%)	-
No. of measurement set fell within 0.1 second of mean of five, N (%)	4 (40%)	7 (70%)	8 (80%)	10 (100%)	-

Measurement of the reading time in the DEM test is usually recorded to the nearest second. All the means, irrespective to whether one, two, three or four repeated measurements were made, fell within 1 second of the mean of five repeated measurement. If 0.5 second is used as the cutoff point for rounding off to the nearest second, then an accurate measurement should fall within 0.5 second of the mean of five repeated measurement. This could be achieved in only 80% of the single measurement in this investigation. Whilst 100% of the mean of two, three or four repeated measurements fell within 0.5 second of the mean of five repeated measurement. If 0.1 second is used as the cutoff point, then four repeated measurements are required to give a mean result equal to the mean of five.

5.2 Discussion

5.2.1 Experienced versus inexperienced administrators

According to the manual of the DEM test (Richman and Garzia, 1987), the three DEM subtests should be presented in a specific order. The procedures described in the manual did not take into account whether the administrator has prior experience of using the test or not. The recording method was very subjectively biased and any variations in the time or error recording could possibly induce unwanted errors in the diagnosis. This part of the study was to find out whether there could be variations in the recording with respect to the experience of the DEM test administrators. The method as stated in the DEM manual was adopted except that the vertical errors were also recorded in this investigation. The exact flow of testing procedures as described in the DEM manual was followed and only one measurement was allowed in the three subtests.

We found that all administrators recorded slightly different reading times for each voice clip. Both experienced and inexperienced administrators recorded differences (range from 1.13 to 4.63 seconds) in adjusted vertical and horizontal times from the pre-set values. There were inaccuracies in picking up the four different types of errors for each voice clip. Addition was most commonly missed in both groups of administrators.

We found statistically significant difference in the adjusted vertical time between the experienced and the inexperienced administrators, that the experienced administrators were more accurate in their recording. None of the previous DEM studies (Garzia et al., 1990; Fernandez-Velazquez and Fernandez-Fidalgo, 1995; Jimenez et al., 2003) reported such an effect before. This result was expected as experience in using the test help the administrator to be more prepared in the recording. Although the same trend was observed in the adjusted horizontal time but the difference was not statistically significant. We speculate that this is related to the reaction time of the administrators; the duration of vertical reading was much shorter than the horizontal reading in the test so less time was allowed for the administrator to get ready for ending the recording. There was a longer duration in the horizontal reading test so the administrator would have more time and psychologically more prepared for ending the recording. Further investigation to observe the effect of reaction time in recording may help to clear the difference in the results between adjusted vertical and horizontal time.

The adjusted time, no matter whether horizontal or vertical, was calculated from both the time and the number of errors. Inaccuracy in measuring either or both of these two parameters would affect the adjusted time calculation. The DEM test diagnosis is based on the percentile ranks listed in the manual. However, no specific cut-off point was recommended to distinguish normal from the subnormal performance. For example, the manual advised that "*Type II problem is characterized as abnormally increased time to complete the horizontal test in the presence of normal performance* *on the vertical test. The ratio would be abnormally high in this case.*" Kulp and Schmidt (1997a) screened young children (aged 5 to 6 years) in kindergarten by using the DEM test. Due to the lack of published DEM norms for kindergartners, test times or errors in excess of the mean by one standard deviation (SD), which was equivalent as at the 15^{th} percentile rank was considered as subnormal performance (Kulp and Schmidt, 1997a). The cut-off point as advised by Kulp and Schmidt (1997a) was adopted in this study. Score at the 15 percentile (or one standard deviation) was used as a cut-off level to identify the poor and average performers. Likewise score at the 85 percentile was used as the cut-off level to identify average and good performers.

How would the inaccuracy in time recording affect the final DEM test diagnosis? The worst case scenario is used to illustrate the effect. Taking the mean deviation of the adjusted vertical time (3.57 ± 0.88 seconds) from the pre-set value in the inexperienced administrators as an example, we round off the 3.57 seconds to 4 seconds. If four seconds are added to the adjusted vertical time at the 15 percentile rank as provided in the DEM manual, a shift in percentile rank results. Similarly, subtraction of four seconds can simulate the effect on the other side of the percentile curve. The concern is at the lower end of the curve that differentiates the poor from average performers. The effects of shifting the percentile ranks to lower ranks across each of the age groups (6 to 11 years) for different time difference are calculated and listed in Table 5.5. The shifting in the ranking is in the range of 5 to 10 percentile so an inaccurate measurement of the adjusted vertical time by 2 seconds can shift the original 15 percentile to lower percentile, and thus mislead the administrator to reach an incorrect DEM test diagnosis.

Table 5.5 Percentile shift from 15 percentile rank for an measurement error of 1 to 4 seconds in adjusted vertical time for different ages

	6 years	7 years	8 years	9 years	10 years	11 years
Percentile shift if 4 second is added (%)	-5	0	-10	-10	-5	-10
Percentile shift if 3 second is added (%)	-5	0	-5	-5	-5	-10
Percentile shift if 2 second is added (%)	-5	0	-5	0	-5	-5
Percentile shift if 1 second is added (%)	0	0	0	0	0	0

In conclusion, we found prior experience in using the DEM test can minimize errors in the time recording and improve the repeatability of scoring in vertical test. However, both groups were not able to correctly pick up the different types of error and it was especially worse in picking up those addition types. If the error in both the time and error recording resulted in exceeding the actual time by 1 second, the administrator regardless of whether he is experienced or not may still run the risk of making a misdiagnosis in those borderline cases.

5.2.2 Number of repeated measurement in reading time

It was emphasized in the manual that due to the memorizing effect from young children, the test should only be administered once to a child and should not be repeated immediately after. We already illustrated that variations among administrators could induce possible errors in the measurement of both time and errors and lead to wrong diagnosis. Would one measurement be clinically reliable? With the use of a digital recorder, it is now possible to find out whether one measurement is clinically reliable in the DEM test and how many measurements would be required in the interest of clinical efficiency. Realini and Lovelace (2003) examined how many individual central corneal thickness measurements are necessary to reliably assess the thickness of a given cornea. They determined whether a mean of fewer than five measurements gives as good an estimate of central corneal thickness as the mean of five. They suggested a different way to address the clinical value of taking multiple measurements is to ask what percentage of fewer-than-five mean values fall within an acceptable range of the mean-of-five value. Their method was adopted in our analysis.

To adopt one second difference from the expected value is not safe. It is because the that the formula used in the DEM test may magnify or minify this "one second" and possibly increasing the risk of error. On the contrary, we need to take four repeated measurements in order to get a reliable result as compared to 0.1 second from the mean of five. This sounds not practical in the clinical situation. At last, we found that 80% of single measurement was in good agreement with the mean of five repeated measurements (to the nearest 0.5 second). Therefore, it is practical to advice that two repeated time measurements are good enough to obtain a mean result 0.5 second from the expected value.

If the test cannot be administered and repeated immediately after due to the memorizing effect, it seems that recording of the voice results is the only way to ensure the repeatability in the measurement of time. We therefore propose that recording of the test results should be inbuilt into the test manual.

So far the focus was on the improvement of time measurement, there was still the issue of the influence of the number of reading errors made by the child. If a child makes many reading errors, this may distract the attention of the administrator while clocking the reading time. To maximize the accuracy of error measurement we suggest the DEM administrator should record the whole process of test for each child and then replay the voice clip, clocking the reading time twice with special attention to the accuracy of the stopwatch measurement. In order to measure the reading errors accurately, the administrator can repeat the voice file as many times as he wishes.

5.2.3 Factors for improving the accuracy of scoring

In addition to the above considerations, other factors related to the testing environment should also be considered as they may also affect the test results.

A quiet place should be used for running the DEM test. This would minimize any external (verbal or audio) distraction to the child and also ensure clear communication between the two parties. Although there are no recommendations on the lighting requirements with the DEM test, light intensity of 480 lux should be sufficient for a near visual acuity test (BS, 1968). The DEM test plate should be placed in a direction such that no glare source is seen by the child.

5.3 Summary

To summarize our findings:

1. The mean differences from the pre-set value of the adjusted vertical time in the experienced and inexperienced administrators were significantly different (un-paired t-test, $p < 0.05$).
2. Both groups of administrators were not able to correctly pick up the different types of error and it was especially worse in picking up those addition types.
3. The mean of two measurements of the reading time in the DEM test falls within 0.5 seconds of the mean-of-five measurements. Thus, measuring the reading time twice can produce a reliable result (to the nearest 0.5 second).

Owing to memorizing or learning effects, the DEM test should not be repeated and the child should only go through the test once. Inaccurate measurement of the reading time and error in the DEM test could result in wrong diagnosis. The test procedures as it stands now are not reliable and warrant further evaluation to ensure accuracy in the test measurement. Based on the findings from this study, in order to obtain accurate measurement of the necessary data in this test, we propose the following for improvement:

1. A digital recorder should be used to record the response of the child during the test.
2. A stop watch to the nearest 0.5 seconds is required for the time recording in this test.
3. The administrator should listen to the playbacks of the voice clips and measure the reading time to the nearest 0.5 second. He should also repeat the measurement twice.
4. Counting of errors can be very accurate, if the administrator is allowed to

revisit the voice clip an unlimited number of times. Therefore, re-visiting the raw data (voice of the child during the DEM test) is very important to maximize the accuracy.

Chapter 6: Result and discussion: The DEM scores in a group of Cantonese-speaking Chinese children

This section describes the results of the DEM scores in a group of Cantonese-speaking children. We investigated whether a language other than English used in the DEM test had any effect on the scores; Chinese (Cantonese) was used in the present study. We also established the normative values of the DEM scores for the Cantonese-speaking children aged 6 to 11 years. Finally, we derived the prevalence of saccadic eye movement and automaticity dysfunction from our samples.

6.1 Results

6.1.1 Subjects

Calculation of the sample size as shown in Section **4.3.2.2** showed that fifty children were required for each age group (allowing for some attrition from the pre-test) and the total number of children required was 350 with ages from 6 to 11 years. A total of 602 letters of invitation were sent to parents via the offices of five primary schools and 368 of them were drawn (lottery by school) and the parents of these children agreed to participate in our study and signed the consent form. Nine of them were sick and did not attend the tests. Owing to technical error, the responses of twelve children were not successfully recorded by the digital recorder and the results from these children were also excluded. Forty two children were excluded too because they did not match the age-to-grade requirement. Finally, three hundred and five children were included. Table 6.1 summarizes the details of the participants. Table 6.2 shows the age distribution of the children and Table 6.3 documents the gender distribution. The proportions of boys and girls were 50.5% and 49.5%, respectively. Eight-two children

(27 %) wore spectacles habitually (Table 6.4).

Table 6.1 Number of children participated in the present study

Number of children invited	602
Number of consent form returned	368
Number of children excluded (sick or technical error)	21
Number of children excluded (not matching age-to-grade criterion)	42
Number of children included	305

Table 6.2 Age distribution of children

Age (years)	6	7	8	9	10	11
No. of children	53	63	54	50	52	33
Mean Age (years)	6.6	7.5	8.4	9.5	10.5	11.5

Table 6.3 Gender distribution of children

Age (years)	6	7	8	9	10	11	Total	%
No. of girls	21	31	30	23	31	15	151	49.5
No. of boys	32	32	24	27	21	18	154	50.5

Table 6.4 Number of children with and without spectacle correction

Age (years)	6	7	8	9	10	11	Total	%
Without spectacle correction	46	50	40	36	30	21	223	73
With spectacle correction	7	13	14	14	22	12	82	27

6.1.2 Vertical time versus adjusted vertical time

Both Garzia et al. (1990) and the manual of the DEM test claimed that the errors made in vertical subtests were minimal and could be neglected in the calculation of DEM scores. In our study, we noted substantial errors in the vertical subtest (Figure 6.1), 175 children made errors ranged from 1 to as many as 13. Table 6.5 shows that 84 (28%) out of 305 children made one to two vertical errors and 66 (21%) made three or more errors. We found Cantonese-speaking children made more errors than the Caucasian population in the vertical tests as quoted by Garzia et al. (1990). In view of this, we propose to adjust the vertical time by the factor for vertical errors for Cantonese-speaking children. The formula has been described in **4.3.2.3** of Chapter 4. For more accurate analysis of the DEM test scores, all of the following calculations were based on the adjusted vertical time, which includes the effect of "addition" and "omission" errors from the vertical test.

Figure 6.1 Frequency distribution of vertical error

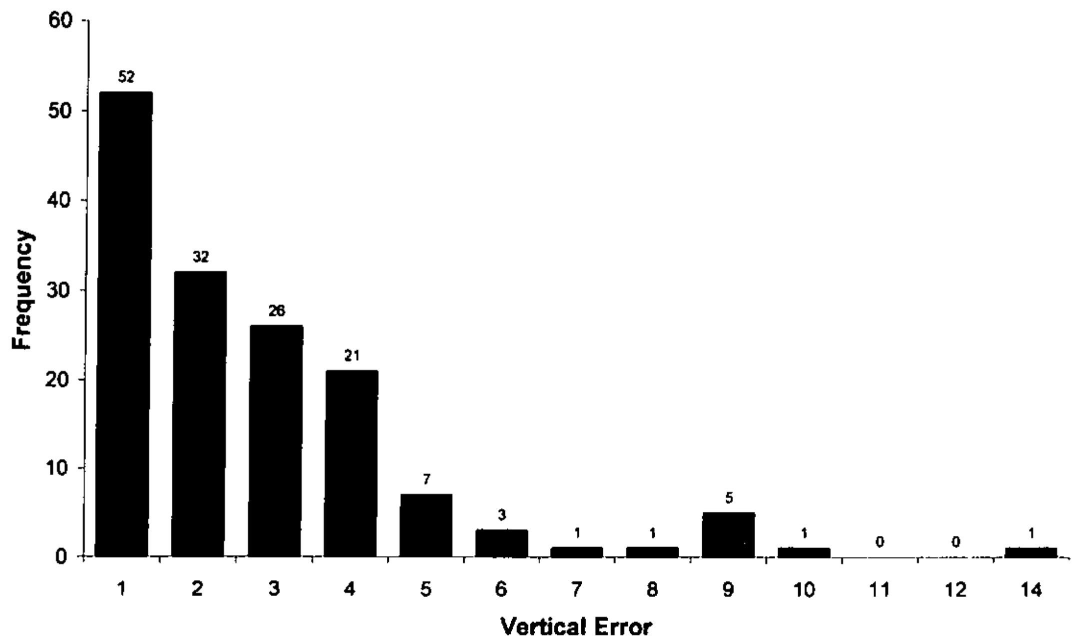


Table 6.5 Vertical error in this study as compared with the Garzia et al. (1990) 's study

Vertical Error	Number of cases having 1 to 2 errors (percentage)	Number of cases having 3 or more errors (percentage)	Total number of cases having errors (percentage)
The present study	84 (28%)	66 (21%)	150 (49%)
Garzia et al. (1990)	17 (11%)	2 (1 %)	19 (12%)

6.1.3 Gender differences

Tables 6.6 to 6.7 show the means of the adjusted vertical time and adjusted horizontal time for boys and girls at different ages. There was no significant difference in any of the DEM scores between boys and girls at any ages.

Table 6.6 Gender difference in the adjusted vertical time

Age (years)	Boys		Girls		Unpaired t-test
	N	Mean adjusted vertical time ± SD (second)	N	Mean adjusted vertical time ± SD (second)	
6	32	51.30 ± 14.92	21	50.49 ± 10.25	p > 0.05
7	32	43.94 ± 9.04	31	42.73 ± 8.64	p > 0.05
8	24	38.39 ± 7.88	30	35.58 ± 8.2	p > 0.05
9	27	34.44 ± 6.54	23	36.64 ± 6.84	p > 0.05
10	21	28.92 ± 6.96	31	29.69 ± 5.37	p > 0.05
11	18	30.25 ± 5.83	15	29.32 ± 4.88	p > 0.05

Table 6.7 Gender difference in the adjusted horizontal time

Age (years)	Boys		Girls		Unpaired t-test
	N	Mean adjusted horizontal time ± SD (second)	N	Mean adjusted horizontal time ± SD (second)	
6	32	70.22 ± 21.43	21	72.87 ± 12.98	$p > 0.05$
7	32	58.30 ± 15.70	31	55.93 ± 12.63	$p > 0.05$
8	24	46.62 ± 10.52	30	48.29 ± 10.79	$p > 0.05$
9	27	43.01 ± 7.17	23	43.05 ± 8.70	$p > 0.05$
10	21	32.93 ± 10.42	31	34.20 ± 7.50	$p > 0.05$
11	18	32.84 ± 7.85	15	32.89 ± 6.17	$p > 0.05$

6.1.4 The DEM scores in relation to age

Since the DEM scores across ages 6 to 11 years in our study were not a Gaussian distribution, non-parametric Spearman correlation was used to calculate the correlation coefficient for each DEM score versus age. The results are listed in Table 6.8. Figures 6.2 to 6.5 show the scatter plots of the four DEM scores against age. Best fit equation is provided in each figure.

Table 6.8 Correlation of the DEM scores with age

(N=305)	Adjusted vertical time	Adjusted horizontal time	Horizontal error score	Ratio score
Spearman Correlation coefficient, P value	r = -0.69, p < 0.01	r = -0.78, p < 0.01	r = -0.47, p < 0.01	r = -0.57, p < 0.01

Figure 6.2 The adjusted vertical time versus age

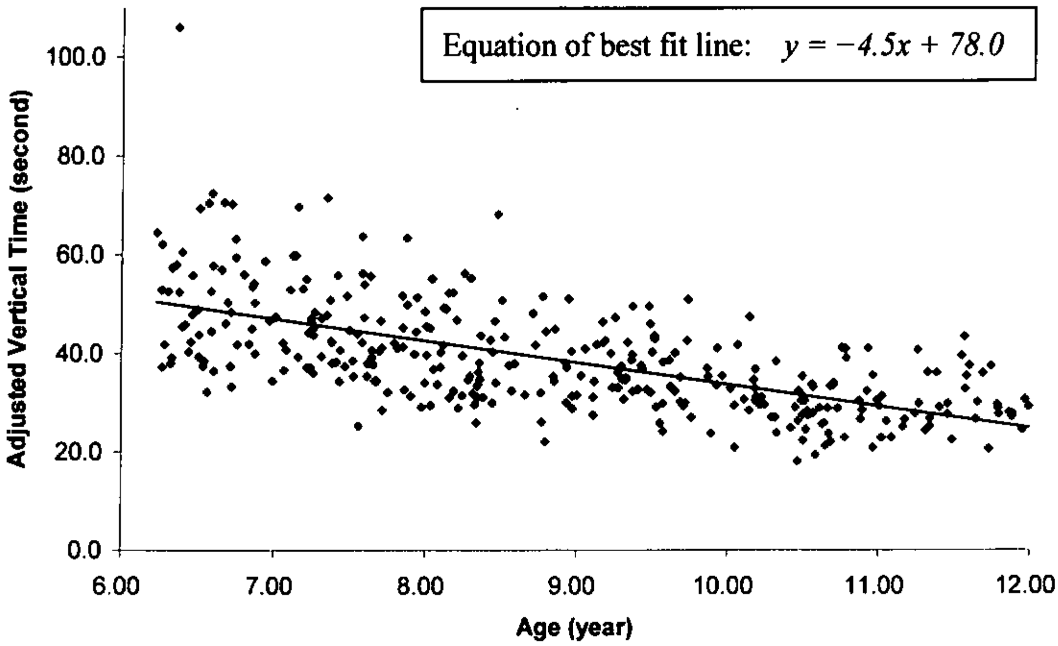


Figure 6.3 The adjusted horizontal time versus age

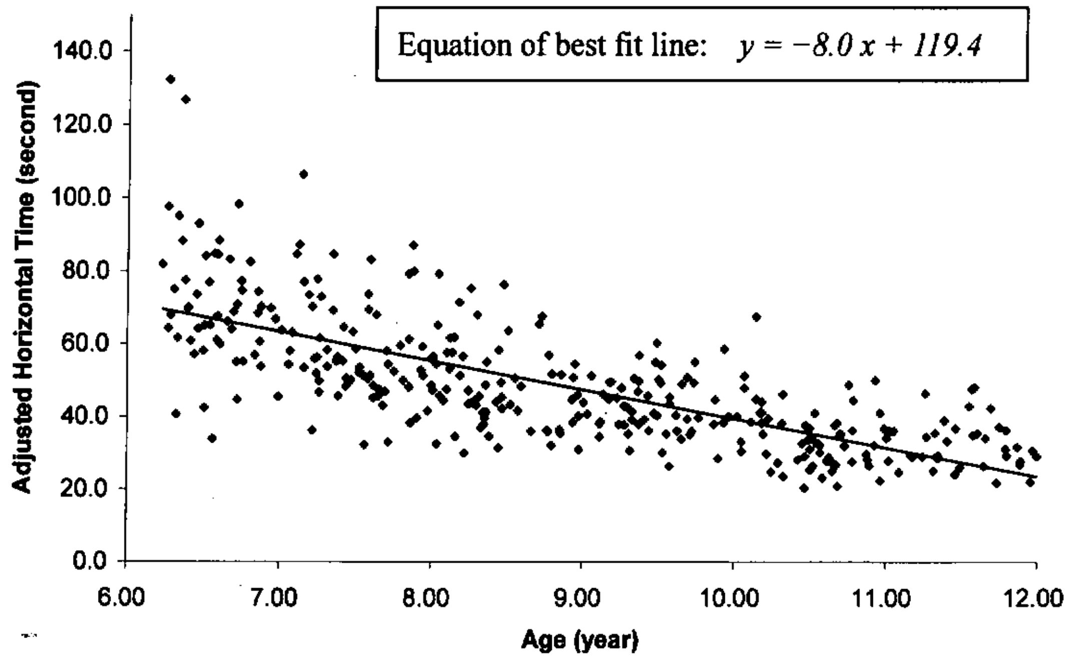


Figure 6.4 The horizontal error scores versus age

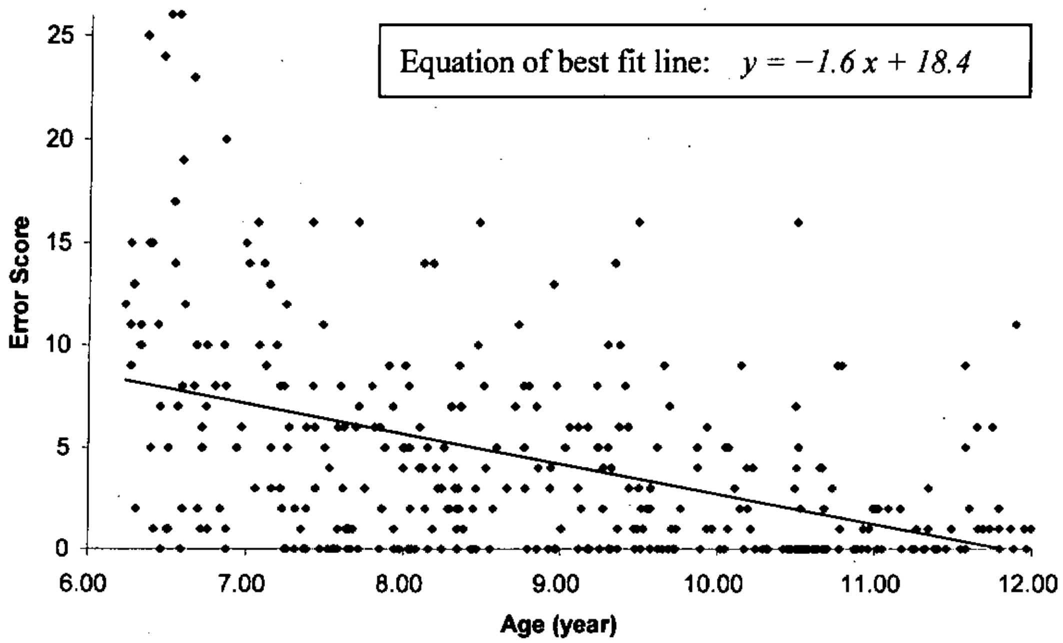
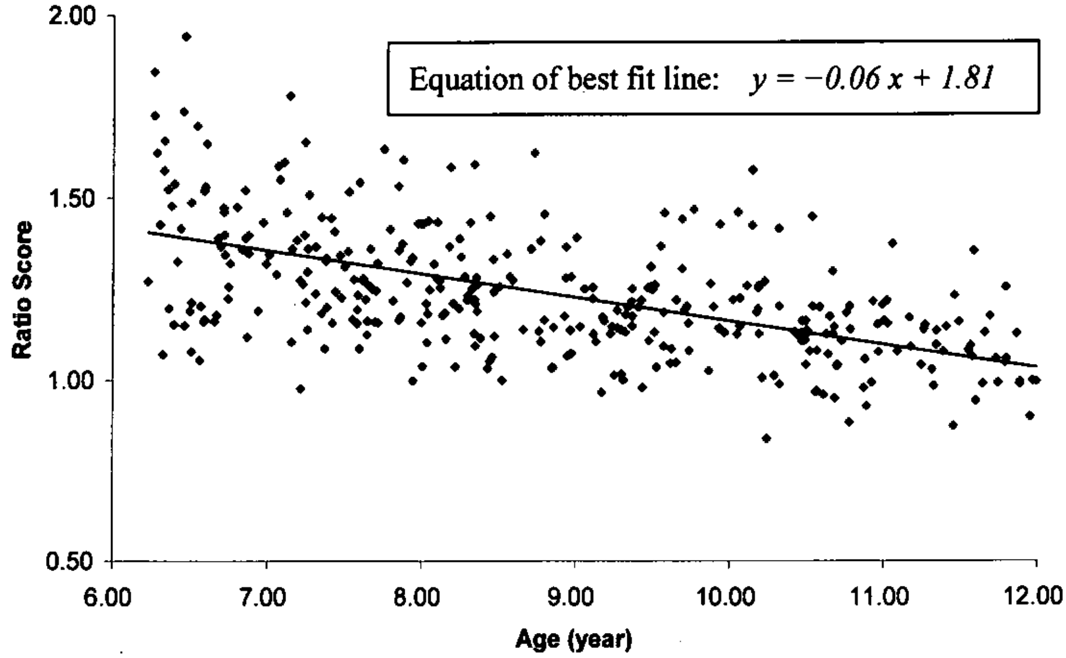


Figure 6.5 The ratio scores versus age



All the four DEM scores were significantly correlated with age (Spearsman correlation, $p < 0.01$). The older the child, the lower the DEM scores .

In addition, the children in this study made numerous reading errors during the horizontal test. Table 6.9a and 6.9b lists the mean of different types of vertical and horizontal error presented in these children respectively. In the horizontal test, children of ages 6 to 7 years mainly made "omission error" in the DEM test while "addition errors" were predominantly in elder children (8 to 11 years).

Table 6.9a Mean vertical errors with sub-types in the DEM test

Vertical errors	6 years	7 years	8 years	9 years	10 years	11 years
Omission	0.3	0.1	0.0	0.0	0.0	0.0
Addition	**1.9**	**1.4**	**0.9**	**1.0**	**0.8**	**0.9**
Substitution	0.3	0.2	0.2	0.1	0.0	0.0
Transposition	0.0	0.0	0.0	0.0	0.0	0.0

Table 6.9b Mean horizontal errors with sub-tests in the DEM test

Horizontal errors	6 years	7 years	8 years	9 years	10 years	11 years
Omission	**5.5**	**2.9**	0.9	1.0	0.1	0.0
Addition	3.7	2.3	**2.9**	**1.8**	**1.3**	**1.6**
Substitution	0.5	0.5	0.2	0.2	0.1	0.1
Transposition	0.0	0.1	0.0	0.0	0.0	0.0

6.1.5 Comparison of the means of the DEM scores between Cantonese-speaking children and the English norms in the manual

Table 6.10 showed the comparison of the design of the current study and the original study by Garzia et al. (1990). There were two main differences in the study design. Our study did not include schools from suburban area because all primary schools are located in urban area. Therefore, the main difference was the language used in the two studies.

Table 6.10 Comparison of study design between Garzia et al. (1990) and the present study

	The present study (Cantonese-speaking)	Garzia et al. (1990) (English-speaking)
Number of subjects	305	534
Age range	6 to 11 years	6 to 13 years
Grade range	Primary 1 to 6	Grade 1 to 8
Age-to-grade consideration	Included	Included
Instruction set	Read carefully as fast as possible (given in Cantonese)	Read carefully as fast as possible (given in English)
School	Urban only	Urban, suburban and parochial schools
Language used in the DEM test	Chinese (Cantonese)	English

Each type of scores was compared with the scores of the age matched English normative sample as listed in the DEM test manual using the unpaired t-test. Tables 6.11 to 6.16 describe the results of the comparisons of the means of DEM scores between Cantonese-speaking children in this study and the English norms for each age group. Adjusted vertical time was used in our study while vertical time was used in the English norms.

Table 6.11 The DEM scores of Cantonese-speaking children and English norms at 6 years of age

	Cantonese-speaking children	English norms from the DEM manual	Unpaired t-test
Number of subject	53	52	
Mean vertical time ± SD (seconds)	50.98 ±13.16	63.11 ± 16.59	p < 0.01
Mean horizontal time ± SD (seconds)	71.27 ± 18.45	98.26 ± 32.61	p < 0.01
Mean of horizontal error ± SD	9.66 ± 7.51	15.22 ± 11.49	p < 0.01
Mean of ratio ± SD	1.41 ± 0.25	1.58 ± 0.45	p < 0.05

Table 6.12 The DEM scores of Cantonese-speaking children and English norms at 7 years of age

	Cantonese-speaking children	English norms from the DEM manual	Unpaired t-test
Number of subject	63	75	
Mean vertical time ± SD (seconds)	43.34 ± 8.82	54.83 ± 9.2	p < 0.01
Mean horizontal time ± SD (seconds)	57.14 ± 14.21	87.94 ± 28.18	p < 0.01
Mean of horizontal error ± SD	5.59 ± 6.72*	12.5 ± 12.91	p < 0.01
Mean of ratio ± SD	1.32 ± 0.16	1.60 ± 0.41	p < 0.01

* Non-Gaussian distribution

Table 6.13 The DEM scores of Cantonese-speaking children and English norms at 8 years of age

	Cantonese-speaking children	English norms from the DEM manual	Unpaired t-test
Number of subject	54	93	
Mean vertical time ± SD (seconds)	38.50 ± 7.99	46.76 ± 7.89	p < 0.01
Mean horizontal time ± SD (seconds)	47.55 ± 10.60	57.73 ± 12.32	p < 0.01
Mean of horizontal error ± SD	3.96 ± 3.74	4.61 ± 6.91	p > 0.05
Mean of ratio ± SD	1.24 ± 0.15	1.24 ± 0.18	p > 0.05

Table 6.14 The DEM scores of Cantonese-speaking children and English norms at 9 years of age

	Cantonese-speaking children	English norms from the DEM manual	Unpaired t-test
Number of subject	50	84	
Mean vertical time ± SD (seconds)	36.53 ± 6.61	42.33 ± 8.20	p < 0.01
Mean horizontal time ± SD (seconds)	43.03 ± 7.83	51.13 ± 13.30	p < 0.01
Mean of horizontal error ± SD	2.98 ± 3.28	2.17 ± 4.10	p > 0.05
Mean of ratio ± SD	1.18 ± 0.12	1.21 ± 0.19	p > 0.05

Table 6.15 The DEM scores of Cantonese-speaking children and English norms at 10 years of age

	Cantonese-speaking children	English norms from the DEM manual	Unpaired t-test
Number of subject	52	73	
Mean vertical time ± SD (seconds)	29.38 ± 6.00	40.28 ± 4.73	$p < 0.01$
Mean horizontal time ± SD (seconds)	33.69 ± 8.72	47.64 ± 10.11	$p < 0.01$
Mean of horizontal error ± SD	1.56 ± 2.16*	1.91 ± 2.68	-
Mean of ratio ± SD	1.14 ± 0.15	1.19 ± 0.17	$p > 0.05$

* Non-Gaussian distribution

Table 6.16 The DEM scores of Cantonese-speaking children and English norms at 11 years of age

	Cantonese-speaking children	English norms from the DEM manual	Unpaired t-test
Number of subject	33	82	
Mean vertical time ± SD (seconds)	29.83 ± 5.36	37.14 ± 5.42	$p < 0.01$
Mean horizontal time ± SD (seconds)	32.87 ± 7.03	42.62 ± 7.61	$p < 0.01$
Mean of horizontal error ± SD	1.70 ± 2.72*	1.68 ± 2.34	-
Mean of ratio ± SD	1.10 ± 0.11	1.15 ± 0.13	$p < 0.05$

* Non-Gaussian distribution

Comparison of the DEM scores between Cantonese-speaking children and the norms provided in the manual showed several distinctive differences:

1. There was a significant difference between the Cantonese-speaking and English-speaking children in the mean vertical and the mean horizontal times for all age groups (unpaired t-test, $P < 0.01$). Cantonese-speaking children completed the DEM test faster than the English counterparts in both the vertical and horizontal test components.

2. Cantonese-speaking children in the group of 6 year old made less horizontal errors than the English children; this was statistically significant (unpaired t-test; $P < 0.01$). For children aged 7,10 and 11 years, comparison of the means of the DEM horizontal error scores was not performed due to the non-Gaussian nature of the data in the present study, non-parametric Mann Whitney Test required the raw data for analysis and it was not possible as the DEM test manual only provided the mean and standard deviation. Anyway in these age groups, the errors made between the two groups were quite similar. There were no statistical differences in horizontal errors in age group 8 and 9 years old.

3. The mean ratio of horizontal time to vertical time (adjusted in the present study and not adjusted in those provided in the manual) was statistically significantly different between Cantonese-speaking and English children in the age groups of 6 and 7 years old (unpaired t-test, $P < 0.01$). The mean ratios were smaller in the Cantonese-speaking children in all age groups. There was not significant difference in the mean ratio between the two groups in other age groups (8 to 11 years).

6.1.6 Comparison of the means of DEM scores with other ethnic groups

There were three published studies describing norms for the DEM test. Garzia et al. (1990) provided the norms for English-speaking American children. Being the developers of the DEM test, the normative values reported by Garzia et al. (1990) were actually the same as in the DEM test manual (Richman and Garzia, 1987). Fernandez-Velazquez and Fernandez-Fidalgo (1995) published the norms for a Spanish-speaking population, while Jiménez et al. (2003) reported norms for the DEM test, which were similar in all aspect to those of Garzia et al. (1990) for another group of Spanish-speaking children. The norms in our study are compared with these studies, as shown in Tables 6.17 to 6.22. Figures 6.6 to 6.9 show the comparison of the DEM scores as a function of age amongst these studies.

Table 6.17a Comparison of the DEM scores amongst Cantonese, English and Spanish at age of 6 years

	The present study (Cantonese children)	Garzia et al. (1990) (English children)	Fernandez-Fidalgo et al. (1995) (Spanish children)	Jiménez et al. (2003) (Spanish children)	One way ANOVA
Number of subject	53	52	224	115	
Mean vertical time ± SD (seconds)	50.98 ±13.16	63.11 ± 15.59	86.30 ± 23.02	65.20 ± 19.07	p < 0.01
Mean horizontal time ± SD (seconds)	71.27 ± 18.45	98.26 ± 32.61	146.90 ± 41.6	97.79 ± 24.59	p < 0.01
Mean of horizontal error ± SD	9.66 ± 7.51	15.22 ± 11.49	7.70 ± 4.43	13.54 ± 9.01	p < 0.01
Mean of ratio ± SD	1.41 ± 0.25	1.58 ± 0.45	1.67 ± 0.37	1.56 ± 0.33	p < 0.01

Table 6.17b Post-hoc test comparing the means of the DEM scores in the present study and other studies for age of 6 years (Tukey-Kramer Multiple Comparisons Test)

The present study (Cantonese children)	Garzia et al. (1990) (English children)	Fernandez-Fidalgo et al. (1995) (Spanish children)	Jiménez et al. (2003) (Spanish children)
Mean vertical time	p < 0.05	p < 0.05	p < 0.05
Mean horizontal time	p < 0.05	p < 0.05	p < 0.05
Mean of horizontal error	p < 0.05	NS	p < 0.05
Mean of ratio	NS	p < 0.05	NS

Table 6.18a Comparison of the DEM scores amongst Cantonese, English and Spanish at age of 7 years

	The present study (Cantonese children)	Garzia et al. (1990) (English children)	Fernandez-Fidalgo et al. (1995) (Spanish children)	Jiménez et al. (2003) (Spanish children)	One way ANOVA
Number of subject	63	75	227	183	
Mean vertical time ± SD (seconds)	43.34 ± 8.82	54.83 ± 9.2	58.27 ± 13.04	53.89 ± 11.00	$p < 0.01$
Mean horizontal time ± SD (seconds)	57.14 ± 14.21	87.94 ± 28.18	81.38 ± 26.91	73.48 ± 21.44	$p < 0.01$
Mean of horizontal error ± SD	5.59 ± 6.72*	12.5 ± 12.91	6.97 ± 6.41	8.50 ± 7.88	-
Mean of ratio ± SD	1.32 ± 0.16	1.60 ± 0.41	1.70 ± 0.29	1.36 ± 0.26	$p < 0.01$

*non-Gaussian distribution

Table 6.18b Post-hoc test comparing the means of the DEM scores in the present study and other studies for age of 7 years (Tukey-Kramer Multiple Comparisons Test)

The present study (Cantonese children)	Garzia et al. (1990) (English children)	Fernandez-Fidalgo et al. (1995) (Spanish children)	Jiménez et al. (2003) (Spanish children)
Mean vertical time	$p < 0.01$	$p < 0.01$	$p < 0.01$
Mean horizontal time	$p < 0.01$	$p < 0.01$	$p < 0.01$
Mean of horizontal error	-	-	-
Mean of ratio	$p < 0.01$	$p < 0.01$	NS

Table 6.19a Comparison of the DEM scores amongst Cantonese, English and Spanish at age of 8 years

	The present study (Cantonese children)	Garzia et al. (1990) (English children)	Fernandez-Fidalgo et al. (1995) (Spanish children)	Jiménez et al. (2003) (Spanish children)	One way ANOVA
Number of subject	54	93	240	197	
Mean vertical time ± SD (seconds)	38.50 ± 7.99	46.76 ± 7.89	49.60 ± 9.65	48.77 ± 13.08	p < 0.01
Mean horizontal time ± SD (seconds)	47.55 ± 10.60	57.73 ± 12.32	68.30 ± 19.57	60.92 ± 17.81	p < 0.01
Mean of horizontal error ± SD	3.96 ± 3.74	4.61 ± 6.91	5.55 ± 5.97	6.37 ± 6.95	p < 0.05
Mean of ratio ± SD	1.24 ± 0.15	1.24 ± 0.18	1.40 ± 0.31	1.25 ± 0.18	p < 0.01

Table 6.19b Post-hoc test comparing the means of the DEM scores in the present study and other studies for age of 8 years (Tukey-Kramer Multiple Comparisons Test)

The present study (Cantonese children)	Garzia et al. (1990) (English children)	Fernandez-Fidalgo et al. (1995) (Spanish children)	Jiménez et al. (2003) (Spanish children)
Mean vertical time	p < 0.01	p < 0.01	p < 0.01
Mean horizontal time	p < 0.01	p < 0.01	p < 0.01
Mean of horizontal error	NS	NS	NS
Mean of ratio	NS	p < 0.01	NS

Table 6.20a Comparison of the DEM scores amongst Cantonese, English and Spanish at age of 9 years

	The present study (Cantonese children)	Garzia et al. (1990) (English children)	Fernandez-Fidalgo et al. (1995) (Spanish children)	Jiménez et al. (2003) (Spanish children)	One way ANOVA
Number of subject	50	84	238	171	
Mean vertical time ± SD (seconds)	36.53 ± 6.61	42.33 ± 8.20	42.37 ± 7.46	43.00 ± 7.16	p < 0.01
Mean horizontal time ± SD (seconds)	43.03 ± 7.83	51.13 ± 13.30	54.54 ± 11.60	50.84 ± 10.31	p < 0.01
Mean of horizontal error ± SD	2.98 ± 3.28	2.17 ± 4.10	1.69 ± 2.66	4.40 ± 5.31	-
Mean of ratio ± SD	1.18 ± 0.12	1.21 ± 0.19	1.31 ± 0.22	1.18 ± 0.14	p < 0.01

Table 6.20b Post-hoc test comparing the means of the DEM scores in the present study and other studies for age of 9 years (Tukey-Kramer Multiple Comparisons Test)

The present study (Cantonese children)	Garzia et al. (1990) (English children)	Fernandez-Fidalgo et al. (1995) (Spanish children)	Jiménez et al. (2003) (Spanish children)
Mean vertical time	p < 0.01	p < 0.01	p < 0.01
Mean horizontal time	p < 0.01	p < 0.01	p < 0.01
Mean of horizontal error	NS	NS	NS
Mean of ratio	NS	p < 0.01	NS

Table 6.21a Comparison of the DEM scores amongst Cantonese, English and Spanish at age of 10 years

	The present study (Cantonese children)	Garzia et al. (1990) (English children)	Fernandez-Fidalgo et al. (1995) (Spanish children)	Jiménez et al. (2003) (Spanish children)	One way ANOVA
Number of subject	52	73	258	178	
Mean vertical time ± SD (seconds)	29.38 ± 6.00	40.28 ± 4.73	40.19 ± 7.65	33.84 ± 7.00	p < 0.01
Mean horizontal time ± SD (seconds)	33.69 ± 8.72	47.64 ± 10.11	47.24 ± 10.37	44.87 ± 10.58	p < 0.01
Mean of horizontal error ± SD	1.56 ± 2.16*	1.91 ± 2.68	0.81 ± 1.76	2.65 ± 3.36	-
Mean of ratio ± SD	1.14 ± 0.15	1.19 ± 0.17	1.25 ± 0.16	1.15 ± 0.13	p < 0.01

* Non-Gaussian distribution

Table 6.21b Post-hoc test comparing the means of the DEM scores the present study and other studies for age of 10 years (Tukey-Kramer Multiple Comparisons Test)

The present study (Cantonese children)	Garzia et al. (1990) (English children)	Fernandez-Fidalgo et al. (1995) (Spanish children)	Jiménez et al. (2003) (Spanish children)
Mean vertical time	p < 0.01	p < 0.01	p < 0.01
Mean horizontal time	p < 0.01	p < 0.01	p < 0.01
Mean of horizontal error	-	-	-
Mean of ratio	NS	p < 0.01	NS

Table 6.22a Comparison of the DEM scores amongst Cantonese, English and Spanish at age of 11 years

	The present study (Cantonese children)	Garzia et al. (1990) (English children)	Fernandez-Fidalgo et al. (1995) (Spanish children)	Jiménez et al. (2003) (Spanish children)	One way ANOVA
Number of subject	33	82	252	161	
Mean vertical time ± SD (seconds)	29.83 ± 5.36	37.14 ± 5.42	36.16 ± 6.32	36.32 ± 6.30	$p < 0.01$
Mean horizontal time ± SD (seconds)	32.87 ± 7.03	42.62 ± 7.61	43.49 ± 10.04	40.63 ± 7.87	$p < 0.01$
Mean of horizontal error ± SD	1.70 ± 2.72*	1.68 ± 2.34	0.51 ± 1.68	1.84 ± 2.96	-
Mean of ratio ± SD	1.10 ± 0.11	1.15 ± 0.13	1.18 ± 0.15	1.12 ± 0.12	$p < 0.01$

* Non-Gaussian distribution

Table 6.22b Post-hoc test comparing the means of the DEM scores the present study and other studies for age of 11 years (Tukey-Kramer Multiple Comparisons Test)

The present study (Cantonese children)	Garzia et al. (1990) (English children)	Fernandez-Fidalgo et al. (1995) (Spanish children)	Jiménez et al. (2003) (Spanish children)
Mean vertical time	$p < 0.01$	$p < 0.01$	$p < 0.01$
Mean horizontal time	$p < 0.01$	$p < 0.01$	$p < 0.01$
Mean of horizontal error	-	-	-
Mean of ratio	NS	$p < 0.01$	NS

To summarize the findings as shown in Tables 6.17 to 6.22:

1. The means of the four DEM scores (vertical time, horizontal time, horizontal error and ratio) were significantly different amongst the four studies (one way ANOVA, $p < 0.001$) in all age groups.

2. From the results of the post-hoc tests, it was found that:

   i. The means of vertical time and horizontal time in our study (Cantonese-speaking children) were significantly shorter than those in the other three studies (English and Spanish-speaking children) in all age groups.

   ii. The means of horizontal errors at 6 year in our study were significantly less than those in Garzia et al. (1990) (English-speaking children) and Jiménez et al. (2003) (Spanish-speaking children).

   iii. The means of the DEM ratio in Fernandez-Fidalgo et al. (1995) (from Spanish-speaking children) were significantly higher than our study in all age groups. The mean ratio in Garzia et al.'s study (1990) (from English-speaking children) was significantly higher than ours at age groups of 7 years. There was no significant difference in the DEM ratio between our study and Jiménez et al. (2003)'s study in all age groups.

Figure 6.6 Comparison of the DEM vertical time in Cantonese, English and Spanish children

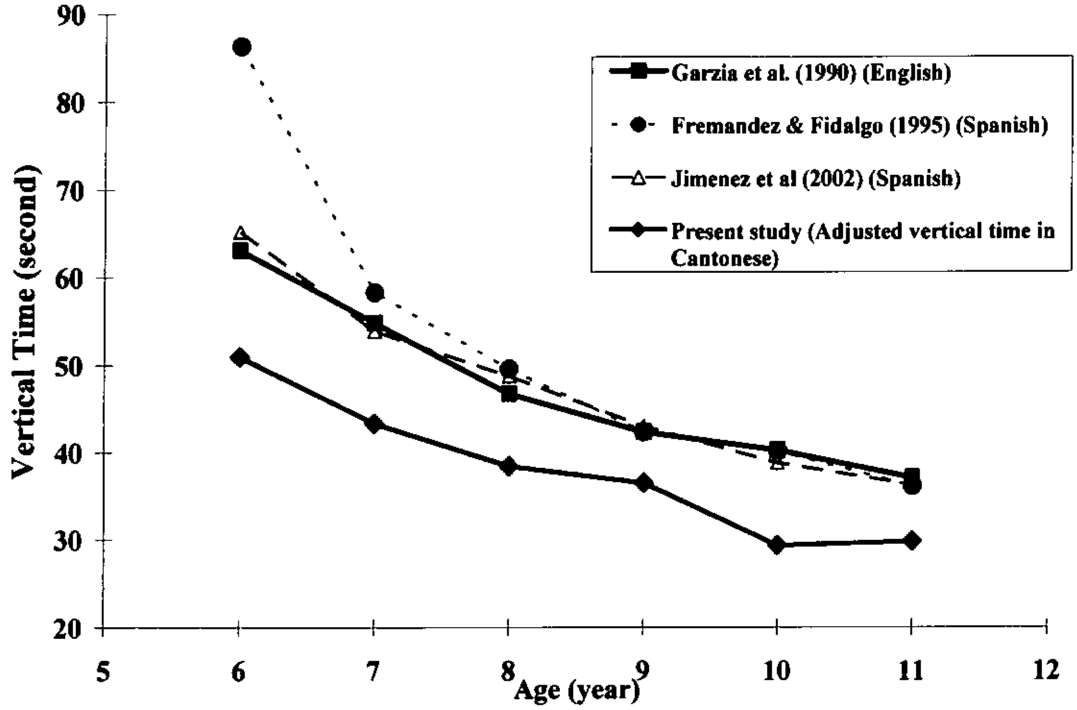


Figure 6.7 Comparison of the DEM adjusted horizontal time in Cantonese, English and Spanish children

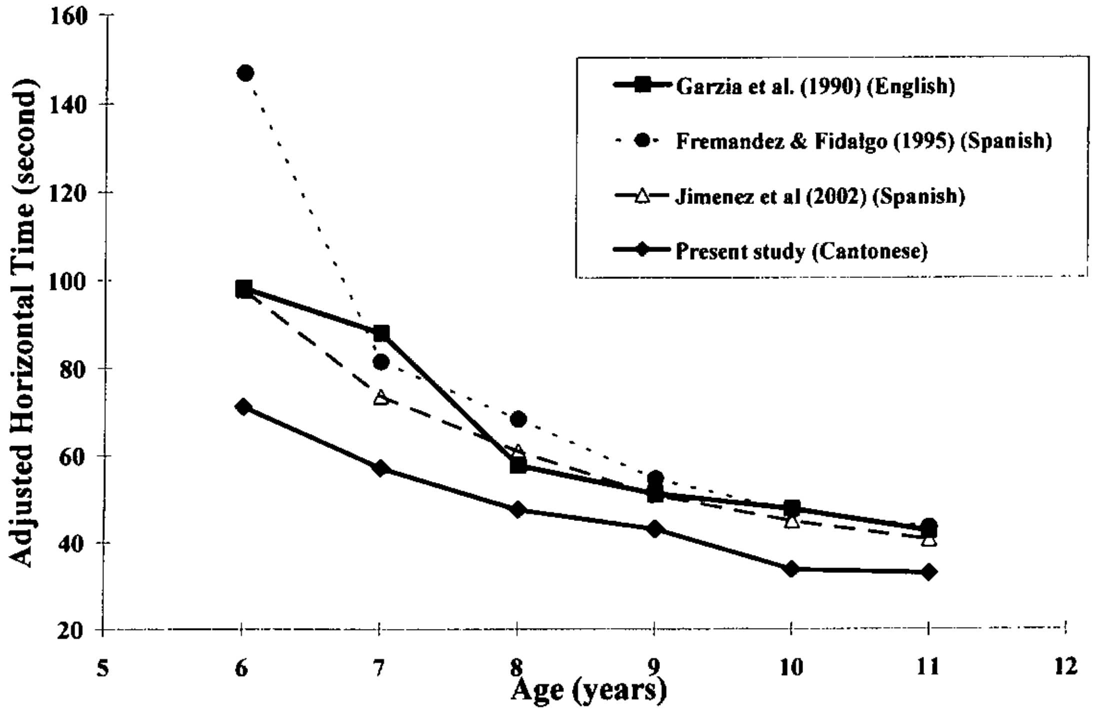


Figure 6.8 Comparison of the DEM horizontal error in Cantonese, English and Spanish children

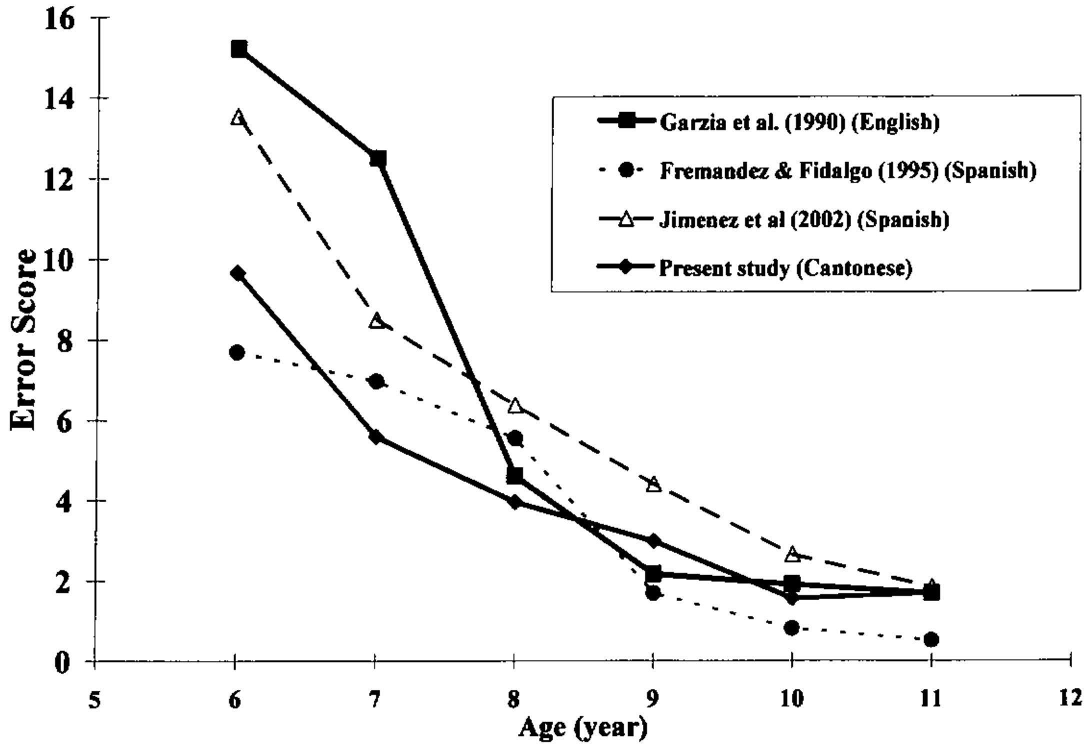
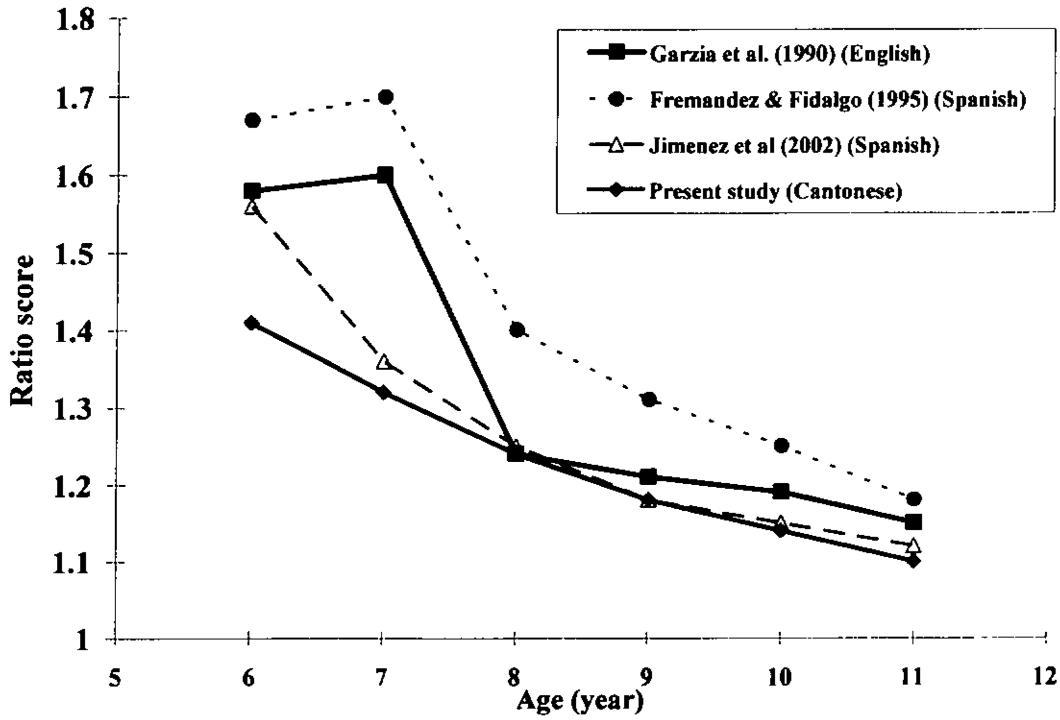


Figure 6.9 Comparison of the DEM ratio in Cantonese, English and Spanish children



In summary, Cantonese-speaking children completed the vertical and horizontal tests much faster than both the English-speaking and Spanish-speaking children. Cantonese-speaking children also made fewer horizontal errors than the Spanish children (Jiménez et al. 2002) but only age groups 6 and 7 among the Chinese made fewer errors than the English children (Garzia et al. 1990). Fernandez-Fidalgo et al. (1995) found a higher mean DEM ratio in Spanish population than Garzia et al. (1990) and our study. Their findings were even higher than another Spanish DEM study by Jiménez et al. (2003).

6.1.7 The norms of the DEM test for Cantonese-speaking children

As there was significant difference in the DEM scores between the Cantonese-speaking children in our study and the norms in the test manual, it is necessary to develop a percentile rank table based on our findings to allow efficient interpretation of the raw clinical data. The percentile rank was calculated in the same manner of percentile segmentation as described in the manual of the DEM test.

In general, the percentile is computed by the following statistical formula:

$$(100\ p)^{th}\ \text{percentile} = X_{(r)} + f\left(X_{(r+1)} - X_{(r)}\right)$$

where p is the fraction of the percentile ($0 < p < 1$); r and f are the integer part and the fractional part of $(n + 1)p$, respectively (Elifson et al., 1998). $X_{(r)}$ is the data at the (r) rank and $X_{(r+1)}$ is the next proceeding data of $X_{(r)}$. The method is generally used to calculate percentile. However, the formula is valid for a data set of increasing order. In the DEM test, the longer the reading time, the lower the percentile rank. Therefore, the equation was adjusted in a reverse order, such that it could be used to calculate the percentile score with a decreasing order data set. Our revised equation is:

$$(100\ p)^{th}\ \text{percentile} = X_{(r)} - f\left(X_{(r)} - X_{(r+1)}\right)$$

For example, in the vertical test for the group aged 6 years, there were 53 results (in seconds):

Data in descending order: 104, 72, 71, 70, 70, 69, 64, 63, 62, 60, ...

Rank of data: $1^{st}, 2^{nd}, 3^{rd}, 4^{th}, 5^{th}, 6^{th}, 7^{th}, 8^{th}, 9^{th}, 10^{th}$...

To calculate the score at the 15^{th} percentile, it would be necessary to find out the percentile rank first: Percentile rank at 15^{th} is 8 (i.e. 53 x 0.15). The 8^{th} result is 63. Then the score at the 15^{th} percentile would be 63 (i.e. 63 – 0.15 (63 – 62)).

Tables 6.23 to 6.28 list the norms of the present study for the age groups of 6 to 11 years. The vertical time is the mean adjusted vertical time in the vertical test; the horizontal time is the mean adjusted horizontal time in the horizontal test (seconds) and the error is the total horizontal error. The ratio is adjusted horizontal time over the adjusted vertical time.

Table 6.23 The DEM norms table for Cantonese-speaking children at 6 years to 6 years 11 months

	Mean (SD) (N=53)
Vertical Time (sec)	50.98 ± 13.16
Horizontal Time (sec)	71.27 ± 18.45
Errors	9.66 ± 7.51
Ratio	1.41 ± 0.24

Vertical test (sec)	Percentile	Horizontal test (sec)	Error	Percentile	Ratio
32	99	34	0	99	1.06
33	96	41	0	96	1.07
37	90	46	1	90	1.15
38	85	55	1	85	1.16
39	80	59	2	80	1.19
41	75	61	3	75	1.20
42	70	62	5	70	1.23
45	65	65	6	65	1.32
46	60	66	7	60	1.33
47	55	68	8	55	1.36
49	50	69	8	50	1.39
51	45	70	10	45	1.41
53	40	72	10	40	1.45
54	35	75	11	35	1.47
57	30	77	12	30	1.51
58	25	82	15	25	1.53
59	20	84	15	20	1.57
63	15	88	19	15	1.66
70	10	95	24	10	1.74
71	5	98	25	5	1.94
104	1	132	26	1	2.13

Table 6.24 The DEM norms table for Cantonese-speaking children at 7 years to 7 years 11 months

	Mean (SD) (N=63)
Vertical Time (sec)	43.34 ± 8.82
Horizontal Time (sec)	57.14 ± 14.21
Errors	5.59 ± 6.72
Ratio	1.32 ± 0.16

Vertical test (sec)	Percentile	Horizontal test (sec)	Error	Percentile	Ratio
25	99	32	0	99	0.98
29	96	36	0	96	1.09
33	90	42	0	90	1.14
35	85	46	0	85	1.16
37	80	47	0	80	1.18
37	75	48	0	75	1.21
38	70	50	1	70	1.23
39	65	51	1	65	1.25
40	60	52	2	60	1.27
41	55	53	3	55	1.28
42	50	54	3	50	1.29
42	45	56	6	45	1.33
44	40	56	6	40	1.34
45	35	58	6	35	1.36
47	30	60	8	30	1.36
47	25	63	8	25	1.40
52	20	67	9	20	1.43
54	15	73	12	15	1.52
56	10	79	14	10	1.55
60	5	87	16	5	1.63
70	1	106	35	1	1.78

Table 6.25 The DEM norms table for Cantonese-speaking children at 8 years to 8 years 11 months

	Mean (SD) (N=54)
Vertical Time (sec)	38.50 ± 7.99
Horizontal Time (sec)	47.55 ± 10.60
Errors	3.96 ± 3.74
Ratio	1.24 ± 0.15

Vertical test (sec)	Percentile	Horizontal test (sec)	Error	Percentile	Ratio
22	99	30	0	99	1.00
26	96	31	0	96	1.03
29	90	33	0	90	1.04
31	85	36	0	85	1.07
32	80	38	0	80	1.10
32	75	40	0	75	1.12
34	70	41	1	70	1.14
34	65	43	2	65	1.18
35	60	44	2	60	1.19
36	55	45	3	55	1.20
37	50	46	4	50	1.21
38	45	47	4	45	1.25
39	40	49	4	40	1.27
40	35	51	5	35	1.28
42	30	53	5	30	1.33
44	25	55	6	25	1.36
47	20	57	7	20	1.38
49	15	58	8	15	1.43
52	10	62	9	10	1.44
55	5	71	14	5	1.58
55	1	79	14	1	1.59

Table 6.26 The DEM norms table for Cantonese-speaking children at 9 years to 9 years 11 months

	Mean (SD) (N=50)
Vertical Time (sec)	36.53 ± 6.61
Horizontal Time (sec)	43.03 ± 7.83
Errors	2.98 ± 3.28
Ratio	1.18 ± 0.12

Vertical test (sec)	Percentile	Horizontal test (sec)	Error	Percentile	Ratio
24	99	26	0	99	0.97
26	96	30	0	96	1.01
28	90	35	0	90	1.03
30	85	35	0	85	1.05
31	80	36	0	80	1.09
32	75	38	0	75	1.11
33	70	38	1	70	1.13
33	65	39	1	65	1.14
34	60	39	1	60	1.15
35	55	41	2	55	1.16
35	50	41	2	50	1.17
37	45	44	3	45	1.19
38	40	45	3	40	1.20
39	35	47	4	35	1.21
40	30	49	5	30	1.22
42	25	49	5	25	1.25
43	20	50	6	20	1.25
43	15	51	6	15	1.30
46	10	55	7	10	1.39
50	5	59	10	5	1.46
51	1	60	16	1	1.47

Table 6.27 The DEM Norms Table for Cantonese-speaking children at 10 years to 10 years 11 months

	Mean (SD) (N=52)
Vertical Time (sec)	29.38 ± 6.00
Horizontal Time (sec)	33.69 ± 8.72
Errors	1.56 ± 2.16
Ratio	1.14 ± 0.15

Vertical test (sec)	Percentile	Horizontal test (sec)		Error	Percentile	Ratio
18	99	20		0	99	0.84
21	96	22		0	96	0.93
21	90	24		0	90	0.96
23	85	26		0	85	0.98
24	80	27		0	80	1.00
26	75	28		0	75	1.06
27	70	28		0	70	1.09
27	65	29		0	65	1.11
28	60	30		0	60	1.13
29	55	32		0	55	1.13
29	50	32		0	50	1.13
30	45	33		1	45	1.14
30	40	34		1	40	1.16
31	35	37		2	35	1.19
31	30	37		2	30	1.20
32	25	38		3	25	1.21
33	20	40		4	20	1.25
34	15	41		4	15	1.26
41	10	45		5	10	1.40
42	5	51		7	5	1.46
47	1	67		9	1	1.57

Table 6.28 The DEM norms table for Cantonese-speaking children at 11 years to 11 years 11 months

	Mean (SD) (N=33)
Vertical Time (sec)	29.83 ± 5.36
Horizontal Time (sec)	32.87 ± 7.03
Errors	1.70 ± 2.72
Ratio	1.10 ± 0.11

Vertical test (sec)	Percentile	Horizontal test (sec)	Error	Percentile	Ratio
21	99	22	0	99	0.87
22	96	22	0	96	0.90
23	90	24	0	90	0.99
25	85	26	0	85	0.99
26	80	27	0	80	1.00
27	75	28	0	75	1.01
27	70	29	0	70	1.04
28	65	29	0	65	1.06
28	60	29	0	60	1.06
28	55	30	0	55	1.08
29	50	32	1	50	1.09
29	45	34	1	45	1.10
30	40	34	1	40	1.14
30	35	35	1	35	1.14
31	30	36	2	30	1.15
32	25	37	2	25	1.16
35	20	37	2	20	1.17
36	15	42	5	15	1.21
39	10	46	6	10	1.25
41	5	48	9	5	1.35
43	1	48	11	1	1.37

6.1.8 The prevalence of automaticity and saccadic eye movement dysfunction

In order to classify the children in this study into the five diagnostic types from the DEM scores, the data on each individual child was evaluated carefully by giving "pass" and "fail" grades to each score, using the Cantonese norms derived in this study (from Tables 6.23 to 6.28). "Fail" means the DEM scores of the child were below the 15 percentile in the norm table for his or her age and "pass" means the child's DEM scores were above the 15 percentile. After determining the pass/fail grade of each component, Type II, III and IV diagnoses could be derived. Type I is "normal" and it is not included in the prevalence analysis. Table 6.29 lists the prevalence of the different problems.

Table 6.29 The prevalence of Type II to VI problems

Diagnosis	Problem	Vertical test	Horizontal test	Ratio	Number of subjects (%)
Type II	Saccadic eye movement problem	Pass	Fail	Fail	**78.7%** (240/305)
Type III	Automaticity	Fail	Fail	Pass	**4.3%** (13/305)
Type IV	Both automaticity and saccadic eye movement problem	Fail	Fail	Fail	**6.9%** (21/305)
Type V	Tendency to automaticity problem	Pass	Fail	Pass	**1.3%** (4/305)
Type V	Tendency towards Type IV	Pass	Fail	Pass	**2.6%** (8/305)
Type VI	Tendency towards Type III	Fail	Pass	Pass	**6.2%** (19/305)

There were eight Type V children who failed the horizontal test but passed the vertical test and the ratio. However, they all got a poor pass (ranked between 15-40%) in both vertical test and ratio. Finally nineteen children failed the vertical test, but passed the horizontal test and ratio. Eighteen of these 19 children poorly passed (ranked between 15 – 40%) the horizontal test and 17 of them ranked high (60 – 99 %) in ratio.

6.2 Discussion

It was unfortunate that technical problem happened with the digital recorder during the data collection process. This led to the necessity of excluding twelve cases, and consequently the number of subjects in age group of eleven dropped to 33, which is slightly less than the expected sample size of 44. It was also not possible to arrange extra sessions at the school to collect extra subjects due to the busy schedule of the students during term time.

6.2.1 Vertical time versus adjusted vertical time

Garzia et al. (1990) as well as in the manual of the DEM test claimed that the errors made in vertical subtests were minimal and could be neglected in the calculation of DEM scores. He reported that only 17 (11%) of a sample of 150 six to ten years old English-speaking children made one error, with only two subjects (1%) exhibiting three or more vertical errors.

In our study, we noted substantial errors in the vertical subtest, 175 children made errors ranged from 1 to as many as 13. Ninety nine (28.5%) children made one to two vertical errors and 76 (21.9%) made three or more errors. We found Cantonese-speaking children made more errors than the Caucasian population in the vertical tests as quoted by Garzia et al. (1990). Jiménez et al. (2003) reported the results for vertical errors in testing a group of Spanish children with the DEM test. Table 6.29 shows the mean of vertical error in Jiménez et al. (2003)'s study and the present study. Statistical test is not possible as the there were no raw data from Jiménez's study and the distribution of the data were not normal. Overall, the Cantonese-speaking children made more errors than the Spanish-speaking children at all ages from 6 to 11 years. To ensure accuracy in the DEM scores, it is proposed that the vertical time should be adjusted by the factor for vertical errors for Cantonese children.

Table 6.30 Vertical error in the present study and Jiménez et al. (2003)'s study

Age (yrs)	6	7	8	9	10	11
Vertical error in Cantonese-speaking children Mean ± SD	2.5± 3.1	1.7 ± 2.7	1.2 ± 1.7	1.0 ± 1.4	0.9 ± 1.6	1.0 ± 1.6
Vertical error in Spanish-speaking children Mean ± SD	1.4 ± 1.9	0.9 ± 1.6	1.0 ± 1.7	0.9 ± 1.6	0.8 ± 1.6	0.55± 0.9

6.2.2 Gender difference

Maples (1997) suggested that there was an intrinsic difference in oculomotor patterns between boys and girls, when he tested the functions with the NSUCO test. He reported that girls tended to perform slightly better than boys up to about ninth years old but he did not report any statistical analysis in supporting his argument. Differences in the DEM scores between boys and girls were not found in the present study. So far, to our best knowledge, none of the previous DEM studies reported a gender difference in the DEM scores. Therefore, it is reasonable to believe that there is no difference in the DEM scores between boys and girls. The data from girls and boys were grouped together for analysis with respect to age and other variables.

6.2.3 The DEM scores in relation to age

The DEM scores were found normally distributed within each age group (except the error scores at age 9, 10 and 11 years). Older children could read faster and make fewer errors. This effect skewed the data, which did not pass the normality test, if all the data from ages 6 to 11 years are grouped together. Therefore, the non-parametric Spearman correlation test was used to investigate the correlations among the parameters. From Table 6.8, significant associations are found in the four DEM scores with age (Spearman correlation, $P < 0.01$). The DEM scores have been found be age dependent in some previous studies (Garzia et al., 1990; Jimenez et al., 2003).

This age trend is similar to other English and Spanish studies of normal values for the DEM test (Garzia et al., 1990; Hatch et al., 1994; Fernandez-Velazquez and Fernandez-Fidalgo, 1995; Jimenez et al., 2003). Hence, as the DEM scores are age specific, administrators should use appropriate age-matched norms for comparing the DEM scores for children of a particular age.

6.2.4 Differences in the DEM scores between Cantonese and English-speaking children

The average reading times in the three DEM subtests were significantly shorter in Cantonese-speaking children than the norms by English populations in all the age groups. Garzia et al. (1990) and Fernandez-Velazquez and Fernandez-Fidalgo (1995) found that the DEM ratios of their children were much higher in the ages of six and seven years. They suggested that this is due to the immaturity of the saccadic eye movement functions in these ages. There is no such trend in the results of the Cantonese-speaking children. This might be due to the fact that the 6 to 7 years old children in the present study made fewer horizontal errors with less effect on the adjusted horizontal time. Why do Chinese children make fewer errors in the horizontal test? Do Chinese children develop saccadic eye movement skills much earlier than the English-speaking children; such that they are more mature in this skill at age 6 and 7 years? The following reasons are proposed.

6.2.4.1 Effect of language and ethnicity

Our results suggest that Cantonese-speaking children can complete the vertical and horizontal DEM tests much faster than both English-speaking and Spanish-speaking children. Actually, the results from Jiménez et al. (2003) (Spanish norms) were similar to Garzia et al. (1990) (English norms), therefore the results of comparison amongst our study and these two were quite similar. However, Fernandez-Fidalgo (1995) reported a relatively higher adjusted horizontal time and ratio in different age groups than ours. The results of the two Spanish DEM studies did not agree with each other, and further investigation of DEM norms in Spanish-speaking children is warrant.

Language is the major reason accounting for the difference. In the DEM test, only single digit numbers are used. It is commonly known that English is an alphabetic language, in which there is a direct correspondence between graphemes and phonemes (Ho and Bryant, 1999). The pronunciation of English words comprises one or more syllables and the letters play different role in a word such as a vowel; consonant or diphthong. The length of an English word can vary from one letter to over twenty. Therefore, a longer time is required to pronounce a lengthy word. For example, two phonemes are required to pronounce "seven" in the DEM test. Indo-European languages have similar phonemic characteristics, therefore the times for the DEM test were similar to those of Spanish-speaking children (Fernandez-Velazquez and Fernandez-Fidalgo, 1995).

By using "numbers" in the test, the design of the DEM eliminates the influence of word frequency or the length of words (Just and Carpenter, 1980). Children of different ethnicities should be able to read Arabic numbers. Visually these numbers look the same and have the same meaning to children from different ethnicities but the pronunciations are quite different. In Cantonese, only one syllable is required for reading the Arabic numbers 0 to 9. Therefore, the time required to read out these numbers in Chinese should be shorter than in English. So the speed and the nature of the verbal Cantonese language could account for the shorter time in completing the DEM tests.

How to distinguish the effect of language and the reading speed of an individual on the DEM test results? Further study can be carried out to test a group of children in Hong Kong who can speak fluent English and Cantonese by comparing the test in English and Cantonese in these children.

6.2.4.2 The difference in the education systems

There was a general trend across all ages for the Chinese children to use less time in completing the DEM task. This could be accounted for by the maturity of spoken language, particularly in recognizing and identifying the numbers in older children. This trend is similar to the findings in the English studies. According to the Education and Manpower Bureau of the Hong Kong Government, Hong Kong children start their formal reading instruction at three years old (Government, 2002), whereas, in general, children in Western countries begin their school reading instruction at the age of five. Therefore, children in Hong Kong have one or more years of experience in reading than the English children in the Western system. This may account for the outcome that our 6 and 7 year old children made fewer errors than the English-speaking children in the DEM test.

6.2.4.3 Behavioural variations

In the traditional primary education in Hong Kong, a child is requested to re-write or re-do the homework again, when there are any mistakes in homework or dictation. The actions of some children reflected this "corrective" behaviour in the DEM test. For example, if a child missed a digit in the row and he realized the mistake immediately after he had completed reading that row, he would say "oh no!" and then he repeated the same line from the beginning. His "corrective" behaviour could possibly converted ONE "omission" error into FOUR "addition" errors. This may be the reason for the relatively higher mean vertical errors in our study. This effect distorts the real picture of saccadic eye movement function. Therefore, it is useful to give prior instruction to the child that "if you realize that you have made an error during your reading, please continue and it is not necessary to go back and make a correction." Further investigation might be necessary to improve the instruction. Our observation was supported by the distribution of errors (Table 6.9), where addition errors were the most frequent errors in ages 8 and above, when the child had developed this corrective behaviour.

In Hong Kong, it is well known that our living style is "fast and busy". Traditional schools use a heavily structured syllabus to train the students. Teachers have to follow the programme and a lot of homework is given to the children daily. Therefore, the children in Hong Kong develop a sense of competing against time, starting from their first year of primary school. When the DEM test was conducted to the Hong Kong children, it was observed that they were a bit anxious, but concentrated. When they heard the instruction to read fast, they did!

6.2.4.4 Attention

Some studies suggested that attention could affect the results of the DEM test (Tassinari, 2001; Adler et al., 2004). The results of these studies suggested that the children might loss concentration at the bottom part of the horizontal test and this affected the final result. To further investigate the effect of attention, further experiment could be set up to compare the DEM test results if only the first 40 numbers of vertical and horizontal sub-tests are used.

6.2.4.5 Intelligence Quotient

All the DEM studies did not purposely control the IQ effect. Since the automaticity and the saccadic eye movement are developmental processes. It is logical to speculate that the IQ could affect the ability to read and thus the DEM result. Further study on the effect of IQ on the DEM test will be useful.

6.2.5 The DEM norms for Cantonese

The children in this study were selected randomly. A quota was set for each school and all the students of that year group were invited. The returned consent forms were drawn at random by the school for entry into our study. As there might have been some hidden motives from parents who suspected their child might have some visual problems, we cannot say that the sample of children was 100% randomly selected, but at least it was not clinically biased. Therefore, the visual parameters collected in this study should reflect the norms for Hong Kong Chinese children.

As there are significant differences between the DEM scores in Cantonese-speaking children and the English norms, the latter are not suitable for use as norms for Cantonese children. Therefore, using data from our 305 Chinese children, tables of Cantonese normal values for the DEM test were prepared for ages 6 to 11 years. The same percentile ranks were used as in the DEM manual, so that cross referencing with the English norms could be easy. Incorrect use of the tables may lead to incorrect DEM results. For example, if the adjusted horizontal time for a 6 year old child is 88 seconds, then the Cantonese table of norms returns a 15 percentile rank, but the English norms suggests a rank in the 50-55 percentile. Thus, incorrect use of the tables of normal values will increase the frequency of false negatives and may lead to a wrong diagnosis.

The Cantonese norms derived from this study are useful to clinicians who use the DEM test (including the Department of Health of the Hong Kong Government) in Hong Kong or for children who speak Cantonese.

6.2.6 The prevalence of the four types of diagnosis in Chinese children

The DEM test provides clinicians with a method for measuring both automaticity and saccadic eye movement function. Automatic cognitive processing ability is related to reading. When we present a letter or number to a child, the naming of such a letter requires a bridging between visual, cognitive and linguistic sub-processes, including feature analysis, attention and articulation.

As there is no clear explanation of what is meant by "abnormal" findings from the DEM manual, advice from Kulp and Schmidt (1997a) was adopted to differentiate abnormal from normal in the present study. According to Kulp and Schmidt (1997a), a test score below one standard deviation away from the mean (or 15^{th} percentile) was considered as "poor" result. So the 15^{th} percentile was used as the "fail" criterion. As mentioned in Chapter 2, Type V and VI were added as new possible diagnostic categories. The DEM data of all these Type V children looked like the clinical picture of a Type IV (failure in all scores). On the other hand, the DEM data of the Type VI children were similar to Type III (failure in vertical and horizontal test, but pass in ratio). Clinical judgment on the DEM data is very important to avoid misdiagnosis.

In the earlier studies of the DEM test, none reported the prevalence of the four types of problems. The prevalence of saccadic eye movement dysfunction (Type II) in our entire population was 4.3%.. Scheiman et al. (1996) described 0.7 per cent as the prevalence of ocular motility disorders by using a subjective observation method on a clinical population of patients aged 6 months to 18 years. Our findings cannot be directly compared with the results of Scheiman et al. (1996) because of the differences in the method of eye movement measurement and the age range.

6.9% of our subjects were found to have automaticity problem (Type III). The automaticity problems were thought to be associated with developmental problems

(LeBerge and Samuels, 1974), particularly in connection with reading difficulty (Garzia et al., 1990; Yap and van der Leij, 1994). If the prevalence of Types III, IV, and V and VI, which contain different proportions of automaticity deficiency, were added together, the sum covers nearly 17% of the population of Chinese children from 6 to 11 years. Why are there so many children with automaticity problems? This value (17%) is alarming and, coincidently, is similar to the prevalence range for specific learning disability as quoted by Lam (2001) in Hong Kong.

As reviewed in Chapter 2, the results of a RAN test have been suggested as a predictor of reading performance and at the same time the RAN is a measure of automaticity. It is possible that these 17% of children, who were diagnosed to have an automaticity dysfunction, were also suffering from reading dysfunction. Failure of automaticity has a broader meaning than the failure of saccadic eye movement functions. Automaticity may contain characteristics of dyslexia/reading dysfunction, which possibly includes poor quality of saccadic eye movement. However, in this study, we cannot say that the Type II children (from the DEM scores) must have a reading problem or dyslexia.

If a child is diagnosed with saccadic eye movement dysfunction (Types II or IV), he should be referred for assessment and possible vision therapy. It has been shown that vision therapy is effective (Cohen, 1988); (Ciuffreda, 2002) for various visual problems including eye movements. On the other hand, if a child is diagnosed to have an automaticity problem (Types III or IV), further investigation should be arranged to allow a more accurate differential diagnosis of the problem. The investigation might include visual perceptual assessments and some other psychological assessment, such as IQ test or other reading tests. Having all the diagnostic information on hand, the psychologist or the clinician can provide an appropriate training programme to improve the child's learning and/or reading.

6.3 Summary

The Development Eye Movement test was administrated to 305 Cantonese-speaking children. No gender difference was found among the four DEM scores in each age group (6 to 11 years). Statistical significant correlation was found between the DEM scores and age. The means of each of the four DEM scores were compared with the English norms for each matched age group. Significant differences in adjusted vertical time and adjusted horizontal time were found among these two groups. The Cantonese children in this study used shorter time to complete the vertical and horizontal tests than the English counterparts. Moreover, the children aged 6 years made less reading errors in the horizontal subtest than the English children of the same age group.

The difference in the means of the DEM scores between Cantonese and English populations suggests that the English norms from the DEM manual are not suitable for the Cantonese speaking children. The Cantonese norms of the DEM test were therefore derived from the results of this study. These norms will be made available to clinicians who use the DEM test in Hong Kong for adoption and verification.

The children in this study made more vertical errors than the English population. Contrary to the instructions in the DEM manual, we recommend adjusting the vertical reading time by adding a factor for the vertical errors, if the test is administrated to

Cantonese-speaking children.

According to the DEM manual, there are four diagnostic types differentiated by the DEM test. We proposed a Type V that has a tendency towards an automaticity dysfunction. The prevalence of Types II to V diagnoses was calculated. We found the prevalence of automaticity increases with age, while saccadic eye movement dysfunction decreases with age. This study provides the first report of such prevalence.

The DEM test is age dependent. Appropriate norms should be used, if it is administrated to a child who speaks in a language other than English. The test is able to identify dysfunction of saccadic eye movements and automaticity. From the results of the test, proper referral or intervention may help the child to improve the quality of reading and learning.

Chapter 7: Result and discussion – Visual functions and their associations with the DEM scores

7.1 Results

One hundred and twelve children were successfully recruited from the second part of the study. Four were excluded because of ocular pathology; strabismus or severe anisometropia. The child with severe anisometropia (over 15 D differences between the two eyes) did not respond well to most binocular tests and therefore he was excluded from this study. As a result, one hundred and eight children, aged 6 to 8 years, were included in this part of the study.

Only the results taken from the right eye were included for monocular functions such as habitual vision, refractive status and lag of accommodation. The means and standard deviations of various visual functions of the children in our study are summarized in Table 7.1. The results from most of the visual functions were combined regardless of age except accommodative amplitude which was reported for the separate age groups.

Table 7.1 The mean of visual functions of Cantonese children aged 6, 7 and 8 years

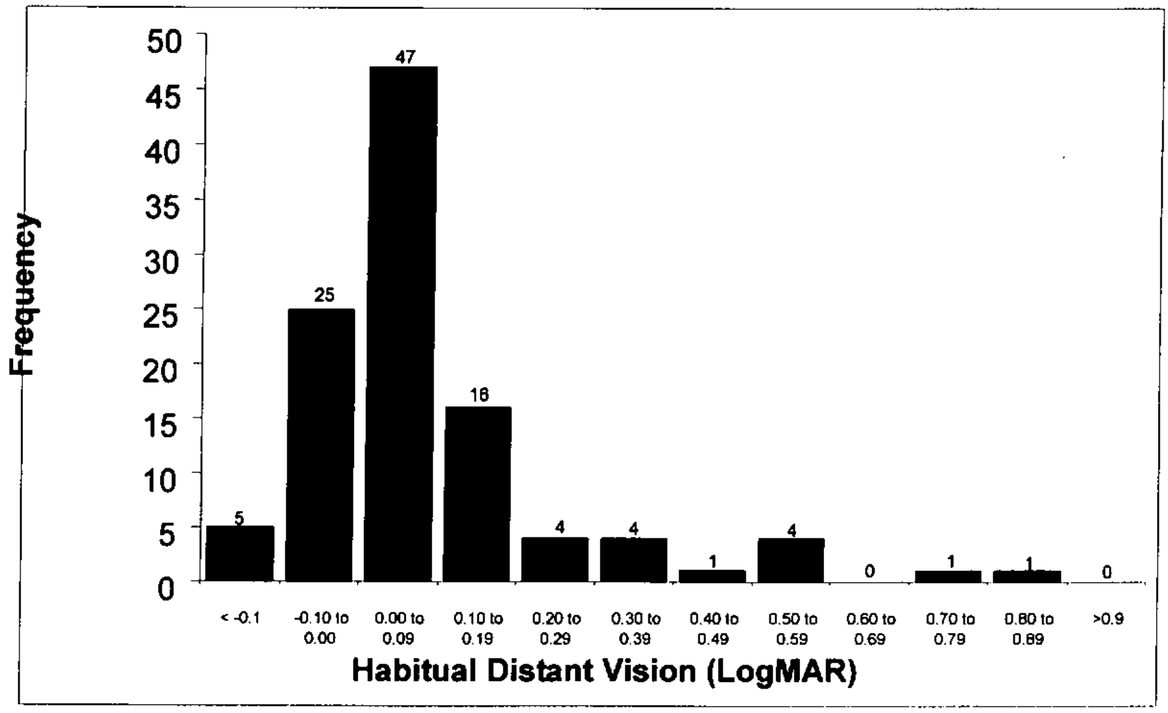
Visual function	6 years (n=30)	7 years (n=51)	8 years (n=27)	6-8 years (n=108)
Habitual Dist vision (logMAR ± SD)	+0.148 ± 0.187	+0.100 ± 0.170	+0.028 ±0.125	+0.094 ± 0.169
Habitual Near vision (logMAR ± SD)	+0.056 ± 0.108	+0.053 ± 0.069	-0.008 ± 0.073	+0.039 ± 0.086
Spherical equivalent (D ± SD)	-0.22 ± 0.88	-0.31 ± 0.98	-0.31 ± 1.26	-0.29 ± 1.02
Refractive error: Sphere (DS ± SD)	-0.13 ± 0.89	-0.17 ± 0.96	-0.25 ± 1.24	-0.18 ± 1.01
Refractive error: Cylinder (DC ± SD)	-0.20 ± 0.58	-0.28 ± 0.44	-0.12 ± 0.25	-025 ± 0.43
Anisometropia (difference in sphere in R and L) (D ± SD)	0.16 ± 0.37	0.21 ± 0.49	0.04 ± 0.11	0.16 ± 0.40
Anisometropia (difference in SER in R and L) (D ± SD)	0.22 ± 0.34	0.17 ± 0.51	0.03 ± 0.07	0.15 ± 0.40
Near horizontal heterophoria (Δ ± SD) (-ve:exo)	-1.30 ± 1.86	-1.90 ± 2.32	-1.40 ± 2.04	-1.60 ± 2.03
Near vertical heterophoria (Δ ± SD)	No incidence	1 case of 1Δ Right hyper	No incidence	1 case of 1Δ Right hyper
AC/A (+1.00 Δ/D ± SD)	2.20 ± 1.58	2.24 ± 1.62	1.93 ± 1.00	2.15 ± 1.46
Stereoacuity (sec. of arc ± SD)	33.33 ± 15.99	37.16 ± 32.59	24.82 ± 6.58	33.10 ± 24.83
Positive fusional amplitude (Δ ± SD)	33.07 ± 8.15	33.80 ± 7.10	32.78 ± 8.24	33.64 ± 7.90
Binocular Accommodative amplitude (D ± SD)	22.2 ± 7.1	20.8 ± 6.4	19.4 ± 4.6	20.82 ± 6.25
Binocular Accommodative facility +/-2.00 (c.p.m. ± SD)	7.60 ± 4.24	8.83 ± 2.71	8.62 ± 4.02	8.60 ± 3.44
Lag of accommodation (D ± SD)	+1.06 ± 0.29	+1.02 ± 0.29	+1.00 ± 0.28	+1.03 ± 0.29

7.1.1 Habitual vision

7.1.1.1 Habitual distant vision

The mean habitual distant vision was +0.094 ± 0.169 (Table 7.1). If +0.300 logMAR (equivalent to 6/12 in Snellen system) (Chan and Edwards, 1994) was used as the criterion for failure in habitual distant vision, eleven children (10.1%) failed at least in one eye. Among these 11 children, four were wearing under-corrected spectacles during the measurement, and the rest were unaided ametropes. All these children had visual acuities better than 0.15 logMAR (or 6/8.5 in Snellen) after the subjective refraction. Figure 7.1 shows the frequency distribution of habitual distant vision in these children.

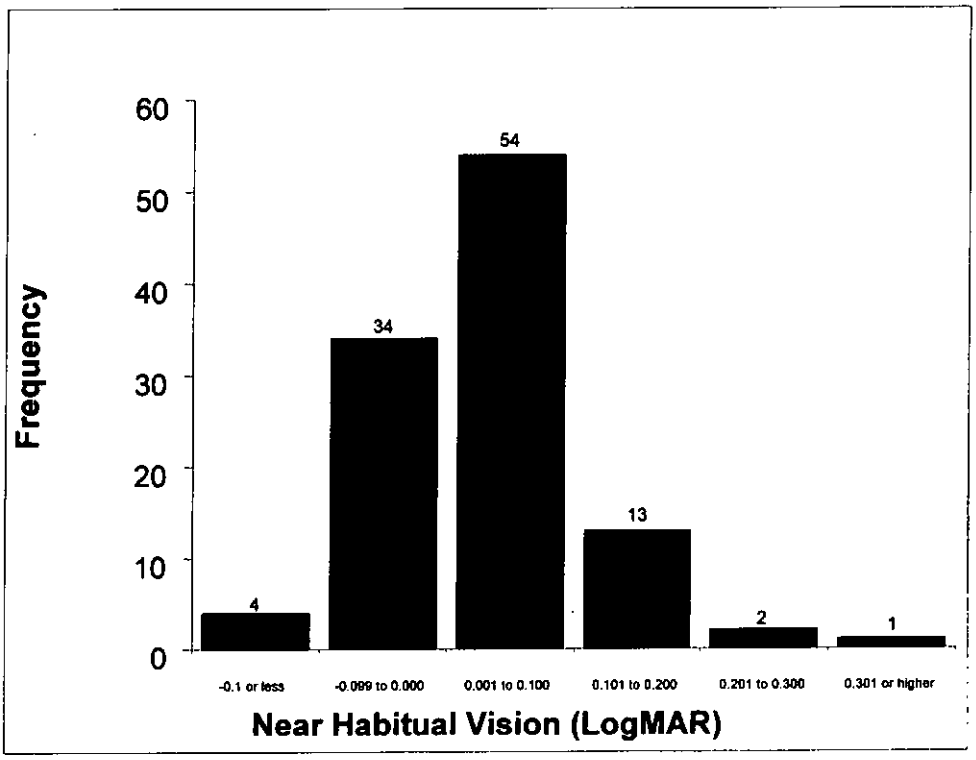
Figure 7.1 Frequency distribution of habitual distant vision



7.1.1.2 Habitual near vision

The mean habitual vision at 40 cm was +0.039 ± 0.086 logMAR in this study (Table 7.1). Similarly when 0.300 logMAR was used to identify children with poor near vision, only one (out of 108) scored higher than 0.03 in the right eye. This child had uncorrected mixed astigmatism. The child had been advised to seek a detailed examination. Figure 7.2 shows the frequency distribution of the habitual near vision in our study.

Figure 7.2 Frequency distribution of habitual near vision



7.1.2 Refractive status

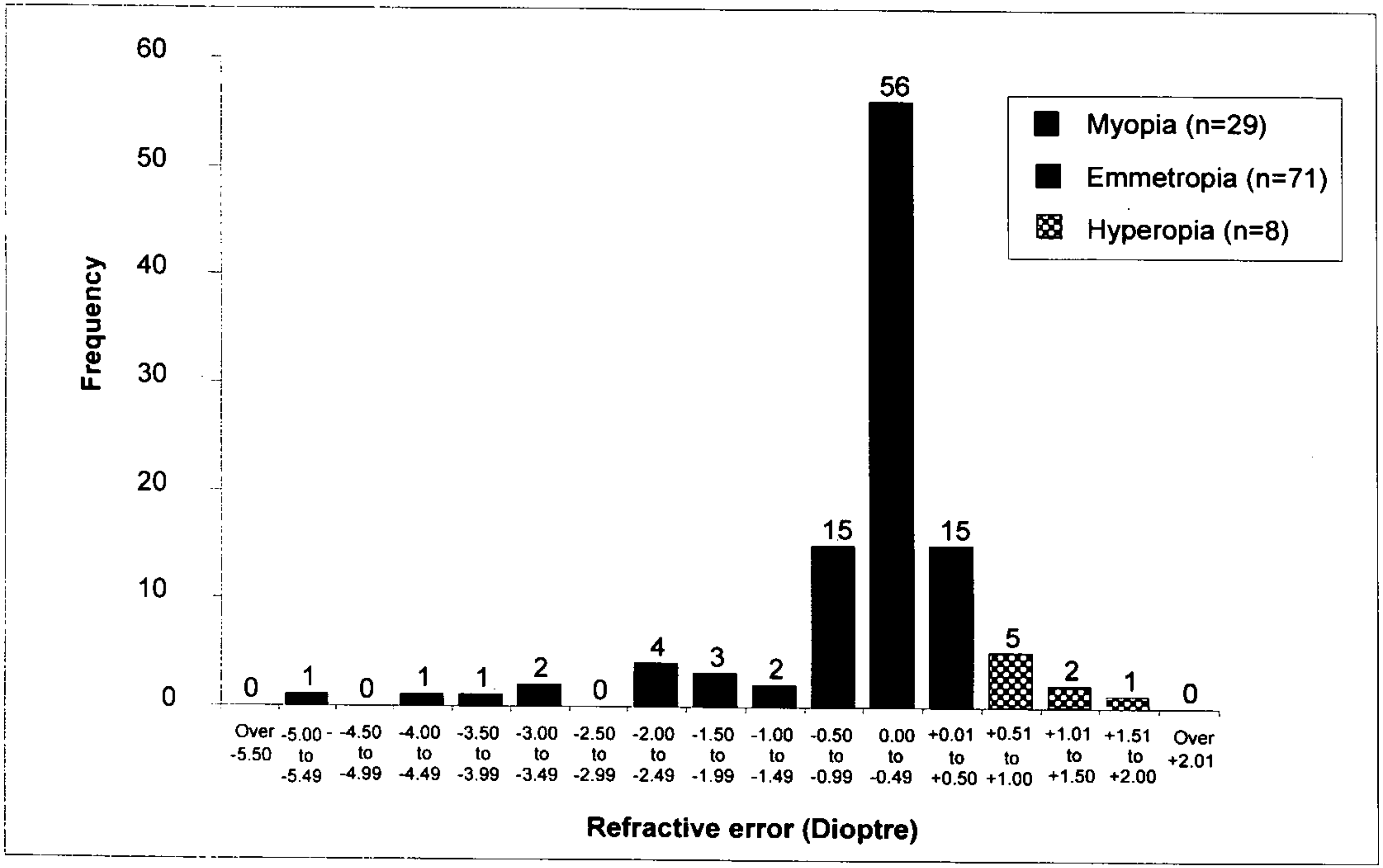
7.1.2.1 Spherical equivalent refraction (SER)

The mean SER of the children in this study (6 to 8 years) was -0.29 ± 1.02 D. Prevalence and frequency distributions of these three groups are listed in Table 7.2 and Figure 7.3 respectively.

Table 7.2 The prevalence of refractive error in the present study

SER (D)	Frequency	Percentage
Myopia (SER ≤ -0.50)	29	26%
Emmetropia (+0.75 < SER < -0.50)	71	66%
Hyperopia (SER ≥ +0.75)	8	7%

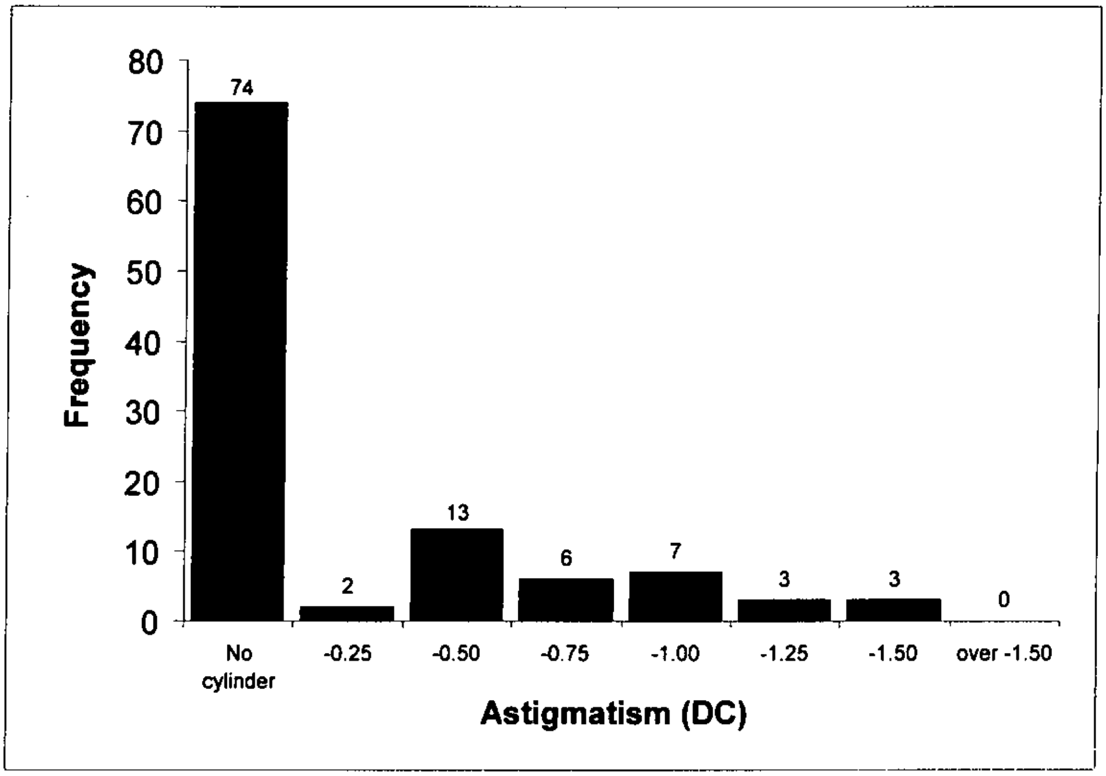
Figure 7.3 Frequency distribution of spherical equivalent refraction (SER)



7.1.2.2 Astigmatism

The mean astigmatism was −0.25 ± 0.43 DC. Six (5.5%) children had significant astigmatic power (equal to or higher than -1.25 D). Figure 7.4 shows the frequency distribution of astigmatic power in our study.

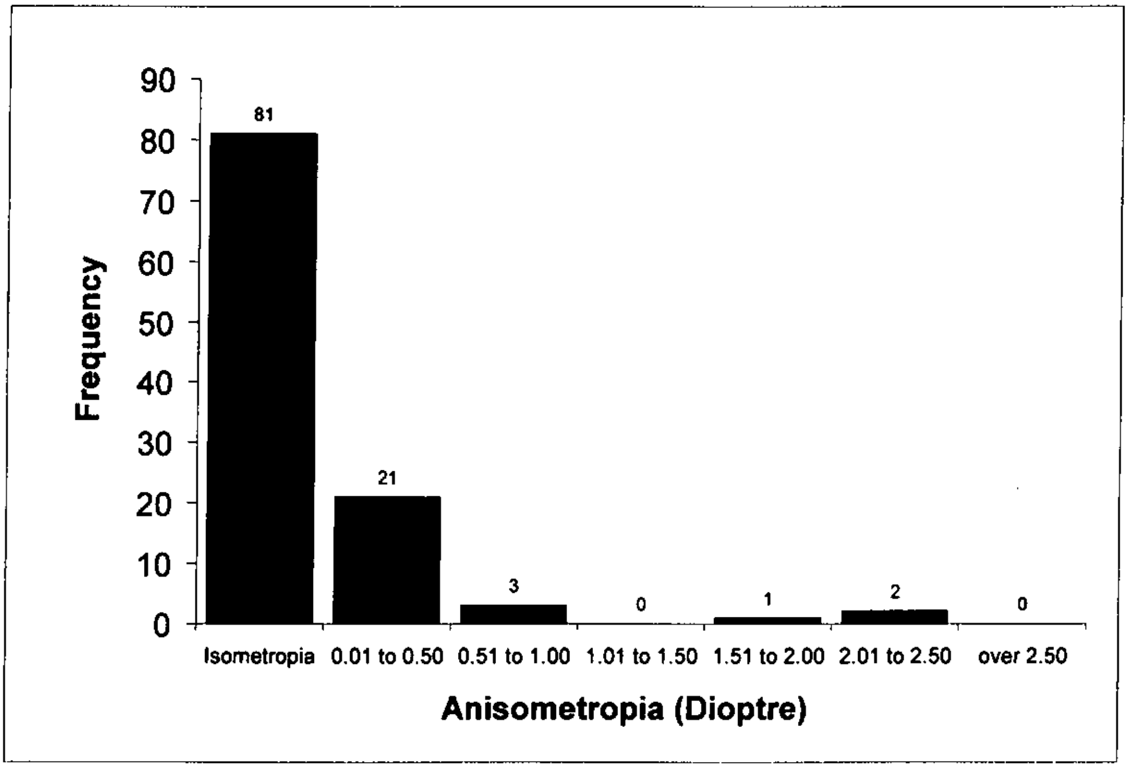
Figure 7.4 Frequency distribution of astigmatism



7.1.2.3 Anisometropia

Anisometropia is the absolute difference between the child's right and left spherical equivalent refractive errors. The mean anisometropia of the children in the study was 0.15D +/- 0.40. Three had significant anisometropia of 1.25D or above. Figure 7.5 shows the frequency distribution of anisometropia in our study.

Figure 7.5 Frequency distribution of anisometropia



7.1.3 Accommodative status

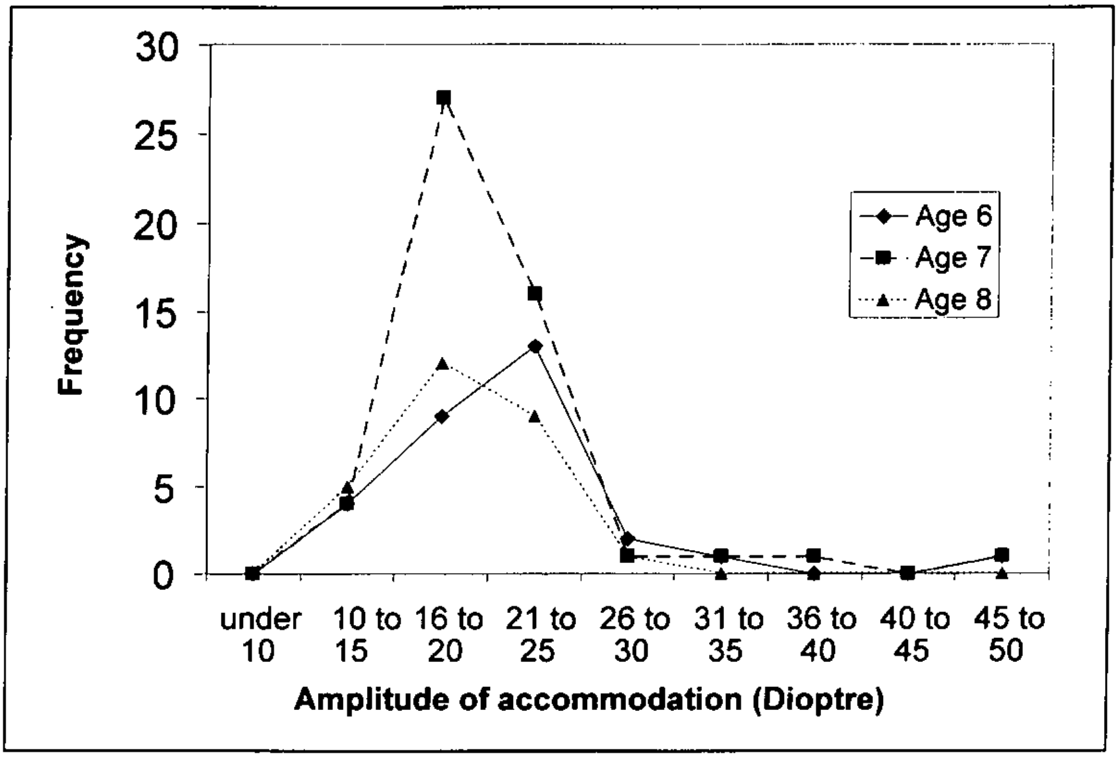
7.1.3.1 Binocular accommodative amplitude (BAA)

The amplitude in dioptres was calculated by the following formula:

Amplitude of accommodation (D) = 1 / Distance of blur (in meters)

For children with spherical refraction higher than +0.75 or lower than -0.50 D, the vertex distance was included to calculate the ocular accommodation. Only the right eyes were used in these calculations. Hence, the means of accommodative amplitude in each of the 6, 7 and 8 years age groups were 22.2 ± 7.1 D, 20.8 ± 6.4 D and 19.4 ± 4.6 D, respectively. Figure 7.6 shows the frequency distribution of the BAA in each age.

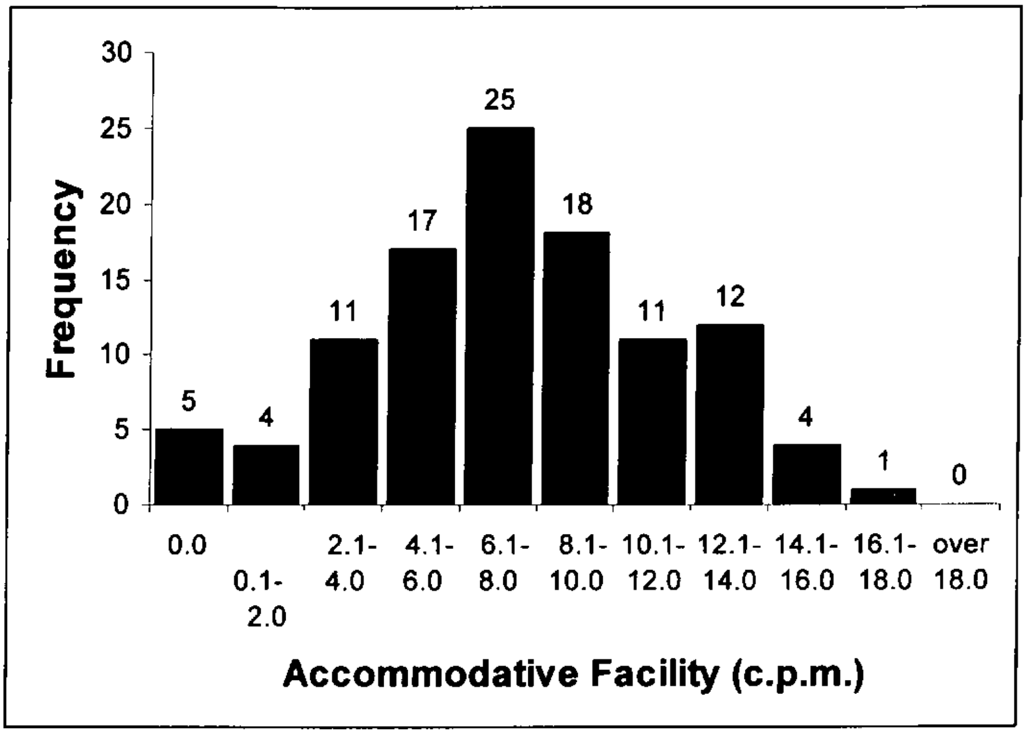
Figure 7.6 Frequency distribution of binocular accommodative amplitude



7.1.3.2 Binocular accommodative facility

Binocular accommodative facility was determined by using ± 2.00 'flipper', the child looked at printed letters of size 0.6 logMAR at 40 cm away. The mean of accommodative facility was 8.60 ± 3.44 cycle per minute (c.p.m.). Figure 7.7 shows the frequency distribution of the binocular accommodative facility in our study.

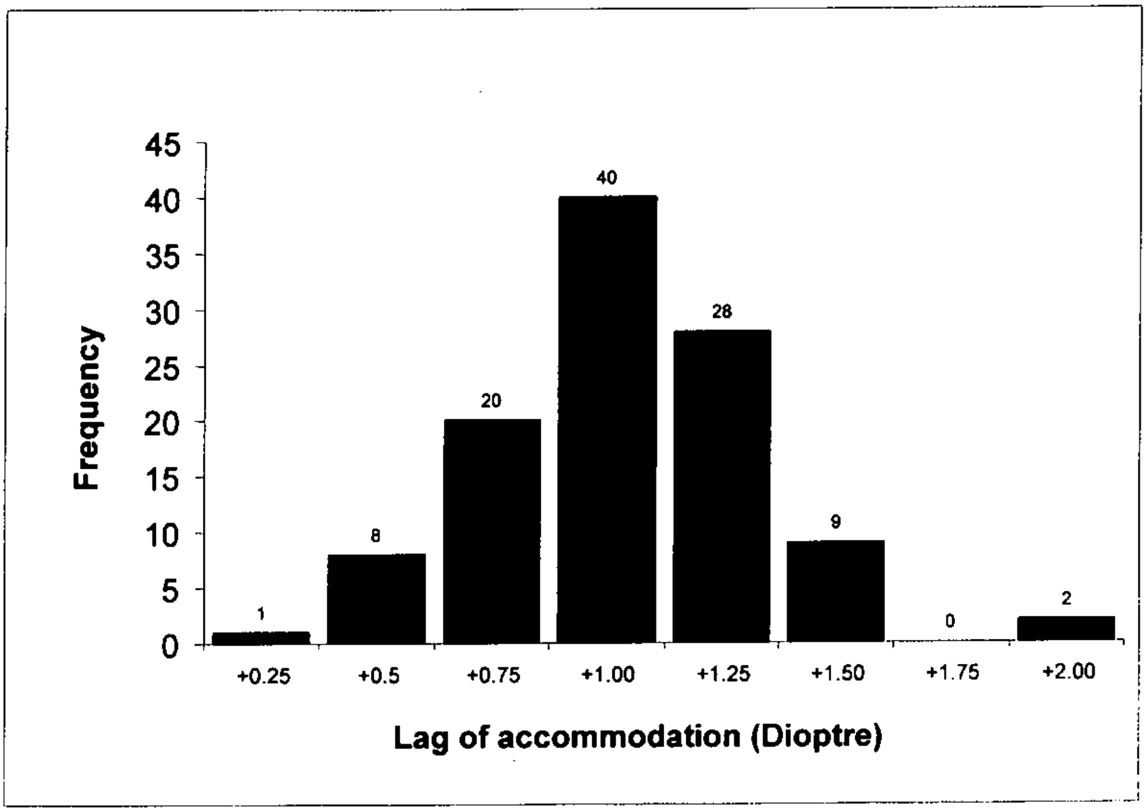
Figure 7.7 Frequency distribution of binocular accommodative facility



7.1.3.3 Lag of accommodation

Lag of accommodation was determined by the monocular estimate method (MEM). The mean value was 1.03 ± 0.29 D in this study. No lead of accommodation was found in any case. The frequency distribution of the lag of accommodation is shown in Figure 7.8.

Figure 7.8 Frequency distribution of lag of accommodation



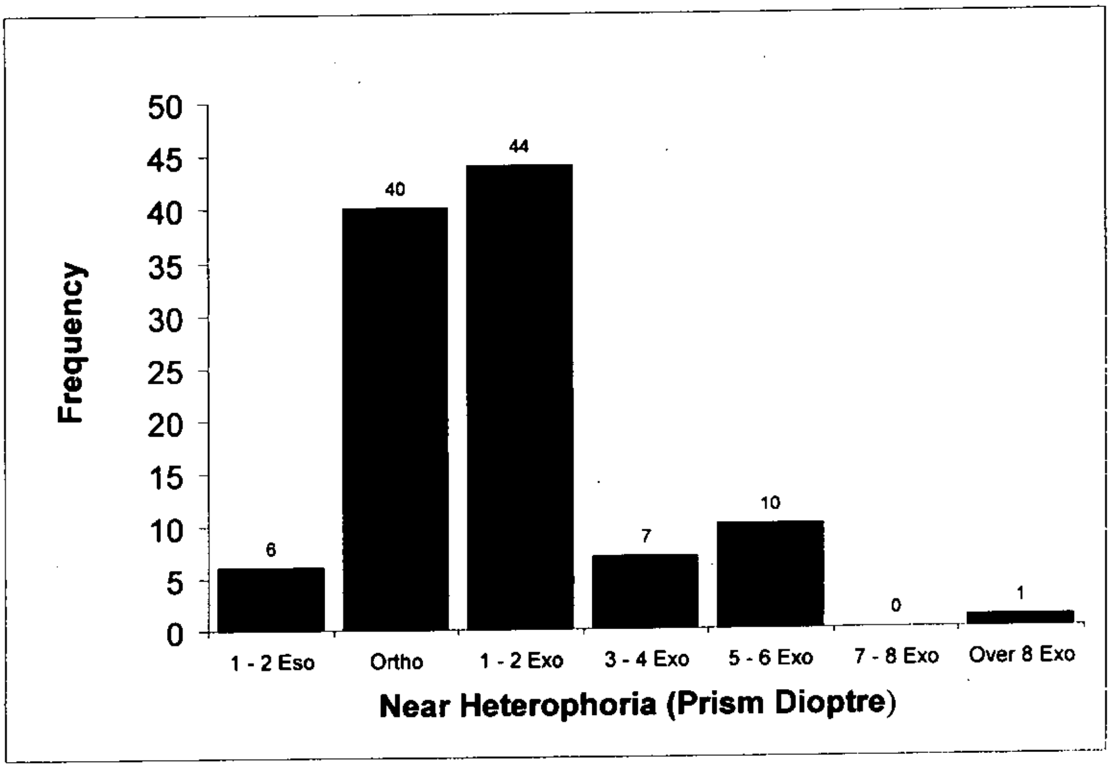
If the children were divided into three refractive status (myopia: equal or greater than -0.50 D in SER; hyperopia: equal or greater than +0.75 D in SER and emmetropia: SER in between -0.50 and +0.75 D), the lag of accommodation of myopia (N=29), hyperopia (N=8) and emmetropia (N=71) were +1.10 ± 0.31 D, +1.13 ± 0.13 D and +0.99 ± 0.31 D respectively.

7.1.4 Binocular status

7.1.4.1 Horizontal heterophoria

The horizontal heterophoria was measured to the nearest 1Δ by Maddox Wing. Most children were orthophoric or slightly exophoric (mean of 1.60 ± 2.03Δ exophoria). Only one out of the one hundred and eight children had a significant near phoria (-10Δ exophoria). Six children (5.5%) had low esophoria. Figure 7.9 shows the frequency distribution of the heterophoria in our study.

Figure 7.9 Frequency distribution of near heterophoria



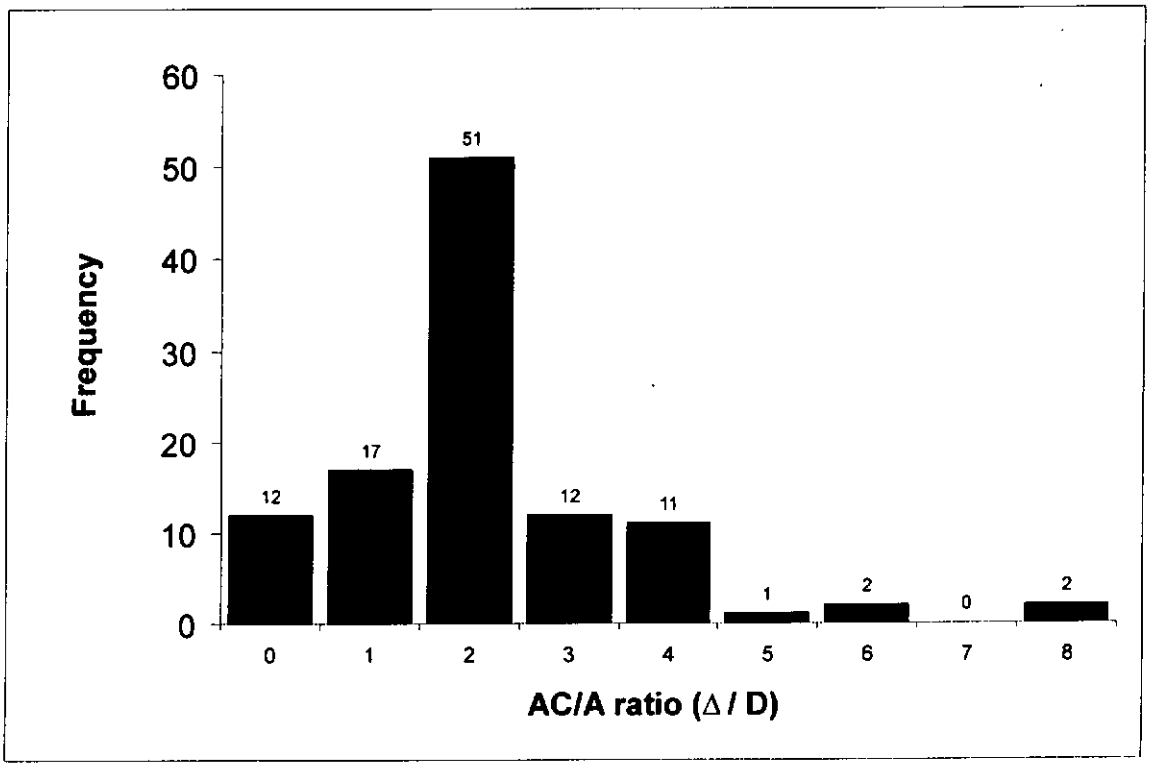
7.1.4.2 Vertical heterophoria

Almost all children were orthophoric in vertical component; only one child had 1 prism dioptre left hyperphoria.

7.1.4.3 Accommodative convergence / accommodation (AC/A) ratio_

AC/A ratio was determined by subtraction of two horizontal heterophoria measurements with and without +1.00 D lenses in the Maddox Wing test. The mean AC/A was 2.15 ± 1.46 Δ/D. No negative value was found. The frequency distribution is shown in Figure 7.10.

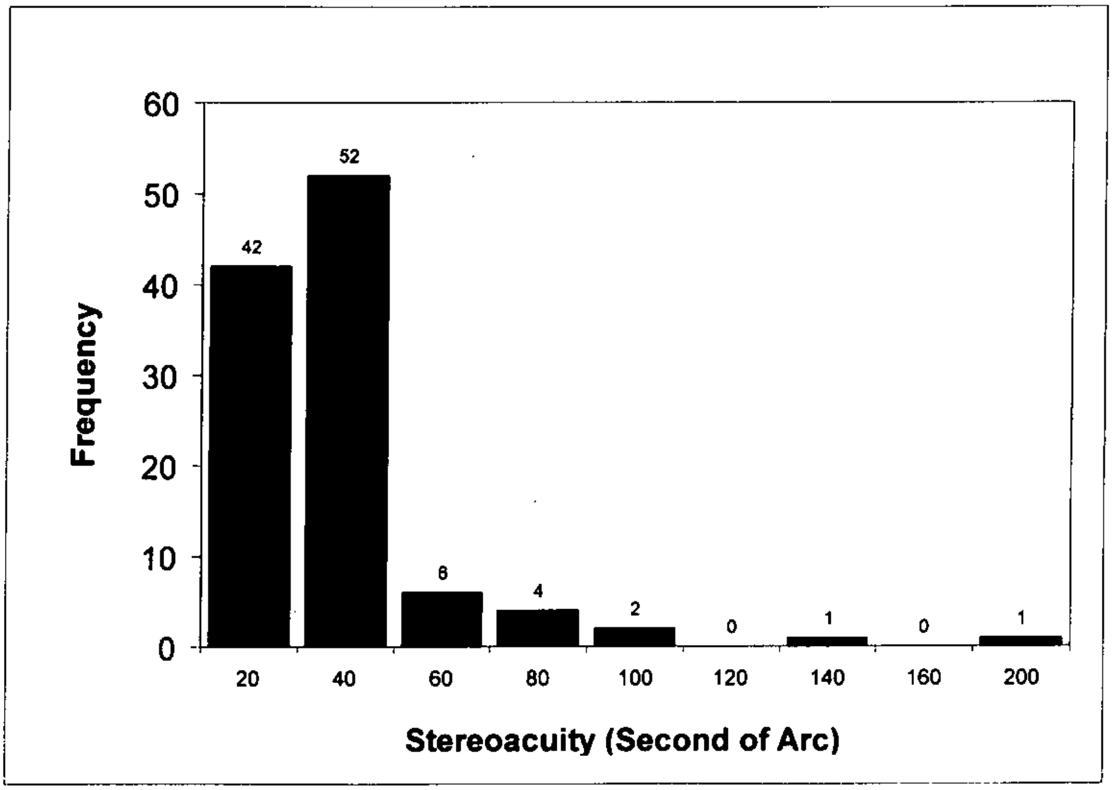
Figure 7.10 Frequency distribution of AC/A ratio



7.1.4.4 Stereoacuity

Randot stereo test was used to determine the threshold of stereoacuity at 40 cm. The mean stereo-acuity was 33.10 ± 24.83 seconds of arc. Figure 7.11 shows the frequency distribution of the stereo-acuity in our study.

Figure 7.11 Frequency distribution of stereoacuity



7.1.4.5 Fusional convergence amplitude

Hand-held prism bar was used to determine the step convergence amplitude; the instrument can measure vergence magnitude up to a maximum of 40 prism dioptres. Using the ranking table suggested by Griffin et al. (2002) , the rank distribution of our children are listed in Table 7.3. Two per cent of the children in our study were weak in fusional convergence; all the others had adequate to very strong fusional convergence.

Table 7.3 Frequency distribution of different ranks in fusional amplitude in the present study

Rank	Description	Breakpoint (Δ)	Frequency	Percentage
5	Very strong	>28	81	75%
4	Strong	22 to 28	13	12%
3	Adequate	19 to 21	12	11%
2	Weak	18	1	1%
1	Very Weak	<18	1	1%

7.1.5 Association between the DEM scores and visual functions

The DEM test was also administrated to these 108 children with their habitual visual correction. Since the DEM test results are age and language-dependent, the norms tables (Tables 6.21 to 6.23) for the Cantonese-speaking children were used to locate individual percentile rank for the four DEM scores for each child. From the results of the percentile ranks in the adjusted vertical time, adjusted horizontal time and the ratio score, a DEM test diagnosis (as listed in Tables 2.1 and 2.2) was given to each child. The number of children in Types I, II, III, IV and V are 80, 7, 8, 2 and 2, respectively. Since the numbers of children were too small in Types IV and V, they are excluded in the following comparison. There were nine children who failed the vertical test, but passed the horizontal test. These children were treated as "unclassified" and the data from this group are not included in the statistical analysis. Table 7.4 describes the means of the various visual functions of the three groups.

There was no significant difference in the means of most visual functions among the three groups of children except the lag of accommodation which was statistical significantly different (Kruskal-Wallis test, $p < 0.05$). Dunn's multiple comparisons post-hoc test suggests that the mean of the lag of accommodation in the Types III ($+1.22 \pm 0.16$ D) is significantly higher than the Type I ($+1.00 \pm 0.31$ D).

Table 7.4 The mean of visual functions in Types I, II and III children

Visual characteristics	Type I	Type II	Type III	Statistical analysis
Number of children	80	7	8	–
Habitual dist. vision (logMAR ± SD)	*0.088 ± 0.177	0.086 ± 0.061	0.050 ± 0.083	Kruskal-Wallis Test, $p > 0.05$
Habitual near vision (logMAR ± SD)	0.036 ± 0.085	0.069 ± 0.129	0.000 ± 0.058	One way ANOVA, $p > 0.05$
Refractive error: sphere (D ± SD)	* -0.23 ± 1.06	-0.11 ± 0.64	0.16 ± 0.67	Kruskal-Wallis Test, $p > 0.05$
Refractive error: cylinder (DC ± SD)	* -0.25 ± 0.40	-0.36 ± 0.63	-0.31 ± 0.64	Kruskal-Wallis Test, $p > 0.05$
Refractive error: SER (D ± SD)	* -0.35 ± 1.08	-0.29 ± 0.64	0.00 ± 0.41	Kruskal-Wallis Test, $p > 0.05$
Anisometropia (D ± SD)	* 0.18 ± 0.45	0.13 ± 0.22	0.06 ± 0.13	Kruskal-Wallis Test, $p > 0.05$
Near horizontal heterophoria (± SD) (-ve: exo)	* -1.50 ± 2.24	-1.29 ± 2.06	-1.38 ± 0.92	Kruskal-Wallis Test, $p > 0.05$
Near phoria (vertical)	No incidence	1 case of 1Δ Right hyper	No incidence	N/A
Gradient AC/A (+1.00) (Δ/D ± SD)	* 2.11 ± 1.48	1.86 ± 0.69	2.25 ± 1.28	Kruskal-Wallis Test, $p > 0.05$
Stereoacuity Percentage of subjects scored 40 seconds of arc or better	85% (65/76)	88% (7/8)	91% (10/11)	–
Positive fusional amplitude (Δ ± SD)	* 33.36± 7.91	31.43 ± 8.52	38.13 ± 3.72	Kruskal-Wallis Test, $p > 0.05$
Accommodation amplitude (D ± SD)	* 17.16 ± 3.38	19.19 ± 3.53	16.80± 3.59	Kruskal-Wallis Test, $p > 0.05$
Accommodation facility +/-2.00 (c.p.m ± SD.)	8.17 ± 4.01	6.64 ± 4.23	7.25 ± 1.93	One way ANOVA, $p > 0.05$
Lag of accommodation (D ± SD)	* +1.00 ± 0.31	+0.93 ± 0.28	+1.22 ± 0.16	Kruskal-Wallis Test, $p < 0.05$, significant

* Non-Gaussian samples

7.2 Discussion

7.2.1 Visual acuity and the DEM scores

The LogMAR crowded test (distributed by Keeler Ltd, UK) was formerly named as "Glasgow Acuity test". The sensitivity and reliability of the test have been discussed in other studies (McGraw and Winn, 1993; 1995; McGraw et al., 2000). Although the test employs English letters as the testing optotypes, all Chinese children in our study understood the instruction and there were no problems in the administration of this test. The prevalence of 10.1% habitual vision or VA failure in our study is similar to previous findings (9%) in Hong Kong Chinese (Fan et al., 1999).

When the results in distance and near habitual vision are compared, it is obvious that the children in this study had fewer failures in near vision than in distant vision. In general, poor near vision is more likely to be associated with significantly uncorrected hyperopia, which stresses the accommodation system (Dwyer and Wick, 1995). The low prevalence in hyperopia possibly explains the low incidence of poor near visual acuity.

No significant difference was found in the means of habitual vision (both distant and near) from the different types of children in our study. As the DEM test is a near function test, it would seem logical that near vision would affect the results of the test. However, only one child in our study scored poorer than 0.300 logMAR in the near VA test and he did pass both vertical and horizontal tests (Type I). This may be due to the size of number used in the DEM test. The height of the DEM test number is 3.0 mm and it is equivalent to a near visual acuity of 0.71 logMAR at 40 cm. Therefore passing the DEM subtest means the child should have a binocular near vision of 0.71 logMAR or better. All the children in our study had a better near vision than 0.71 logMAR in any one eye and it is logical that they all pass the DEM pretest. As a result, the DEM test does not demand a high visual acuity level at 40 cm and passing the pretest is sufficient to enter the test.

7.2.2 Refractive status and the DEM scores

Lam and Goh (1991) reported that the prevalence of myopia in 6 to 7 year old children was approximately 30%. In another vision screening, the same authors found that 23.9% and 33.8% of boys and girls at the age of 7 years were found to be myopic, respectively (Goh and Lam, 1993). The prevalence of myopia in our study falls within a similar range as in previous studies of Chinese children.

The mean and prevalence of astigmatism from the children of this study were lower than those reported by Lam and Goh (1991) (Girls: -0.36 ± 0.49 DC, boys: -0.42 ± 0.63 DC and prevalence of 48% in both boys and girls). However, their study covered a wider age group from 6 to 17 years. If we apply the referral criterion of Chan (1994), thirteen children (12% of the whole population), who required cylindrical correction of -1.0 dioptre (DC) or more, failed the criterion.

From the statistical analysis, there was no association in refractive error and the results of the DEM test. In other words, the DEM test could be suitable for children with different refractive errors.

7.2.3 Accommodative status and the DEM scores

7.2.3.1 Binocular accommodative amplitude

The push-up method usually returns a higher value of accommodative amplitude as compared with the minus lens method (Rosenfield and Cohen, 1996). This effect is due to the presence of convergence under binocular condition. According to the formula (Hofstetter, 1944) for age norms for accommodation (18.5 – (0.33 x age)), the expected norm at age 8 years should be 15.8 (the formula supplied only applicable for age 8 to 62.5 years). The children in this study showed a much higher value (19. 4 ± 4.6 D) than the expected or calculated norms. According to a review by Chen et al. (2000), the common factors attributed to the differences in result were: (1) different targets used (ii) different population group, (iii) different environmental factors, (iv) different ethnic population.

There was no association found between the amplitude of accommodation in different types of children in our study. The DEM test's working distance is approximate 40 cm, the accommodative demand should be 2.5 D. The children in this study should have sufficient accommodative amplitude to respond to this 2.5 D stimulus. If a child suffers from high uncorrected hyperopia, it is likely that the unstable focus may affect the accuracy of reading numbers in the DEM test. But there was no such child in our study and further investigation is indicated to testify this speculation.

7.2.3.2 Binocular accommodative facility

The means of BAF in the age group of 6, 7 and 8 years were 7.6 ± 4.2, 8.0 ± 3.4, and 8.1 ± 4.4, respectively. Our findings were much higher than the expected norms from Scheiman et al. (1988) who used special charts and their subjects were requested to read three numbers during each flip of the lenses (3 ± 2.5, 3.5 ± 2.5 and 5 ± 2.5 for children of ages 6, 7 and 8 to 12 years). Reading three numbers requires more time than just saying "clear" as in our study. Secondly, the lowered facility result at ages 6 and 7 years might be related to the demand for rapid automatic naming and some studies have demonstrated these age groups are significantly slower in rapid reading (Garzia et al., 1990). Furthermore, Junghans et al. (2002) compared the methods for testing accommodative facility and found that children could achieve faster facility, if they were tested by +/- flippers using black print on a white card as target than those methods with suppression checks.

Again, there was no effect of accommodative facility with the three types of children in the DEM test. The DEM test is a stable accommodative stimulus and demands only a short period of time, so the design of the test does not challenge the efficiency of the accommodative system.

7.2.3.3 Lag of accommodation

Motsch and Mühlendych (2000) proposed that hypoaccommodation exists, if the child reports that it is clearer and reads more fluently after the addition of the +1.00D lens. Using this method, they found six out of sixteen children with reading difficulty were found to have hypoaccommodation. The authors tested the children's accommodation without using the full corrective power, this might lead to an incorrect result if a child is under or over corrected. Secondly, the term "hypoaccommodation" is inappropriate. It confuses low amplitude of accommodation with lag of accommodation. A better way to determine the lag would be by the MEM method, which is an objective method of higher reliability (Rouse et al., 1984).

The mean of lag of accommodation in this study (+1.03 ± 0.29 D) is much higher than those reported by many other studies (ranged from +0.25 to +0.75 D) (McKee, 1981; Poynter et al., 1982; Locke and Somers, 1989; Jackson and Goss, 1991a; Cacho et al., 1999; Chen et al., 2003). Our findings (+1.03 ± 0.29 D) were quite similar to those from Chat and Edwards (2003) who measured lags of accommodation (mean +1.10D) in 33 children of age 4 to 6 years by an open-field autorefractor. In the contrary, Chen et al.(2003) found the lag of accommodation in myopic and emmetropic Chinese children to be 0.45 ± 0.37 D and 0.63 ± 0.31 D, respectively. When we compare the means for myopic children in our study with those in Chen's study, there was a statistically significant difference in the mean of the lag of accommodation (unpaired t-test, $p < 0.001$). Chen et al. (2003) used an open-field autorefractor to record the accommodative status. This system is found objective and reliable for determining the accommodative response (Chat and Edwards, 2001; Davies et al., 2003). The MEM test is an also objective method but requires the judgment from the examiner with the retinoscope. To minimize the inter-observer difference in our study, all measurements were done by the same investigator. 0.6 logMAR print was used as the target, although the influence of letter size on accommodative response is known to be negligible (Lovasik et al., 1987). The children were wearing trial lenses when we measured the lag of accommodation with the MEM test. Therefore, these contradictory findings yield further validation.

Interestingly, the Type III children, who had automaticity dysfunction, were found to have a significantly higher lag of accommodation (+1.22 ± 0.16 D) than the Type I (+1.00 ± 0.31 D) and Type II (+0.97 ± 0.28 D) children (Kruskal-Wallis Test, $p < 0.05$). Our findings agree with Poynter et al.(1982) who found a marginal relationship between lag of accommodation and reading ability as shown in Type III.

Does accommodative lag affect the DEM scores? In the vertical sub-tests of the DEM test, the eyes move downwards when the child reads the numbers down a column. However, in the practical situation, the DEM test book is placed on a table and the book is not at 90 degrees to the visual axes of the child. The top region is further from the eyes than the lower region. Under such clinical conditions, there should be a slight increase in accommodation and vergence demand from the top to the bottom of the test plate. Some children turn their heads slightly downwards, when they read down the column in the vertical test; this head movement reduces the working distance slightly. Therefore, there is approximately one quarter dioptre change in accommodative stimulus along one column of numbers in the DEM vertical test. The child is required to accommodate more when he reads down the numbers, relaxes accommodation slightly when he switches to the top of the next column and finally increases the accommodation again in the second column.

A similar effect exists when the child reads the numbers in the horizontal test. Additionally, there is a minor horizontal shift of the vergence symmetry, when the child reads across the row. Some children may use horizontal head movements to assist the eye movements. The vergence error is only limited to around 10 minutes of arc when the eyes move laterally while reading and a normal vergence system should be adequate to cope with this horizontal vergence change (Ciuffreda and Hokoda, 1985).

Although we found significant difference in lag of accommodation amongst the Type I, II and III DEM groups, the sample size was so small that further research is required to validate our findings.

7.2.4 Binocular status and the DEM test

7.2.4.1 Horizontal heterophoria and AC/A ratio

According to Table 7.4, there was no relationship of DEM scores in either measure of heterophoria or AC/A ratio. Chen et al. (2003) used the Howell-Dwyer card to determine the near heterophoria in Chinese children aged 8 to 12 years. They found the mean heterophorias at near for myopes and emmetropes were -1.04 $^{\Delta}$ exophoria and 0.71$^{\Delta}$ exophoria, respectively but there was no significant difference between these two groups. The mean heterophorias of the myopic and emmetropic children in this study were exophoria 0.97 ± 2.11$^{\Delta}$ and exophoria 1.76 ± 2.09$^{\Delta}$. Our data could not be compared with those from Chen et al. (2003) because of the age differences. The average heterophoria in the present study was approximately 1$^{\Delta}$ exophoria and is somehow lower than the previously published norms of 3 $^{\Delta}$ ± 3 (Jackson and Goss, 1991b; Scheiman and Wick, 1994a). Our findings supported the work by Lam et al. (1996), who suggested that children usually had a low incidence of heterophoria at near.

The gradient AC/A ratios in this study were lower than those measured by Chen et al. (2003), Mutti et al. (2000), Gwiazda et al. (1999) and Rosenfield and Gilmartin (1987). The difference may be due to the different experimental design used in the various studies. Gwiazda et al. (1999) and Rosenfield and Gilmartin (1987) used the Maddox Rod to measure the heterophoria, Chen et al. (2003) used a free space card Howell-Dwyer test to obtain the heterophoria and the Maddox Wing was used in this study. Chen et al. (2003) found the AC/A ratios of Chinese myopic and emmetropic children were 3.24 ± 4.19 $^{\Delta}$/D and 2.46 ± 3.38$^{\Delta}$/D, respectively. They measured the AC/A ratio in 8 to 12 year old children using +2.0 D lenses and the Howell-Dwyer card. In our study, the AC/A ratio of myopic (n=29) and emmetropic (n=71) children (at ages 6 to 8 years) were 2.17 ± 1.28 $^{\Delta}$/D and 2.13 ± 1.56$^{\Delta}$/D, respectively. Although the subjects were not matched, our findings (age group 6-8 years) supported the findings of Chen et al. (2003) (age group 8-12 years) that there is no elevated AC/A ratio in Chinese myopic children.

Chen et al. (2003) calculated the AC/A ratios by carefully considering the actual accommodative demand, which was affected by the back vertex distance and the refractive power of the spectacles. Although the ratio here was not calculated in the same fashion, our results should be reasonably reliable because only two out of one hundred and eight children had significant refractive error (equal or greater than -4.0 D), which would alter the accommodative demand at near.

No significant differences in the means of AC/A ratios in the three types of children were found, nor in the means of near heterophoria with the three types of the diagnosis from the DEM test. Our findings echoed the results of Kiely et al. (2001), who studied the various visual functions in normal and reading disabled groups. They found no differences in various visual functions among their groups of subjects. Although Kiely et al. (2001) were looking at reading problems, it is logical to assume that saccadic eye movement dysfunction would be a factor affecting the reading quality.

7.2.4.2 Fusional convergence amplitude

According to Table 7.4, no relationship was found between DEM scores and fusional convergence amplitude. The prism bar used in this study has a maximum measuring capacity of 40 prism dioptres. Griffin et al. (2002) suggested that a convergence amplitude higher than 28 prism dioptres is considered as "very strong". Therefore, it is of no clinical value to continue the measurement beyond 40 prism dioptres because it is still classified as "very strong" convergence. Hence, 40 prism dioptres was recorded as the children's convergence amplitude, if they could sustain the single binocular vision for 3 seconds at this vergence demand.

In this study, most children had very strong convergence amplitude; the mean amplitude of convergence was 33.64 prism dioptres. Only one child (out of 108) had a convergence amplitude of 14 prism dioptres which failed the step vergence criterion suggested by Scheiman et al. (1989).

Morad et al. (2002) evaluated the amplitude of convergence by different methods and correlated the results with the DEM scores in a group of children aged 8 to 11 years. They found the mean amplitudes of convergence at near using a 3-D computer stereogram (controlled accommodation) and a penlight and prism bar method (non-accommodative target) were 20.7 and 27.9 prism dioptres, respectively. The mean in this study is higher than the findings of Morad et al. (2002). The difference could be attributed to the target used. We used a vertical line of Snellen letters as the target, which provided better accommodation control for the vergence system.

Morad et al. (2002) further found that the convergence amplitude measured by 3D computer stereogram correlated with the DEM scores. However, there was no difference in the convergence amplitudes in the three types of children diagnosed from the DEM test in this study. We cannot compare their findings with ours because in the calculation of the DEM scores, Moard et al. (2002) added 5 seconds for every reading error by a child, which is not a standard recording method for the DEM test (Richman and Garzia, 1987). Secondly, the DEM scores are age dependent and Morad et al. (2002) did not group and analyze their results in separate ages.

Our finding also differs from that of Bedwell (1980) , who concluded that reading-disabled children had poorer vergence amplitudes than normals. The difference in the results could be attributed to the difference in the experimental design. Bedwell (1980) selected children with a reading problem assessed by reading scores and lateral dominance and they used the Titmus vision tester to measure the fusional amplitude. Therefore, further investigation is required to ascertain if convergence amplitude is correlated with the DEM scores.

7.2.4.3 Stereoacuity

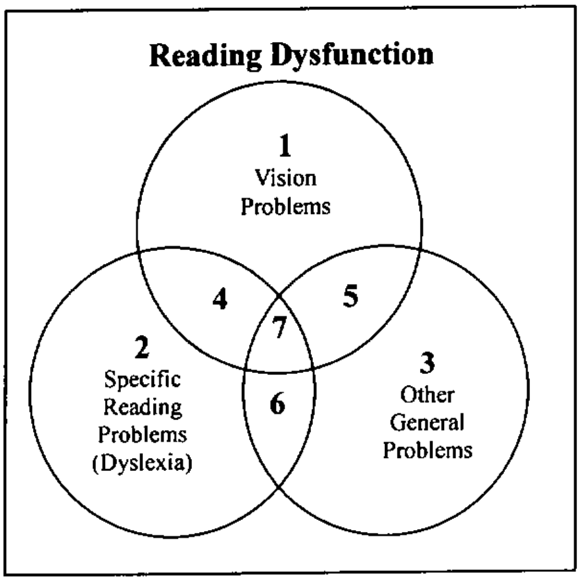
Two studies have reported the norms of stereoacuity using the Randot test. Oduntan et al.(1998) found that the mean stereoacuity of 56 Arabian children aged 6 years was 29.11 seconds of arc (SD not provided). Leat et al.(2001) reported the Randot's norm was 30.2 ± 1.43 seconds of arc for children aged 5 to 8 years. There were only 17 subjects in their study and hence the sample size would be too low to conclude a normative representation. We could not compare our results with Leat et al. (2001) because there was no raw data from their study to carry out the calculation by parametric test. From the mean of stereoacuity in our study (33.10 ± 24.83 seconds of arc), our finding is quite similar to those found by Leat et al. (2001).

Although Kulp and Schmidt (1998) found a "trend towards a significant difference" ($p = 0.07$) in those children who failed both the Randot test (between 50 and 100 second of arc) and the DEM ratio, we did not find any significant difference in stereoacuity amongst children in the three types of DEM diagnoses. A recent study suggested that monocular occlusion (a disruption of stereopsis) could improve the binocular control of reading in dyslexic persons (Stein et al., 2000). The occlusion breaks down the unstable binocular system in the dyslexic children, and they learnt to read again gradually during the monocular phase. The result of Stein et al. (2000) implied that stereo-vision or binocular vision may, possibly, be a cause of reading disability. Therefore, it is still controversial to say that stereoacuity is associated with reading disability.

7.2.5 Diagnostic value of the DEM scores

According to Griffin (1997), reading dysfunction consists of three core problems, namely vision, specific reading (dyslexia) and other general problems. These three areas overlap, Figure 7.12 further illustrates this relationship.

Figure 7.12 The relationship between factors in reading dysfunction extracted from Griffin et al. (1997)



Segment 1: The visual problems are associated with factors such as uncorrected high hyperopia, significant convergence insufficiency, poor eye fixation and

saccadic eye movements, visual perceptual dysfunction and visual-auditory integration dysfunction.

Segment 2: Typical dyslexia has poor phonetic decoding and encoding speed and quality, these children should have normal intelligence and education opportunities.

Segment 3: The "other general problems" refer to children with low intelligence, educational or socio-cultural deprivation, primary emotional or mental health problem, attentional problems and other causes such as allergies, poor nutrition.

Segment 4: Vision problems with dyslexia;

Segment 5: Vision problems with other general problems;

Segment 6: Dyslexia with other general problems;

Segment 7: A mix of all visual, dyslexic and general problems;

Segments 1, 4, 5 and 7 are related to visual problems. The DEM test can identify saccadic eye movement problems, which are included in these four segments. On the other hand, segments 2, 4, 6, and 7 are related to dyslexia. The DEM test can identify automaticity problems, which are associated with dyslexia. If we link the type of diagnosis derived from the DEM scores with Griffin (1997)'s model, the DEM test is able to identify children with problems in segments 1, 2, and 4 directly (illustrated in Table 7.5).

Table 7.5 Matching of diagnosis from the DEM test and reading dysfunction classification by Griffin (1997)

Diagnosis derived from the DEM test	Reading dysfunction model (Griffin 1997)
Type II: Saccadic eye movement dysfunction	Segment 1: Vision problem
Type III: Automaticity dysfunction	Segment 2: Dyslexia
Type IV: Saccadic eye movement and automaticity dysfunction	Segment 4: Vision problem + dyslexia

The main uses of the DEM test are to identify the saccadic eye movement and automaticity problem. These two types of problem are distinctive and independent of each other. Because automaticity is a development process, the deficiency in automaticity is one of the indicators in some delayed development children. Further assessment of sensory and motor functions, perceptual skills or even intelligence quotient could be beneficial to these children. Of course, there are some other general factors, such as education opportunity…etc. On the other hand, children with saccadic eye movement problems can be treated by visual therapy. Thus, the DEM test serves as a fast and effective tool in screening children from these two types of problems.

7.3 Summary

Significant differences were found in the means of lag of accommodation among

Types I, II and III children in the DEM test. Lag of accommodation was highest in Type III children, who had automaticity problem or dysfunction. However, further investigation with bigger sample size is suggested to verify our finding.

Chapter 8: Concluding remarks

8.1 Introduction

The Developmental Eye Movement (DEM) test is a visuo-verbal test to determine problems of saccadic eye movements and automaticity in young children. Among the several available clinical tests, the DEM test is the most commonly used and has the advantages of being inexpensive, easy and quick to administer and effective in identifying automaticity and saccadic eye movement problems.

An administrator measures the DEM test scores subjectively. Under normal circumstances, the test should not be repeated immediately to the same child owing to memory or learning effects. Hence, there is only one chance for the administrator to record both the reading time and the quantity of each of the different reading errors made by the child. Using such an approach, the accuracy of the objective judgment of the administrator is thus important.

The current norms for chronological ages were derived from only English-speaking or Spanish-speaking children. It has not been shown whether these norms are also suitable for Chinese-speaking children.

Furthermore, we wished to know if there are any differences in the visual characteristics of children who have different type of DEM diagnoses. This could lead to a better understanding of the relationship between saccadic eye movements and other visual skills.

8.2 Summary of the principle findings

8.2.1 Repeatability of the DEM test

If the conventional method of the DEM test is used (allowing only one chance to measure the DEM scores), the administrator is very likely to report an inaccurate reading time for the DEM test, regardless of whether he is experienced or not. This measurement error may lead to an incorrect clinical conclusion. In this study, there is a significant difference in the mean difference in the adjusted vertical time from the expected values between experienced and inexperienced DEM administrators.

We found that the mean of two repeated measurements is as accurate as the mean of five repeated measurements to the nearest 0.5 second. To minimize the human error in the measurement of reading time, we suggested making a digital audio recording of the DEM test process. Then, the administrator can re-listen to the voice files and repeat the measurement of the reading time. In addition, if the administrator has any doubt on the accuracy of counting the reading errors for the child, he can replay the clips until he is confident of the result.

Hence the current approach in administrating the DEM test is not ideal and is prone to unnecessary errors made by the administrators. We propose an objective approach by using a digital recorder and the voice of the child can be retrieved for re-evaluation if necessary. Further investigation is warrant to ensure standardised procedures in clinical eye movement tests and screening protocol.

8.2.2 The DEM scores in Cantonese-speaking children

We administrated the test to a group of Cantonese-speaking children, who were age-matched to those in the DEM test manual. We compared the DEM scores from these Cantonese children with the DEM norms for English-speaking and Spanish-speaking children. From this, we derived DEM norms for Cantonese-speaking children.

We found that the children in our study made more vertical errors than those in other published studies. Therefore we proposed to use the adjusted vertical time in the vertical test for Cantonese-speaking population.

In both vertical and horizontal subtests, the Cantonese-speaking children (age groups 6 to 11) completed the tests more quickly than the English-speaking or Spanish-speaking children. The differences of the means were significant (t-test; $p<0.0001$) in all age groups. The mean errors made by the subjects were similar to the given norms from the DEM manual, except that the Cantonese-speaking children made fewer errors than their English counterparts in age groups for 6 years. The mean ratios were similar in all populations.

Hence, the norms provided in the DEM manual or from the Spanish studies are not suitable for Cantonese-speaking children. We proposed a set of norms for Cantonese-speaking children based on our data from the 305 children aged 6 to 11 years.

Language appears to be the major reason for the above difference. The time required to read out the numbers 0 to 9 in Cantonese is less than reading them in English. Another possible reason is the difference in the education system. The children in Hong Kong start their formal language training much earlier than in their Caucasian counterparts. The development of the language will be greater and reading ability faster then for Caucasians of the same age.

By combining the performance of the vertical test, the horizontal test and the ratio result, we derived the prevalence of automaticity and saccadic eye movement problems from our samples. Prevalence of Type I, II, III and IV are 78.6%, 4.3%, 6.9% and 1.3% respectively in this study. The prevalence of automaticity dysfunction increases with age and the prevalence of saccadic eye movement dysfunction decreases with age. These figures are alarming. If a child is diagnosed with saccadic eye movement dysfunction (Types II or IV), he/she should be referred to an optometrist for assessment and possible vision therapy. On the other hand, if a child is diagnosed to have an automaticity problem (Types III or IV), further investigation such as visual perceptual assessments and some other psychological tests should be arranged to allow a more accurate differential diagnosis of the problem. Having all the diagnostic information on hand, the psychologist or the clinician can provide an appropriate training programme to improve the child's learning and/or reading.

8.2.3 Relationship between the DEM test scores and visual functions

We did not find any association between the DEM diagnoses and most visual functions, except that there was a significant difference (Kruskal-Wallis Test, $p<0.05$) in the means of the lag of accommodation among the Types I, II and III children. Children with automaticity dysfunction had a higher lag of accommodation. This findings suggest that the DEM test result is not influenced by majority of visual functions.

8.3 Future research

As the DEM test is designed to be administered once so we did not repeat the test. It might be worthwhile to confirm whether the test is repeatable. From the results of the first investigation, we found that experienced DEM administrators were more accurate than the inexperienced ones in determining the adjusted vertical time, but there were no differences in accuracy between the two groups for determination of adjusted horizontal test time. Further investigation to observe the effect of reaction time in recording may help to clear the difference in the results between adjusted vertical and horizontal time.

Further investigation is required to testify the effect of our newly suggested instruction for the DEM test: "If you realize that you have made an error during your reading, please continue and it is not necessary to go back and make a correction. Don't move your head or your body during the test." This could be done by repeat the DEM test to the same group of children in separate occasions by using the original and our modified instruction.

As the DEM norms for Cantonese are so different from those for English, it is essential that norms be obtained for other ethnic groups. Also, it would be of interest to compare the norms of Cantonese-speaking and Putonghua (Mandarin)-speaking children.

8.4 Conclusion

The conventional method as suggested in the manual for recording the DEM test scores is not sufficiently accurate. With our findings we established a more objective procedures for the DEM test. We suggest recording the response from the child during the DEM test and this allows re-listening to and reassessment of the data. The recorded time should be measure twice to obtain the mean to ensure accuracy. We believe that using this method for the DEM test will permit the clinicians to obtain more accurate results and thus reduce the chance of false positive or false negative findings or an incorrect diagnosis.

We found significant differences in the DEM scores amongst Cantonese, English and Spanish-speaking populations with matched ages. It is very important to obtain normal values for a particular population to minimize the bias caused by other factors such as languages or education. We established the norms for the Cantonese-speaking children in Hong Kong. Our norms will be communicated to the Department of Health, the Department of Education and other clinicians who frequently use the DEM test for adoption and verification. We also established the prevalence of automaticity and saccadic eye movement problems in this population. The prevalence of automaticity dysfunction in our sample is quite high and this figure is alarming.

Further investigation into confirming the diagnosis and treatment for this group of children may enhance the referral criteria.

There is an association between lag of accommodation and automaticity dysfunction. Therefore, if a child is found to have a high lag of accommodation during a normal eye examination, the DEM test should be used to identify if there is any dysfunction in automaticity.

There are many specific learning-disabled students in Hong Kong and a majority of these are likely to have reading difficulties. Saccadic eye movement problems can be predictors of the reading problems. An early diagnosis of saccadic eye movement dysfunction in children may be remedied by vision training exercises to improve the reading skills. The DEM test plays a role in identifying this problem. With the modified norms for Cantonese-speaking children, the DEM can detect efficiently the five types of clinical conditions involving automaticity and saccadic eye movements for Chinese children Prompt intervention or referral for further assessments could help these children finding the real cause of their learning and reading difficulties.

As the DEM norms for Cantonese are so different from those for English, it is essential that norms be obtained for other ethnic groups. Also, it would be valuable to compare the norms of Cantonese-speaking and Putonghua (Mandarin)-speaking children.

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